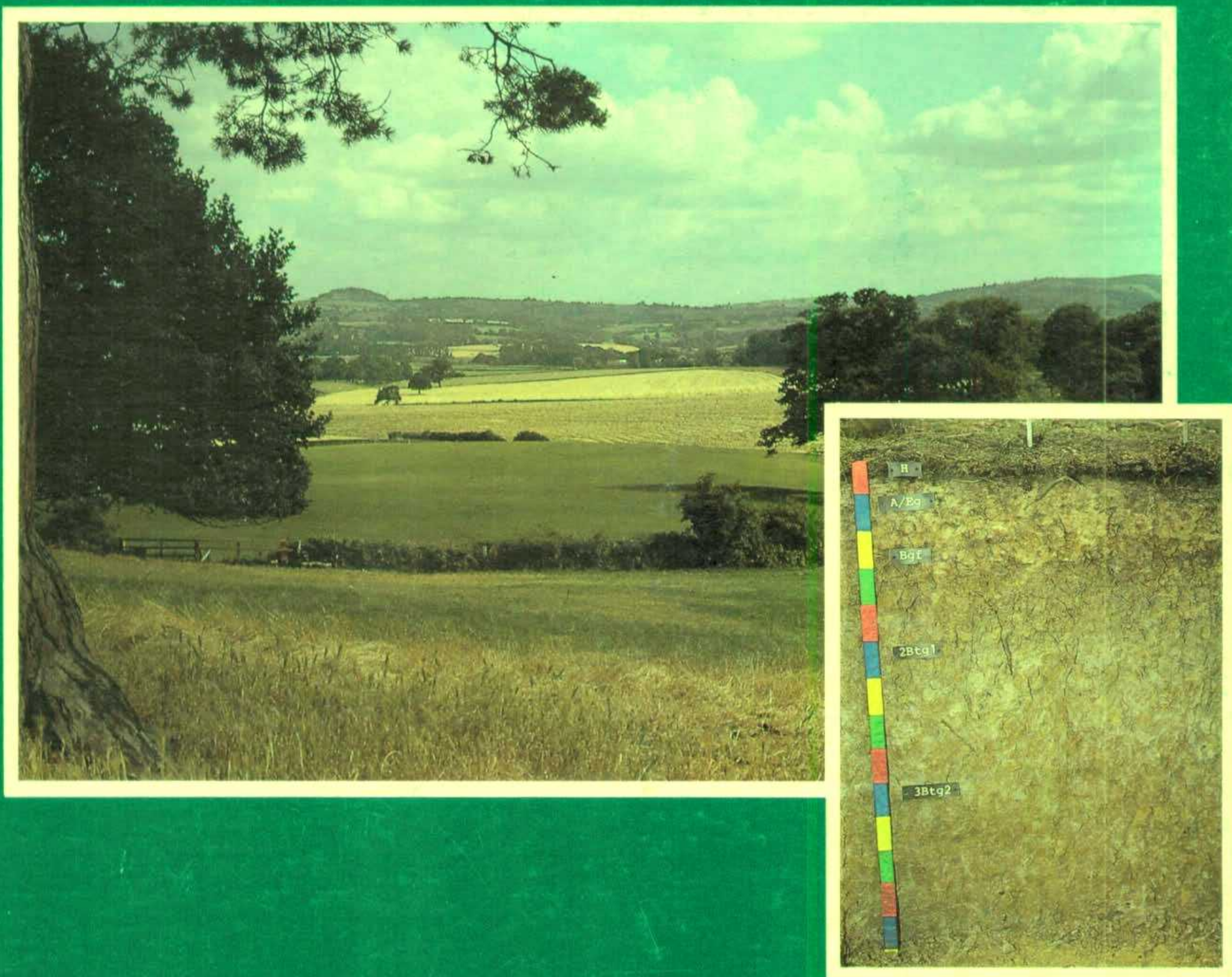
SSLRC

INSTITUTE OF TERRESTRIAL ECOLOGY



Institute of Terrestrial Ecology
Soil Survey & Land Research Centre

AN ASSESSMENT OF THE PRINCIPLES OF SOIL PROTECTION IN THE UK

Volume I. Concepts and principles

Natural
Environment
Research
Council

AN ASSESSMENT OF THE PRINCIPLES OF SOIL PROTECTION IN THE UK

Final report in three volumes, prepared under DoE/NERC Contract PECD 7/2/45

Volume I. Concepts and principles
Volume II. Reviews of current major threats
Volume III. Risk and suitability mapping in selected areas

Edited by P J A Howard, T R E Thompson, M Hornung and G R Beard

INSTITUTE OF TERRESTRIAL ECOLOGY

ISBN 1 870393 13 9

AN ASSESSMENT OF THE PRINCIPLES OF SOIL PROTECTION IN THE UK

Volume I. Concepts and principles

P J A Howard and M Hornung

1989

Soil Survey & Land Research Centre
Silsoe Campus
Silsoe
Bedford MK45 4DT

Institute of Terrestrial Ecology
Merlewood Research Station
Grange-over-Sands
Cumbria LA11 6JU

TABLE OF CONTENTS

Volume I - Concepts and principles

		Page
Executive summary		i.
1.1	**Introduction: The aims of the study**	1
1.2	**Historical perspective**	4
1.2.1	World-wide development of soil conservation policies	
1.2.2	Development of policies in Europe	
1.2.3	Current soil protection policies in the EC	
1.2.4	Soil protection in the UK	
1.2.5	Summary and conclusions	
1.3	**Some concepts used in soil protection policies**	21
1.3.1	Soil protection v. soil conservation	
1.3.2	The functions v. uses	
1.3.3	Multifunctionality	
1.3.4	Relating land use to the most suitable soil	
1.3.5	Protection of soil for future generations	
1.3.6	The protection of soils in their own right	
1.3.7	Summary and conclusions	
1.4	**Soil - its definition and characteristics**	27
1.4.1	Definition	
1.4.2	The mineral and organic constituents of soil	
1.4.3	Soil organisms	
1.4.4	Depth - the problem of the lower limit of soil	
1.4.5	Soil pores, gases and solutions	
1.4.6	Soil heterogeneity	
1.4.7	The dynamic nature of soils	
1.4.8	Soils as parts of ecosystems	
1.4.9	Soil fertility	
1.4.10	'Soil' vs 'Land'	
1.4.11	Summary and conclusions	
1.5	**Why protect soil?**	40
1.5.1	Practical considerations: Uses and functions of soils	
1.5.2	Philosophical and ethical considerations	
1.5.3	Summary and conclusions	
1.6	**Current threats to soils and ecosystems**	46
1.6.1	Loss to urbanization and infrastructure	
1.6.2	Erosion	
1.6.3	Acidification	
1.6.4	Pollution of soils	
1.6.5	Pollution of groundwater by nitrate and phosphate	
1.6.6	Soil organic matter: Losses and additions	
1.6.7	Soil compaction	
1.6.8	Summary and conclusions	

1.7 Soil quality 71

1.7.1 Definition of the concept
1.7.2 Application of the concept
1.7.3 Application in land capability and land suitability
1.7.4 Summary and conclusions

1.8 Soil degradation 90

1.8.1 Definition
1.8.2 Forms of degradation
1.8.3 Assessment of soil degradation
1.8.4 Ecosystem degradation
1.8.5 Summary and conclusions

1.9 Buffering capacity and resilience 111

1.9.1 Definition
1.9.2 Assessment
1.9.3 The buffering capacity of ecosystems (ecosystem stability) and ecosystem resilience and restoration
1.9.4 Summary and conclusions

1.10 Sensitivity and susceptibility to stress 118

1.10.1 Definition
1.10.2 Assessment
1.10.3 Ecosystem sensitivity
1.10.4 Summary and conclusions

1.11 Reversibility 125

1.11.1 Definition
1.11.2 Assessment
1.11.3 Reversibility of changes in ecosystems: Ecosystem restoration
1.11.4 Summary and conclusions

1.12 Critical loads 130

1.12.1 Definition
1.12.2 Assessment
1.12.3 Summary and conclusions

1.13 Acidification 132

1.13.1 Introduction and background
1.13.2 Soil quality in relation to acidification
1.13.3 Acidification as soil degradation
1.13.4 Buffering capacity and resilience
1.13.5 Sensitivity of soils to acid deposition
1.13.6 Reversibility
1.13.7 Critical loads
1.13.8 Summary and conclusions
Appendix A: Effects of acid deposition on soils

1.14 The scientific aims and principles of a soil protection policy 157

1.14.1 The context of a policy
1.14.2 The importance of the definition of soil
1.14.3 The overall aims of the policy
1.14.4 Definition of the aim
1.14.5 The elements of a soil protection policy
1.14.6 Summary and conclusions

1.15 References 177

Appendix 1 Glossary 190
Appendix 2 Soil protection/conservation in other countries 196
Appendix 3 European soil charter and World soil charter 266

Figure 1. Activities and weights of soil invertebrates in various types of ecosystem (after Macfadyen 1963) 29

Figure 2. Degrees of desirability of a soil reference parameter (after Vegter undated) 72

Figure 3. Smoothed map of lead concentrations in topsoils from England and Wales (mg Pb kg^{-1} soil) (After McGrath 1987a) 95

Figure 4. Schematic relationship between the amount of a compound in soil and its effect, for an essential and a non-essential element. From de Haan (1987) 99

Figure 5. Areas of soil erosion risk in England and Wales (After Morgan 1985) 104

Figure 6. Relationships between type of reversibility and values of a reference parameter 126

Figure 7. The pH of soil samples taken at various times from (a) the surface horizon of the Park grass Experiment, and (b) three horizons from the Geescroft Wilderness (from Johnson et al. 1986) 133

Figure 8. Changes in base saturation of stagnopodzol B horizons at Plynlimon, mid-Wales, predicted using the Magic model 139

Figure 9. Distribution of soils in England and Wales which have large, moderate, and little or no neutralizing capacities 143

Table 1. The functions and uses of soil 41

Table 2. Calculation of reference values for soil parameters (after Vegter undated) 74

Table 3. Reference values for inorganic compounds (from Moen & Hosman 1987) 77

Table 4. Reference values for organic compounds (from Moen & Hosman 1987) 78

Table 5. Normal background and maximum permissible heavy metal concentrations in agricultural soils (from Sauerbeck 1987) 82

Table 6. Forms of degradation and degrading processes (after Yassoglou 1987) 92

Table 7. Forms of soil degradation (from Sparrow et al. 1984) 93

Table 8. Types of soil degradation and units of measurement (FAO 1979) 94

Table 9. Soil degradation classes (FAO 1979) 97

Table 10. Method for calculating the risk of a given type of soil degradation (FAO 1979) 103

Table 11. Sensitivity coefficients used by Federoff (1987) to calculate the sensitivity of the soils of north west Europe to intensive agriculture 119

Table 12. Relative ratings of soil sensitivity to degradation in southern Europe (Yassoglou 1987) 121

Table 13. Soil buffering classes (Catt 1985) 145

Table 14. Classification of pH, the content of exchangeable cations, and their equivalent contribution to the exchange capacity as measures of the elasticity of soils, with respect to acid toxicity and the supply of K and Mg to tree species tolerant to acidity (from Meiwas et al. 1986) 146

Table 15. Base saturation of the O_H H horizon of the humus layer as a parameter of elasticity for acidification (from Meiwas et al. 1986) 146

Table 16. Soil sensitivity ratings (after Wang & Coote 1981) 148

Table 17. Sensitivity of soils to acid precipitation (after McFee 1980) 148

Table 18. Mineralogical and petrological classification of soil material (from Nilsson & Grennfelt 1988) 150

Table 19. Critical load for forest soils (0-59 cm) (from Nilsson & Grennfelt 1988) 150

Table 20. Conditions influencing critical loads to forest soil (from Nilsson & Grennfelt 1988) 152

Table 21.	(a) Measurements and frequency of measurement, of soils used in the Swedish National Monitoring Programme	174
	(b) Observations, and frequency of observation, of vegetation in the Swedish National Monitoring Programme	175
Table 22.	Guide values for assessing soil contamination by organic substances (from Leidraad Bodemsanering 1983 - Soil clean-up guideline)	205

EXECUTIVE SUMMARY

The work undertaken, has been divided into three sections, covered by separate volumes of this report. The 3 Executive Summaries and a Glossary are included in each volume.

Volume I

This reviews the concepts and principles being used in the discussion of soil protection, and the development of soil protection policies, particularly within Europe. A report on soil protection/conservation policies in **nine countries,** and the **European** and **World Soil Charters,** are presented as appendices.

Moves since the mid 1970's, towards a recognition of the need for soil protection in western Europe, and towards development of soil protection policies, are examined. The factors stimulating these moves, and the underlying rationales of existing policies, are identified and discussed. Soil **protection** is contrasted with earlier soil **conservation** policies. The UK has **no explicit soil protection policy.** But there is a range of legislation, guidelines and voluntary codes which provide **implicit protection.**

The definition of soil **use,** has a major influence on soil protection policies. The **nature** and **definition** of soils are discussed; it is emphasised that soils are complex, dynamic, heterogeneous, living systems, which themselves form part of ecosystems. Soil protection implies **protection of the whole system.**

The concept of soil **quality,** which is a central part to some soil protection policies in Europe, is discussed. Although the concept is useful, its **quantitative** definition is complex because of the natural **heterogeneity** of soils, and the variations in their responses to **stresses.** To date, quantitative definitions have been attempted only for heavy metals and some organic pollutants. In most instances, soil quality can be defined only with respect to a particular **use.**

The aim of a soil protection policy could be the prevention of **degradation**. The concept is defined, along with the various forms of physical, chemical and biological degradation. Approaches to the evaluation of current **levels and rates of degradation,** the assessment of **sensitivity** of soils to degradation, and the **prediction** of degradation, are outline and discussed.

Soil types **differ** in their responses to different types and levels of stress. The concepts of soil **sensitivity, buffering capacity, resilience** and **susceptibility** to stress, are defined and discussed. Conceptual and/or parametric models exist which allow soils to be ranked in terms of their sensitivity, or their buffering capacity, towards a given stress. The mathematical models necessary to permit **quantitative** definitions have been developed, **but only for one or two stresses.**

The concept of the **reversibility** of changes in soils is also important. Some changes in soils which result from Man's activities are **irreversible,** because of either the type or magnitude of change. Others can be **reversed naturally.**

The **critical load** concept was developed in the context of acidic deposition, in which it is defined as the **maximum input of acidity which will not lead to adverse changes in the functioning of the soil system.** The approach is applicable to other stresses, and provides a means of linking control measures with impacts.

Some **requirements** for a UK soil protection policy are discussed. The ideal aim of a soil protection **policy** should be to limit changes to those which are **reversible,** wherever practicable. A primary requirement is a **qualitative** definition of the aim of that policy, eg maintenance of good soil **quality,** or prevention of **degradation,** or prevention of **adverse changes** in soils. Soil quality, degradation or acceptable limits of change, should eventually be defined, quantitatively.

The implementation of such a policy would thus require:

i. A **characterization** and **assessment** of the soils of the UK. Existing data bases need evaluation and enhancement, in the context of soil protection.

ii. **Monitoring of changes in soils over time.** A national network of sites would allow assessment of **natural changes,** and those due to **regional, national** and **global pollution .**

iii. **Assessments of the impact of Man's activities on soils.** These should cover **current** activities, and the result of **changes** in land **use/ management,** and the introduction of **new technologies. Assessment** should involve use-oriented, or stress-oriented monitoring and experimentation, and **prediction.** The necessary predictive models are **not** available for most stresses. But soils can be ranked in terms of **sensitivity** or **buffering capacity.**

iv. Definition of **critical** or **acceptable loads** of given stresses. This requires the development of cause-effect or **dose-response** models.

v. Development of **alternative management** methods and techniques to reduce the impact of Man's activities on soils.

vi. Definition of **target values** of soil parameters to be used in the **rehabilitation** of damaged soils.

The achievement of these aims will be governed, however, by the extent to which the **magnitude** of each threat, (a) can be assessed, and (b) is perceived to warrant investment of the necessary resources. The **variations** of UK soils, and the uses to which they are put, also mean quantitative definitions of acceptable limits to change will have to be applied **pragmatically** by authorities, and by land managers, at local and working levels.

Volume II

This reviews the main, **perceived threats** to soils in Europe, and assesses currently-available models for **evaluating and predicting** the **sensitivity** of soils to damage, from these threats. Recommendations for further work are included in the text of the appropriate section.

Heavy metals

Heavy metal contents of soils vary, naturally. They are augmented by contamination from industrial activity, fertilizers, sewage sludge and other wastes. The factors controlling their **availability** and **mobility** in soils, are discussed. Soil protection policies should aim to establish **current** levels in UK soils, the **degree of risk,** and **methods for controlling** any increases. The information required for **assessment,** is considered. Current databases are incomplete for subsoils and some elements. But areas of land currently at risk from **high levels** can be delineated, regionally. There is a need for a unified approach to the establishment of **permissible/threshold** levels in soils typical of Europe.

Nitrates

The main concern is with soils as a source or pathway for **nitrate** entering ground and surface **waters.** The **main sources of nitrate** are fertilizers, manure, soil organic matter, and atmospheric deposition (see **acidification).** Total losses of nitrate are equivalent to 30-50% of fertilizer inputs. **Soil type and geology** play an important role in determining the amounts of nitrate, leached. The soil factors **controlling** nitrate leaching, are discussed. Models are available which can be applied **regionally** to evaluate the likelihood of nitrate leaching, under a **given management regime,** ie. to identify **sensitive** areas. Application of models at the **local level** is hampered by the lack of detailed input data. There is a need to improve data on **sensitive areas,** and to improve the leaching models.

Pesticides and organic solvents

There is concern about impacts on the soil system and on water quality. Soil **flora** and **fauna** may suffer deleterious effects; the effects of several pesticides on soil organisms are considered. There are **no specific regulations** for the levels of pesticides in UK soils. But there are some **EC maximum admissible concentrations. Recommended** concentrations exist for drinking water. Problems have been documented arising from **agricultural** and **non-agricultural** applications of pesticides. Contamination of soil or aquatic ecosystems by **organic solvents** is usually associated with **point sources** in urban or industrialized areas. The soil **properties** affecting pesticide **movement** and **degradation** in soils are highlighted. These properties have often been neglected in soil studies. Several models exist for **risk** and **sensitivity** assessment. Further model validation and testing are needed, in a UK context.

Soil erosion

Soil erosion is a natural process that can be accelerated by climate extremes and by Man's activities. Some soils are more **susceptible** to erosion than others. **Wind** erosion is confined largely to light soils and lowland peats under intensive cropping. **Water** erosion occurs on upland peats and on lowland arable soils; light soils in the lowlands are more likely to erode than are heavy ones. In arable situations, **rates** and **severity** of erosion are well documented for specific sites. But the **regional** extent is poorly known. Figures from the USA show the costs incurred in **off-site damage** resulting from erosion, are fifty times greater than those from lost crop production. Models are available to predict erosion. The data requirements for the models, are outlined. Simple models have been developed in the UK to predict the likelihood of erosion at a **national** scale, and these could be improved to give more detailed and localised predictions. Further research is needed on soil erosion **processes,** and the **factors** affecting them, especially on the **uplands** and in relation to **off-site impacts.**

Soil compaction

Soil compaction involves an **increase in soil density** and a **reduction in permeability.** The risk of compaction has increased with the introduction of heavier machinery. It is not restricted to **agricultural land** but is also associated with **construction activities, forestry operations,** and **recreation. Compacted** soils restrict rooting and inhibit microbiological activity. Any soil can be compacted, given the right conditions and sufficient loading. But precise overall values of damaging loads cannot be defined because damage **varies** with **soil properties** and **vegetation cover.** Compaction can be corrected by subsoiling. Earthwork activity, root development and shrink/swell will relieve or reverse **shallow compaction** naturally, over time. The opportunity for **non-damaging operations** on agricultural land is easily predicted from soil properties and climate. A more sophisticated model could be designed by incorporating **land use** and **soil regeneration** capabilities.

Farm waste

Pollution from **farm waste** is a major problem in some European countries. The effects of farm waste on soil are poorly understood. But they can affect soil organisms and can lead to **surface scorch, soil compaction** and **surface smothering.** The main concern is with soil as a vector of pollution to **surface and ground waters,** and to the **atmosphere.** Four types of farm waste are considered: **silage, effluent, livestock manures, yard washing,** and **vegetable processing effluents. Yard washings** have low pollution potential and vegetable washings are not usually important but can cause point source pollution. **Silage effluent** is very polluting and guidelines for disposal have been developed by MAFF. **Manures** are valuable sources of plant nutrients but soluble substances present in excess of plant demand, can be readily leached to **ground waters** on permeable soils. On slowly permeable soils, lateral runoff can pollute **surface water. Farm slurries** can also contain heavy metals. Models are available to rank soils in terms of their ability to accept **slurry.** High **risk areas** can be pinpointed at the regional scale. Further work to improve and validate models, is required.

Acidification

The **concepts** discussed in Volume I are applied and tested in the context of **acidification.** Acidification is a **natural** process but the rate can be increased by Man's activities - **pollution, fertilizer additions, drainage of acid sulphate soils, and planting of acidifying vegetation.** The clearest examples of recently-enhanced acidification in the UK are linked to **land use** or **management.** But acidity of blanket peats in Scotland varies with inputs of **acidic deposition.** The process of **soil acidification** is relatively well understood. Models exist which enable soils to be ranked in terms of **sensitivity, buffering capacity, risk of acidification** and **reversibility.** These models can be applied to existing UK data bases to give regional predictions. **Rates of acidification** as a result of changes in acid deposition can be predicted using a range of models. But the models need improvement and further validation. The required **input data** are rarely available. **Critical loads** for acidic deposition can be calculated using models, developed mainly in Scandinavia.

Volume III

This volume demonstrates the application of the **principles** and **available** models for assessing soil **sensitivity** to currently-perceived **threats,** in the field (ie. **vulnerability mapping).**

It is recognised in the earlier volumes of this report that the **sensitivity** and **vulnerability of land** to imposed threats change from one place to another in line with variations in **soil, site, land use,** and **climate.** The mapping of variations in soil and water vulnerability should form a part of **any** policy of resource protection.

In consultation with the contracting Department and the Steering Committee, three pilot areas representing a range of landscapes were identified at Sleaford in Lincolnshire, Wilton in Wiltshire, and Lynton in Devon. Each was 5 km square. Appropriate topics for crop suitability and risk maps were identified, for each of the pilot areas. These included not only the perceived threats in Volume II, but also studies of **bracken infestation, forest suitability** and **wetland regeneration.**

Detailed **soil, land use** and **slope maps** were digitised for each site using a geographic information system. A single set of **climatic data** was used for each area.

Using a commercially-available geographic information system mounted on a personal computer, the data from the three basic maps for each area were used to derive **crop suitability** and **environmental risk** maps. Representative examples are reproduced in this report together with analyses of the **reliability** of the models and data used, at the local level. Much more work is needed before this approach can be used with certainty to predict **certain suitabilities and risks.** Our knowledge of the processes involved, and available data bases are frequently inadequate to meet such needs.

RECOMMENDATIONS FOR FURTHER WORK

These recommendations are made on the **assumption** that there will be moves towards a soil protection policy or policies, designed to limit changes to those which are reversible, wherever practicable (Volume (I). It is also assumed that the threats discussed (Volume II), and possibly others, **may be perceived as sufficiently serious** to merit action. They are made **without prejudice** to the requirements of the Department of the Environment or to any other potential funding body. But it is clear many of the recommendations are not mutually exclusive, and would involve basic as well as applied research.

Databases and their applications

i. An evaluation of existing UK databases on soils in the context of soil protection and currently perceived threats. Preliminary assessments suggest that data on soil fauna and flora in terms of toxicity assessment, on organic matter, and on heavy metals, are probably inadequate.

ii. A ranking of soils - especially the main and the rare types - nationally in terms of sensitivity to perceived threats to soils, followed by sample, detailed surveys in those areas identified as 'highly sensitive' to each threat, to provide improved localised predictions and counter measures.

iii. The application and improvement of the approaches explored in Volume III, in a larger test area or areas, in co-operation with local planning authorities and the main "land using" industries. This might be linked with other work on land use, utilising remote sensing and other surveillance techniques.

iv. The testing of current data bases and models, in impact assessments for a range of land uses/management practices.

v. The establishment of a national network of sites to monitor and interpret changes in soils over time resulting from natural causes, regional pollution, and possibly climate change. This could be linked with the NERC LONG TERMS exercise.

vi. The eventual development of guidelines for use in the assessment of the impact of localised threats, and for application in the implementation of planning, pollution control, and other pertinent legislation.

Reference parameters and reference values

i. The identification of an agreed set of **reference parameters** for use in **national monitoring programmes,** and in use-related and threat-related monitoring and impact assessment.

ii. The evaluation of the **applicability of reference values** for parameter's **other than** heavy metals and organic pollutants.

iii. The definition of the **limits of naturally reversible changes** in soil parameters, and of the **rates of reversal.**

Process studies

i. The processes controlling the **mobility** and **availability,** to soil fauna and flora and plants, of **heavy metals.**

ii. The processes controlling the **mobility** and **degradation** of **pesticides** and other organic chemicals, in soils.

iii. **Soil erosion processes** and the factors **controlling** these processes, notably in the **uplands.** This should be coupled with work on **'offsite' impacts,** especially effects on **surface water quality.**

iv. The factors controlling the **regeneration** of soil structure.

v. The processes controlling **nitrate production** in soils, and possibly **nitrate leaching** from soils.

vi. The **impacts of heavy metals, pesticides, and excess nutrients on soil fauna and flora,** and the processes mediated by biota.

vii. Processes and factors, controlling **solute transfers** through soils.

Model development and application

i. The development of models for the **quantification of the sensitivity and buffering capacity** of soils to perceived threats, and their interactions with land use.

ii. The development of models to assess and predict the reversibility, including **timescales,** of given changes in soil parameters.

iii. The development of **mechanistically-based models to predict** the impact of given stress **loadings.**

iv. The development of models for the determination and definition of **critical loads** for perceived threats.

v. The development and application of models to assess and predict the **suitability of soils to support various land uses and land management practices.**

VOLUME 1. CONCEPTS AND PRINCIPLES

1.1 INTRODUCTION: THE AIMS OF THE STUDY

The contract related to this report was initiated, by DoE, in response to the growing pressures in Europe for the CEC to adopt a comprehensive policy for the protection of soils, on the grounds that they are natural resources which must be protected and conserved for use by future generations. In the development of any UK policy, or UK input to a CEC policy, the DoE felt it needed

"i) Advice on the basic principles of soil protection which might be appropriate to the UK and ii) recommendations on what may be the best use for soils in terms of minimal risk and their location, in relation to designated areas where there may be restrictions in use."

The aims of the project were defined, by DoE, as

i. To identify the factors which must be taken into account in the formulation of soil protection policies and in the management of soils to protect other resources (e.g. groundwaters, rare habitats). Three, not necessarily independent, categories must be considered:

   a. land use practices including those of agriculture and forestry
   b. natural processes (e.g. erosion)
   c. pollution and waste disposal activities

ii. To identify and review those characteristics of soils which are indicative of response to the above factors and which are generally desirable for soil protection and good management.

iii. To define criteria and to develop indices for soil protection and management which take account of agricultural and forestry practices and of other needs (e.g. conservation, landscape maintenance, water catchment). In particular, to examine the application of possible indices reflecting:

   a. the ability of soil to support vegetation (carrying capacity) appropriate to type, location, habitat and uses
   b. the fragility of soil under stress by the factors identified above

c. the reversibility of changes in soil from which such stress have been removed

d. such other criteria of soil and its quality as may be devised and deemed appropriate

iv. To correlate the above indices with the geographical distributions of:

a. major soil types

b. major land use types

in the UK with a view to identifying those areas where soils are;

c. most likely to be at risk from any of the major stress factors

d. soils which may be placed at risk by major changes in agriculture and forestry support policies and practices which influence land use.

It is imperative that the contractor makes optimum use of existing expertise, data bases and methods to develop and apply the above indices. Work on (ivd) must be correlated closely with other DoE work on land use change in the UK.

v. To recommend, in the light of (i) to (iv) the basic principles, criteria and indices to be applied to the protection and management of soils in the UK, and to assess the applicability of these findings to soil protection in Western Europe.

The work undertaken for the contract has been divided into three sections which are covered in separate volumes of this report:

Vol I a review and overview of the concepts and principles being used in discussion of soil protection, and the development of soil protection policies, particularly within Europe.

Vol II a review of a series of perceived threats to soils in Europe and an assessment of currently-available models for evaluating the sensitivity of soils to damage from these threats.

Vol III the application of the available models for assessing soil sensitivity to the currently-perceived threats in three test areas.

The Institute of Terrestrial Ecology has acted as the main contractor with subcontracts let with the Soil Survey and Land Research Centre.

1.2 HISTORICAL PERSPECTIVE

"......it is astonishing that soil protection was not an issue of environment policy in our countries (the EEC) until relatively late in the day." (Schneider 1987).

1.2.1 World-wide development of soil conservation policies

Many countries have policies, and associated legislation, designed to maintain the productive potential of the soil resource. Most of the existing policies address 'soil conservation' and explicity refer to the maintenance of the soil as the basis of the production of crops. The policies may specifically consider 'soil conservation' or 'soil conservation' may be included as part of broader land use/land conservation policies. The development of soil conservation policies in recent times covers the last 50 years. The United States' Soil Erosion Service was established in 1933 and the Soil Conservation Service in 1935. In central and southern America, Mexico passed a Soil and Water Conservation law in 1946, followed by Costa Rica in 1953, Haiti in 1962, Guatamala in 1964, Venezuela and Uraguay in 1969. Similarly, in sub-Saharan Africa, a number of States have enacted soil conservation legislation over the last 30 years; e.g. the Malagasy Republic 1958 and Kenya 1962; while Cameroon, Chad, Guinea and Niger have organizations with formal responsibilities for soil conservation. In the Middle East and north Africa, Cyprus 1959, Israel 1941, Morocco 1963; Tunisia 1963 and Turkey 1955 have legislation. In the Far East and Oceania, a number of Australian States, Ceylon 1951, Fiji 1967, Japan 1960, the Republic of Korea 1962, Malaya 1960, New Zealand 1941 have legislation.

Much of this legislation refers to 'soil conservation' but actually focusses almost entirely on the prevention or limitation of soil erosion; in some countries the legislation is designated 'soil erosion control'. Similarly, although reviews of soil conservation, e.g. Fournier (1972), or of soil conservation legislation, e.g. Christy (1971), include a broad definition of soil conservation, they largely focus on the prevention of erosion. Indeed, 'soil conservation' has almost become synonymous with the control of soil erosion.

1.2.2 Development of policies in Europe

The "European Soil Charter" (Appendix 3) was adopted by the Committee of Ministers of the Council of Europe on 30 May 1972. This document emphasizes that soil is a limited natural resource which is easily destroyed and which must be protected against certain agricultural techniques, erosion, pollution, and damage caused by human habitation and civil engineering. The World Soil Charter was published in 1981. It aimed to establish a set of principles which should serve as a basis for the most rational use of the world's soil resources and their protection against irreversible degradation. The Charter calls for a commitment on the part of Governments and International Organizations to pursue programmes of soil conservation and reclamation. It recommends that decisions about land use and management be made for long-term advantage rather than short-term expediency. Land use techniques should permit sustainable or improving levels of production. Special attention is called to the need for developing land use policies and legislation, to build up institutional capabilities, to conduct inventories, to organize training courses and public awareness campaigns, to initiate research programmes, and to involve local populations in conservation activities (FAO 1981).

Despite the existence of the two soil charters, Kromarek (1984), in a review prepared in 1984, concluded that at that time no European country had an explicit soil policy. There were policies for areas of land to be used for particular purposes, there were agricultural policies, and there were environmental policies. Some countries, such as the Netherlands and the Federal Republic of Germany, were working towards soil policies by including soil standards in other planning policies. In Belgium there was no indication of general concern for soil protection, and there was no integrated view of environmental policy: the general state of the soil was considered to be satisfactory, even though some "black spots" existed. However, Belgian scientists had become concerned about possible soil degradation. The French did not did not seem to have a soil policy so much as an approach to environmental matters in which problems which affect soil may be taken into account. France had long dealt with soil problems in its overall environmental management policy, although that was concerned only with agricultural land.

However, the situation in Europe, and the climate of opinion were changing while Kromarek (1984) was carrying out her survey, and have continued to change rapidly since (see Appendix 2).

1982 December. A ' Soil Clean-up' Act was introduced in the Netherlands.

1983 January. The Federal Republic of Germany decided to draft a soil protection policy and established an inter-ministerial working party on soil protection.

1983 February. Seven Federal Ministers of the Federal Republic of Germany agreed a joint plan of action regarding soil protection policy.

1983 October. In Switzerland sections of an Environmental Protection Act were agreed. These set indicative values in soils for substances thought likely to harm soil fertility. Section 34 of the same Act stressed that limitations on emissions and measures concerning dangerous substances should take into account the requirements of soil protection.

1985 February. The Federal German Government published its "Bodenschutzkonzeption", which recognized that "Despite all efforts to reduce injurious pollution, serious damage and long-term risks with respect to soil quality cannot be precluded. For this reason, a durable protection of the basic environment including soil and its functions requires a comprehensive interdepartmental approach in environmental policy." Also, "Soil protection must set standards for maintaining the soil's functions within nature in order to prevent hazards for natural ecosystems and ecosystems close to nature and for ecosystems dominated by agriculture and forestry as well as to reduce existing hazards." The Bodenschutzkonzeption is discussed in more detail in Appendix 2.

Also, during 1985, soil quality monitoring networks were establised in four regions of France: Aquitaine, Lorraine, Nord Pas de Calais and Brittany.

1986 June. A Decree concerning soil pollutants was passed in Switzerland. It established a network of sites to monitor soil quality and pollutant levels.

1986 July-October. The European parliament referred three separate motions concerned with soil erosion to their relevant committees for consideration.

1986. Proposals for the development of a policy to protect soils were included in the Fourth Environment Action Programme submitted to the Council of Ministers of the EC. This Fourth Action Programme proposed specific actions to tackle the three main causes of soil degradation:

- contamination by harmful substances of various origins (urban, industrial and agricultural waste, agro-chemical products, widespread atmospheric pollution)

- degradation of the physical structure of soils by compaction and erosion

- misuse of soils

1986 October. A symposium was organized jointly by the Senate of Berlin and the Commission of European Communities (CEC) to discuss the scientific basis for soil protection in the European Community (Barth and l'Hermite 1987).

1987 January. The Dutch Soil Protection Act became operative. The first explicit soil protection legislation in north-west Europe.

The Parliamentary Assembly of the Council of Europe adopted Recommendation 1048 on the consequences for agriculture of current soil degradation. It recommended that the Governments of member states give new impetus to their soil protection policies by combining the quantitative aspect with the maintenance of soil quality and take all appropriate measures against erosion damage.

1987 March. Council of Europe's Steering Committee for the conservation and management of the environment and natural habitats (CDPE) set up a group of experts on soil conservation; this group recommended the preparation of a convention on the protection of soils, updating the European Soil Charter and broadening its scope. To facilitate this, the Council of Europe set up a

Committee of Experts on Soil Protection (PE-SO) with the terms of reference: "To elaborate a feasibility study on possible national and/or European actions in the field of soil protection, taking into account the need for groundwater protection." This study, which should present in particular possible options for the legal instrument(s) to be prepared, will be submitted to the 6th European Ministerial Conference on the Environment. Soil protection would be one of the main topics discussed at the Ministerial Conference.

1987 April. The report of the World Commission on Environment and Development, "Our Common Future", was published. This stressed the need for countries to move towards policies which would ensure sustainable development, and stated that "At a miniumum, sustainable development must not endanger the natural systems that support life on earth: the atmosphere, the waters, the soils, and the living beings."

1988 March. The United Nations Economic Commission for Europe (UNECE) produced a "Draft Regional Strategy for Environmental Protection and Rational use of Natural Resources in ECE Member Countries Covering the Period up to the Year 2000 and Beyond" (ECE/ENVWA/3/Add.1). Among a number of objectives, the strategy stated that ECE Governments should take the necessary measures to prevent and reduce air, water and soil pollution a well as other damage to flora, fauna and their habitats, directly or indirectly caused by various types of human activity.

1988 June. The Council of Europe Group of Consultants for Soil Protection had its first meeting and discussed the method to be used to draw up the feasibility study. Chapters I and II of the feasibility study would be drafted by Professor W. Blum on the basis of his report published in March (Blum 1988). Chapter III would be drafted by Professor Prieur, and would take the form of a synthesis of existing national legislations. The Secretariat would draft chapter IV, presenting work undertaken and results obtained in this field and in the context of other international organisations. It was proposed that the contents of the first four chapters and the possible contents of Chapter V would be discussed at a meeting in Strasbourg in November 1988. The outline proposals were discussed at the first meeting of the Committee of Experts in September 1988.

1.2.3 Current soil protection policies in the EC

The change in the climate of opinion in Europe during the last ten years arises from a recognition of:

i. the fact that erosion is now a significant problem in some north European countries (see Graziani 1987)

ii. the entry into the EC of countries from southern Europe with a long-standing erosion problem (see Graziani 1987)

iii. a number of other threats to the maintenance of the productive potential of the soil resource, e.g. heavy metal contamination, acidification by acidic deposition, (see sections 1.6, 1.7, 1.13, Volume II of this report, and Blum 1988)

iv. the role of soil in mediating other pollution problems, e.g. nitrate contamination of ground waters (section 1.6.5 and Volume II of this report)

v. accelerated changes in ecosystems resulting from soil eutrophication (e.g. Appendix 2, Federal Republic of Germany, the Netherlands, Denmark

vi. increased sealing of soils by urbanization, industrialization, and roads

These pressures have together brought a realisation not only of the importance of, but also the fragility of, the soil resource and the need for policies to maintain that resource.

Despite a general increase in the awareness of the need for soil protection in Europe there are differences between countries in the approaches being taken to provide that protection. The differences in approach, and in legislation, reflect variations in the nature and the perceived seriousness of soil protection problems between countries and in the extent of the protection afforded by pre-existing legislation. Thus, soil policy in the Netherlands is embedded in general environmental policy which aims to ensure that protection of one part of the environment should not lead to deterioration of another part. A central concept of the policy is that of being "a guest in our own environment". The goal of ensuring the health and well-being of people and the preservation of animals, goods, and forms of use has been translated into the task of preserving the properties of the soil which are important for various possible present and future functions, the so-called 'multifunctionality' concept. This aims at keeping all options open for future generations. The policy also has two tracks, one source oriented and one effect oriented. The effect oriented aspects are built around the concept of 'soil quality' and its quantitative definition. The quantitative limits of soil quality will then be used to determine maximum permissible loads; and to set targets, for reduction of emissions from pollutant sources.

Current legislation in the Federal Republic of Germany "provides a framework for striking a balance between the demands made on the soil by the various uses and the prevention of damage, hazards, and long-term risks. The concept of soil protection is integrated into legislation embracing protection of nature and the landscape, air pollutant abatement, noise prevention, protection of water resources and waste disposal. The soil protection programme has seven basic principles: prevention (of soil damage), the 'polluter pays', co-operation (between Ministers and sectors of industry), thrifty management of fertile land, use of soil as a pollution indicator, the social function of soil ownership (stewardship of soil). The German approach also states clearly that, irrespective of their use to mankind, natural resources are worth saving for their own sake" (Delmhorst 1987). It is also stressed that more must be done to use land for purposes to which natural conditions of the site are best suited, and to reduce the demands made on soil. Any remaining undisturbed areas, or areas still in an almost natural state, should be safeguarded. The Federal Government recognized that international and intergovernmental co-operation will be necessary, partly because of transborder pollution and partly to avoid disadvantages of economic competition, particularly in the industrial and agricultural sectors. The Bodenschutz principles will also need to be examined in relation to the EC Directive on environmental impact assessment.

Apart from Article L 421.1 ff of its Forestry Code, which concerns erosion in certain areas, France does not have explicit soil protection policies. French policies which involve soil protection are concerned only with agricultural land. Priority has been given to the study of heavy metals because their accumulation in soils presents a serious problem, and they are easy to measure. However, plant health products (pesticides, fungicides), erosion, and other forms of physical degradation are also being considered. Currently, in France, special attention is being paid to statistics on soil use under different types of agriculture, and to the different soil functions (Prieur 1988).

Danish soil and water protection are dominated by eutrophication of ground and surface waters. There is also concern about acidification of terrestrial ecosystems, largely through dry deposition of ammonia and nitrogen oxides and of the acidification of groundwaters through oxidation of pyrite in shallow sandy aquifers. Although heavy metals and pesticides are not currently a problem, they are being controlled and monitored. Soil protection is dealt with under the provisions of the Environmental Protection Act, last amended in 1987, and is oriented strongly to the prevention of soil contamination. No actual quality standards are set, and no attempt is made to define "good quality" soil, air, or water. Inherent within the Environmental Protection Act is the concept that land use should be related to the capacity of the land to support it, and that the nature of the land should influence land use.

Apart from measures for protecting forest soil in mountainous areas with a view to preventing avalanches, current Swiss legislation is concerned largely with controlling pollution, protecting farmland, and with using land efficiently. However, they have an extensive research programme which looks at soil from three different viewpoints: (i) soil as a natural object (ii) soil as building ground and (iii) soil as an economic commodity and a legal object. The Swiss philosophy has much in common with that of the Dutch, and they have taken up the concept of multifunctionality.

1.2.4 Soil protection in the UK

Although there is no explicit soil protection legislation in the UK, a number of laws and regulations do provide implicit protection, thus land has been protected under legislation covering the creation and management of National Parks, Nature Reserves etc., which has, to a greater or lesser extent, protected the soils within the areas of the Reserves or Parks. Landscape and nature conservation in the countryside is achieved through the negotiation of voluntary management agreements between the relevant authorities and the land owners or occupiers. DoE circular 27/87 (WO 52/87) gives guidance to planners on matters connected with nature conservation. Other relevant circulars include DoE Circular 32/81 (WO Circular 50/81) "Wildlife and Countryside Act 1981" and DoE Circular 24/82 (WO Circular 38/82) "Wildlife and Countryside Act 1981 Commencement of Part I", and DoE Circular 22/84 (WO Circular 43/84) "Memorandum on Structure and Local Plans". All of these circulars are published by HMSO. The Wildlife and Countryside Act 1981 seeks to provide effective mechanisms for protecting wildlife habitats within a framework of goodwill and voluntary co-operation. In these cases, soil is afforded some protection but the protection of soils was, however, largely incidental and fortuitous.

In 1984 MAFF introduced a new scheme which would help to protect some of the most beautiful parts of the British countryside, called Environmentally Sensitive Areas (ESAs), from the damage and loss that can come with agricultural change. With advice from the Countryside Commission and the Nature Conservancy Council, farming methods which are "environmentally friendly" have been identified. Farmers in ESAs who decide to join the scheme and use the appropriate methods are paid by MAFF for the cost of reconciling conservation with commercial farming. To date, ten such ESAs exist: the Pennine Dales, the North Peak, the Shropshire Borders, the Norfolk Broads, Breckland, the Suffolk River Valleys, the Somerset Levels and Moors, Test Valley, the South Downs and West Penwith. This scheme also has the effect of providing some protection to soils on a limited scale.

Planning legislation outwith that designed specifically to protect the rural environment can also provide some 'protection' to soils. Separate planning legislation applies to England and Wales, to Scotland and to Northern Ireland, based on similar principles and procedures and administered by separate government departments. The primary responsibility for the formulation and implementation of land-use polcies for urban and rural areas rests with the local planning authorities. They carry out this task within the framework of the legislation and government policy for which the Department of the Environment (DoE) is responsible in England. In particular, the Town and Country Planning Act 1947 introduced a comprehensive land-use planning system for the UK. The use of land for agriculture or forestry is specifically excluded from the definition of development in the Town and Country Planning legislation, the main aim of which is to control development, i.e. any building, engineering, or other works or material change of use (Saunders 1987). The provisions of the 1947 Act were incorporated into the subsequent Town and Country Planning Act 1971, applicable to England and Wales (and, for Scotland, the equivalent 1972 Act).

For England and Wales, general planning policy and principles are given in PPG1 (1988), the first of a series of Planning Policy Guidelines issued by the DoE. PPG7 (1988) describes the contribution that the planning system can make to the rural environment by providing a mechanism for balancing the requirements of development and the continuing need to protect the countryside. The power to impose conditions on a planning permission for the development and use of land can enable many development proposals to proceed where it would otherwise be necessary to refuse planning permission. DoE 1/85 (WO 1/85) (HMSO) describes the use of conditions in planning permissions.

An important requirement of the Town and Country Planning Act is that in deciding whether or not to give planning permission, the planning authority "shall have regard to the development plan for the area and to any other material considerations". The value of the soil for any purpose in any location may be regarded by the planning authority as a material consideration if the value or quality of that soil could be demonstrated adequately.

For more than 20 years, agricultural land has received some protection from non-agricultural development as planning authorities have attempted to restrict building on Grade 1 and 2 land. Government policies on the development of agricultural land required that no more land should be taken than was necessary, that poorer quality land should be used first, and that special consideration had to be given before new development took place on Grade 1 and 2 land. That policy is implemented through development plans and development control under the Town and Country Planning Act 1971. From 1965 the implementation of this policy was made possible by the 5 grade MAFF Agricultural Land Classification system. (MAFF 1966, 1976).

Because there are now substantial surpluses of the main agricultural products in western countries, the need now is to foster the diversification of the rural economy. The Government's policies for agriculture and for the rural economy are explained in "Farming UK" and "Rural Enterprise and Development" published by HMSO on 10 March 1987. DoE Circular 16/87 (WO 25/87), published by HMSO, gives guidance to planners on development involving agricultural land.

Mineral working has, in the past, been a major cause of dereliction of land and damage to soil, largely on sites worked before the introduction of planning controls under the Town and Country Planning Act 1947, and due to inadequate planning controls in the early years after the Act was passed. Provided that great care is taken with the stripping and storage of the soils which overlay the mineral, with the replacement of these soils after the mineral has been extracted, and with the management of the land after it has been initially restored (after-care), it should be possible, under planning control, to return the site of mineral workings to a beneficial use such as agricultural production, forestry or amenity.

A Memorandum on the Control of Mineral Working in England and Wales (the 'Green Book') was first prepared in 1951 as a guide to the planning control of mineral working, and to indicate the broad lines of policy on the planning problems raised by mineral working. A revised edition was published in 1960. Subsequent changes in the statutory provisions and in Government policy are explained in a series of Minerals Planning Guidance Notes. MPG1 (1988) covered the general principles and national considerations of minerals planning with specific advice on the development plan system. A draft MPG (1988) gives advice on planning considerations, consultations and conditions which are relevant to the reclamation of mineral workings. In particular, it deals with environmental assessment, the stripping, movement, and storage of soils, restoration, aftercare, and reclamation for different after-uses.

The 1971 Act, and the Control of Pollution Act 1974 (administered by DoE), regulate the disposal of controlled waste materials (i.e. household, commercial and industrial wastes). DoE and Her Majesty's Inspectorate of Pollution (HMIP) issue a series of Waste Management Papers which give guidance on waste disposal matters. WMP26, Landfilling Wastes (HMSO 1986), includes guidance on restoration of landfill sites.

The marketing of pesticides is controlled by the Food and Environment Protection Act 1985 which is administered by MAFF. The properties of the different products are examined in relation to toxicity to animals, to wildlife, and to man and in relation to their persistence in food and water, soil and air. The Act also assesses the conditions under which the product may be safely marketed.

MAFF is responsible for reducing the pollution caused by agriculture and for promoting research on the polluting effects of agricultural practices. Air pollution from agricultural activity may be a nuisance to nearby non-agricultural property uses, but it is not considered to be a serious environmental problem.

The risk of erosion depends on soil type, topography, climate, and land use. The Forestry Commission gives advice for forestry. MAFF has codes of good agricultural practice which aim to minimise erosion, but they depend on the co-operation of the landowner or manager.

There are small inputs of toxic elements (metals) to soils from the atmosphere and fertilizers. However, the greatest input is from sewage sludge and other waste products. Guidelines on the maximum amounts of the most common elements which can be added to soils over a long period are agreed between MAFF and the Department of the Environment. Toxic element concentrations in sewage sludge and in the soils to which it is applied are monitored to ensure that these maxima are not exceeded (Saunders 1987).

The recommendation of the Commission on Environmental Pollution formulated in 1976, to adopt a concept of 'best practicable environmental option' has been approved by the UK Government in principle. However, the exact implication which this principle has for soil remains still unknown (cf. Kromarek 1984).

On 27 June 1985 the Council of Environment Ministers of the European Communities adopted a Directive "on the assessment of the effects of certain public and private projects on the environment". This Directive, also known as the Environmental Assessment (EA) Directive, was notified to the Governments of Member States on 3 July 1985. Under article 12(1) the measures necessary to comply with the Directive had to be taken by 2 July 1988. Article 3 of the Directive requires that an environmental impact assessment will identify and assess in an appropriate manner the direct and indirect effects of a project on the following factors:

- human beings, fauna and flora
- soil, water, air, climate and the landscape
- the interaction between the factors mentioned in the first and second indents
- material assets and the cultural heritage

The background to the EA Directive was reviewed by Turnbull and Aitken (1985), who noted that initially MAFF declined an invitation to participate in a working party set up by DoE to consider the application of the Directive in England and Wales, on the grounds that agricultural projects were not affected by planning controls and hence would not be affected by the Directive's provisions. Agricultural projects are excluded from Annex I of the Directive, which lists developments for which environmental assessments are obligatory. However, eight agriculture/forestry topics for which assessments may be required feature in Annex II of the Directive.

The DoE working party's principal conclusion was that the requirements of the Directive can be met within the context of the existing planning system, and that the implementation of the Directive would provide a valuable opportunity for rationalising the existing planning activities and advising on good practice.

The list of developments for which assessment is not obligatory includes many potentially-damaging activities, mainly industrial. In general, it appears that the Government does not foresee that it will be necessary to make the carrying out of formal assessments mandatory in such cases, the existing planning legislation is considered to be adequate. However, it was proposed that the appropriate Secretary of State should have the power to direct that an assessment should be carried out in a particular case if it is deemed to be necessary. The Government hopes that developers will use these procedures voluntarily.

The Environmental Assessment Regulations 1988 implement the requirements of the EC Directive No 85/337 so far as it applies to projects which require planning permission in response to an application under Part III of the Town and Country Planning Act 1971. The Regulations came into force on 3 July 1988. A booklet "Environmental Assessment of Major Projects in England and Wales", produced by DoE, offers advice on the use, scope, and content of environmental assessments. The Town and Country Planning (Assessment of Environmental Effects) Regulations 1988 implement the requirements of the CEC Directive No 85/337. DoE Circular 15/88 (WO 23/88) explains the provisions of the Regulations and gives advice on their implementation. It also sets out the provisions which will be made in respect of local authorities' own development and Crown development. Similar provision for projects subject to planning control is being made in Scotland and Northern Ireland.

Lummis (1984) reviewed the principal problems faced by the UK in protection of soil and ground, and existing or planned solutions to the problems. Because of various limitations, the study was confined largely to matters concerning England and Wales. Both Lummis and, in another review, Kromarek (1984) concluded that the concept of an overall and all-embracing policy of soil protection is alien to thought in the UK. The pragmatic approach to problems which has governed legislation and attitudes for very many years dictates against a conceptual philosophy such as appears to be inherent in a policy for soil protection. Lummis (1984) stressed, however, that the problems of pollution and damage to soil are not being overlooked or treated with less than due regard. On the contrary, he concluded that all the forms of actual and potential harm to soil discussed in his study were subject to controls and measures of one kind or another, all aimed at protecting or restoring soil and at making the best use of it. "Whether more co-ordination of such policies would improve the end result is a reasonable question to ask: some think that there is such a need. There are no signs in present official thinking that this kind of initiative would be pursued at present" (Lummis 1984).

However, Lummis drew attention to the fact that over three-quarters of the surface of the UK (or at least of England and Wales) is excluded from planning control by virtue of being under agriculture or forestry. He noted that there is increasing evidence that the exemption of most forms of agricultural and forestry development is being challenged, and that some change would be needed if the system were to be considered to provide an effective policy for soil protection. Any proposed change of use of a piece of land from agriculture and forestry would, of course, bring it under planning control.

1.2.5 Summary and conclusions

Until relatively recently, most policies concerning soils were for soil conservation, which in reality focussed almost entirely on the prevention or limitation of erosion. Although in Europe soil erosion has always occurred to some extent, it has not been the subject of government policies.

In 1972, the European Soil Charter (Appendix 3) was adopted by the Committee of Ministers of COE. It emphasized that soil is a limited natural resource which is easily destroyed and which must be protected from certain agricultural techniques, erosion, pollution, and damage caused by human habitation and civil engineering. However, the Charter did not stimulate much activity. In 1981 the World Soil Charter was published, it aimed to establish a set of principles which should serve as a basis for the most rational use of the World's soil resources and their protection against irreversible damage. Even so, in 1984 it was noted that no European country had an explicit soil policy although some countries, notably the Netherlands and the Federal Republic of Germany, were working towards soil policies by including soil protection in other planning policies.

However, at that time, the situation in Europe and the climate of opinion were changing, and have continued to change, due to a recognition of increasing problems with erosion, heavy metal and pesticide contamination, acidification, contamination of groundwaters by nitrate, and loss of soils under buildings and roads.

The reactions of the various European countries have reflected variations in the nature and perceived seriousness of the problems and the existing legislation. The main planks of the existing policies in mainland Europe are:

i. Soils are complex systems which carry out functions upon which mankind depends for food, timber, and the multiplicity of ecosystems which given the environment its diversity.

ii. A principle aim of the Dutch policy is that 'good soil quality' must be maintained. The definition and assessment of soil 'quality' (section 1.7) is a subject of current research.

iii. The principle of 'the polluter pays' has been adopted in many European countries.

iv. The principle that land should be used for the purpose for which it is best suited is inherent in the Danish Environment Protection Act, and is embraced in the Federal Republic of Germany's "Bodenschutzkonzeption", although the latter is as yet a philosophy rather than a planning policy (Appendix 2).

v. The view that soils are natural objects which are worth protecting in the way that plant and animal species and communities are worth protecting is also growing. It is contained in the "Bodenschutzkonzeption", and in the Swiss National Soil Research Programme (Appendix 2).

vi. Some countries, notably the USA and the Netherlands, have policies which stress the stewardship of natural resources, including soil, on behalf of future generations. The Dutch express this by saying that we should regard ourselves as "guests in our environment" (not masters of it).

vii. The Dutch have two tracks of environmental policy: 'source-oriented', in which the emphasis is on defining parameters for 'good soil quality', and 'effect-oriented', in which the goal of ensuring the health and well-being of people and the preservation of animals, plants, goods, and forms of use has been translated into the task of preserving the properties of soils which are important for the various functions. This is the so-called 'multifunctionality' concept (Appendix 2).

viii. The concept of multifunctionality emphasizes the importance of the functioning of soil as rooting medium, a source of nutrients and water, and as a filter, buffer and transformation system.

ix. Several countries have taken the view that monitoring 'soil quality' is an essential part of a soil protection policy, and have estabished networks of sites, initially for monitoring pollution.

x. Currently, the UK has no policy specifically for soil protection. Urbanization and related developments are controlled by the Town and Country Planning Act, which aims to restrict building on the best agricultural land. Guidelines for the control of erosion are issued by MAFF, but their effectiveness depends on the co-operation of the landowner or manager. Acidification is a problem which has to be dealt with by air pollution legislation. Small amounts of heavy metals may come from the atmosphere, but the greatest input is from sewage sludge and other waste products the control of which depends on guidelines issued by MAFF and DoE. The marketing of pesticides is controlled by the Food and Environment Protection Act, which is administered by MAFF, but the use of the materials depends on the users complying with the manufacturer's instructions. Leaching of nitrates into groundwaters depends on a voluntary approach, and every incidence of water pollution in accordance with the Control of Pollution Act is not considered as pollution if it corresponds to good agricultural practice.

Two points need to be made about the situation in the UK. The first is that the various instruments which are available are not linked or co-ordinated under a broad policy, and responsibilities are spread between departments. It is reasonable to ask if more co-ordination of such policies where they affect soils would improve the end result. The second is that three-quarters of the UK, or at least of England and Wales, is excluded from planning control by virtue of being under agriculture or forestry. This exemption from control is being challenged, and some change would be needed if the system were to be considered to provide an effective policy for soil protection. Any proposed change of use of a piece of land from agriculture and forestry would, of course, bring it under planning control.

1.3 SOME CONCEPTS USED IN SOIL PROTECTION POLICIES

In the previous section, a number of concepts were identified which have been incorporated into soil protection policies currently being developed in Europe. Six of these concepts are discussed further in this section.

i. The use of the term 'soil protection' as opposed to 'soil conservation'.
ii. The emphasis on the functions of soils rather than uses of soils.
iii. The emphasis on protecting all the functions which soils perform.
iv. Relating land use to the most suitable soil.
v. That the exploitation of soils by this generation should not impair their potential for future generations.
vi. The recognition of soils as natural bodies worthy of study and protection in their own right.

1.3.1 Soil protection v. soil conservation

The use of the term soil protection, as distinct from soil conservation, is a relatively recent trend and seems to have originated in Europe and particularly within the EC. As noted above (section 1.2), soil conservation had become almost synonymous with the control of soil erosion, although this is not implicit in the term. Soil protection is generally used to indicate a broader approach to maintenance of the soil resource which considers all threats to the resource, including erosion. There would appear, however, to be further differences: the existing soil conservation policies throughout the world are aimed at maintaining agricultural or forest productivity and are often part of broader legislation covering agriculture and forestry. Soil conservation implies conserving the soil for a particular use. There is an immediate economic imperative to soil conservation.

Current ideas about soil protection are not linked to any particular use of soils but, instead are tied in with our view of soil as a complex system which carries out various functions, and are thus related to the way in which we define soil. The soil protection policies being discussed, or adopted, in Europe view the soil resource as part of the broader environment, and soil protection policies are often embedded in a general environmental protection policy.

1.3.2 The functions v. uses

Soil protection policies currently being formulated in the Netherlands and the Federal Republic of Germany and being discussed within the CEC emphasize consideration of the functions which soils perform rather than the uses to which man puts soils. This could be seen as a further attempt to emphasize that soil protection is not linked to a particular use of soils. It represents, however, a rather more fundamental change in approach and one which is more flexible than a use-oriented policy. When we use soils we exploit one or more of the functions which soils perform. One function may be exploited in a variety of uses but different uses generally exploit a different combination of functions. Consideration of the functions which a given use exploits identifies any possible conflicts between uses and forms a sound basis for the assessment of the impact of a given use on particular soils. The functions which a soil can perform are a consequence of the fundamental characteristics of soils; the range of functions which a particular soil can perform is characteristic of that soil. Concentration on the functions does not make any judgement about future uses of soils which may not be currently considered; many future uses could still be assessed and evaluated by examining their impact on the functions of soils.

1.3.3 Multifunctionality

In the Netherlands, the discussion of the functions of soils has led to the development of the concept of 'multifunctionality'. This concept recognizes the various functions which soils can perform and stresses that the exploitation of one function of soils by man should not impair the operation of the other functions which soils are able to perform. While this can be the aim and form one of the bases of a soil protection policy it must be recognized that it is an ideal which can never be achieved in full. Some uses of soils will inevitably restrict the number of functions that those soils can perform in the short or medium term. Thus, the use of a given soil as a foundation for buildings or roads means that it cannot function as a source of nutrients and water for plants, or of anchorage for roots, at least in the medium term. Similarly, the extraction of sand and gravel or of brick clay from large excavations involves the removal of soil and the creation of a quarry and therefore inevitably limits the uses to which that particular area can be put and limits the functioning of the soil of that area. A soil protection policy which aims to maintain all the functions of soil should recognize these conflicts.

An assessment of the impact of man's various uses of soil on the various functions which a soil can perform in both the short, medium and long term should be included in any policy. Wherever possible, the aim should be to modify uses, or their implimentation, so that the multifunctional nature of soils is maintained in the medium to long term. Those uses which inevitably restrict the major functions which soils can perform should be clearly identified and should not be implemented in a given area without a thorough and intensive assessment of their impact on the functions of the soils of that area. Where a given use of soil by man limits its functioning in the short to medium term for example, the use of soil as a foundation for buildings, the aim should be to restore the soil when the use ceases such that it can perform as wide a range of functions as possible.

The concept of multifunctionality and of the protection of soil functions rather than the protection of soils for particular uses represents quite a marked change in the way most people conventionally think about soils. Most people consider soils in the context of a particular land use. However, the apparent conflict between use-oriented and function-oriented soil protection policies is perhaps less important than the distinction between a policy designed to protect a single function of soils, or protect soils for a given use, as opposed to one which aims to protect all the functions of soils, or protects the soil for a wide variety of uses. A broadly based policy which aims to protect as many as possible of the range of soil functions would of necessity protect soils for a wide range of uses. Protection of soil for a wide range of uses would similarly protect most of the functions of soils. As noted above, 'soil protection' as currently used, implies a broadly based policy.

1.3.4 Relating land use to the most suitable soil

The response of soils to a given stress or loading varies considerably between soil types as a result of their inherent differences in soil properties (cf. section 1.4). The impact of a given form of land use, or land management, will, therefore, be less on some soil types than others. A particular soil type will, however, vary in its response to different stresses, or forms of land use. The likelihood of a soil being adversely affected by a particular stress can be referred to, and assessed, as its sensitivity to that stress (cf. section 1.10). Conversely, the ability of a given soil to adsorb, or neutralize, particular stress is often referred to as the buffering capacity of the soil (cf. section 1.9). The overall impact of man's activities on soils would be minimized if particular uses were sited on those soils which were least sensitive to the stresses arising from that form of land use/management. For this reason, the soil protection policy being formulated in the Federal Republic of Germany, stresses that soils should be used for those purposes to which they are most suited, i.e. those uses to which they are least sensitive.

1.3.5 Protection of soil for future generations

The concept of the stewardship of land by present generations on behalf of future generations is not a new one; it is central to the thinking that has given rise to soil conservation policies in the United States of America and many other countries. As noted earlier, it also underlay the way in which rural communities exploited the soil resource and was the basis of the way in which family farms had been managed in Europe for many hundreds of years. It can also be seen as an extension of the multifunctionality concept; the protection of the various functions of soils will ensure that the use-options of future generations are not limited by the actions of the present generation. The concept also has much in common with the concept of sustainable development which was propounded by the United Nations World Commission on Environment and Development in their report "Our Common Future". The concept of sustainable development has been endorsed by the United Kingdom government. The concept is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

1.3.6 The protection of soils in their own right

The emphasis on the fact that soils are natural bodies worthy of protection in their own right is linked to the recognition that: (i) policies had become necessary which give explicit protection to soils, (ii) soils are dynamic functional systems, (iii) protection of the landscape requires protection of soils, (iv) the complex of soils form a potential valuable gene reservoir because of the wide variety of flora and fauna they contain, (v) there is a need to understand the basis for predicting the impact of land use on soils.

The protection of species and biotopes has normally been limited to such animal and plant species, and plant and animal communities, which are either rare or endangered. Man is not obviously endangered, but our basic environment is influenced by a variety of interconnected causes and effects which apparently do not improve any imminent effects on mankind. However, because of our reliance on the functions carried out by soils, a soil protection policy must include the protection of soils for their own sake, i.e. irrespective of their perceived exposure to threats.

1.3.7 Summary and conclusions

For some time the term 'soil conservation' has been applied to measures for reducing the rate of soil erosion, chiefly in order to maintain agricultural and forestry production and to protect water courses and reservoirs from silting up. More recent concern about wider aspects of the deterioration in quality of the soil resource as a result of various threats has resulted in the use of the term 'soil protection', which is not linked to any particular land use. Instead, it considers soil as a complex system which performs various functions, the range of functions being characteristic of a given soil type. When we use soils we exploit the functions, so that protecting the functions also protects the range of uses to which a soil may be put. This is the basis of the 'multifunctionality' concept which plays a large part in the soil protection philosophies of the Netherlands, the Federal Republic of Germany, and Switzerland. From this viewpoint, the exploitation of one function of a soil should not impair the other functions that the soil can normally perform. This represents a marked change from the idea of protecting a soil for a given use.

Consideration of the functions which a given use of soils exploits identifies any possible conflicts between uses, and forms a sound basis for assessing the impact of a given use on a particular soil. However, the various soil types differ not only in the range of functions which they can perform, but also in their responses to different types of stress. Hence, we have the concepts of the sensitivity of a given soil to a particular form of stress and the soil's buffering capacity for that stress. In order to minimize the impact of man's activities on a soil, and thereby protect its functions, any particular form of land use/management should be applied on soils which are least sensitive to, and well-buffered for, the resulting stresses. This principle is incorporated in the soil protection concept of the Federal Republic of Germany.

The idea of protecting the functions of soils is implicit in the concept of sustainable development propounded by the United Nations World Commission on Environment and Development and endorsed by the UK government.

1.4 SOIL - ITS DEFINITION AND CHARACTERISTICS

1.4.1 Definition

The term 'soil' may be defined in a number of ways, depending on the viewpoint adopted, the uses to which we put soils and the functions which we expect them to perform.

Thus, for example, the view of 'soil' will differ widely between a gardener, a farmer, an agronomist, a forester, a civil engineer, a sand and gravel company and a soil scientist. The gardener, farmer, agronomist and forester will all see soil primarily as a medium in which plants grow but they may disagree over the depth limit placed on 'soil' and on its important characteristics. The Civil Engineer will view soil as a foundation material or as an overburden and may include in the definition all unconsolidated material overlying in situ bedrock. The sand and gravel company will regard the lower layers of soils formed in sands and gravels as raw materials. The soil scientist will see soils as dynamic, living systems comprising mineral and organic constituents, solutions and gases and which are worth studying as natural objects. It is clearly difficult to reconcile these different viewpoints in one, short simple definition.

The definition used in the context of a soil protection policy will also be influenced by the philisophical basis of that policy. Thus, a policy which aims to protect one function of soils, or protect soils for one given use, e.g. agriculture, could be very different from one based on a multifunctional, or multiuse approach. The latter needs to recognize all the important characteristics of soils which enable them to perform a variety of functions and uses. Such definitions become descriptions rather than definitions sensu stricto. The 'definition' used by the FAO is an example of such a descriptive definition:

"The soil is not an inert mass. It is a very delicately balanced assemblage of mineral particles, organic matter, and living organisms in dynamic equilibrium. A soil possesses characteristics, such as depth, bulk density, permeability, structural stability, pH and cation exchange capacity, which together result in qualities such as moisture, oxygen and nutrient availability, and workability. Soils differ very widely in their characteristics, responses and suitability for different purposes, and fertility. This variability results, primarily, from three factors, first the parent material from which the soil was formed, secondly the environment in which it developed, and thirdly the length of time that environment has remained relatively unaltered. Soils are formed over very long periods of time, but if their environments are changed (for example by the removal of vegetation cover), the delicate balance is upset. This can be compensated for by careful use and management (for example by the addition of organic matter), but all too often it is not, and a process of deterioration or degradation begins" (FAO 1983).

1.4.2 The mineral and organic constituents of soil

The solid part of soils comprises both mineral, inorganic and organic materials. Both the inorganic and organic constituents are important in determining the properties of the soil. The initial mineral constituents are derived from the soil-forming material, be it bedrock, glacial debris, or alluvium, for example, but these minerals are then modified by weathering and other soil processes. The nature of the resultant mineral matrix depends on the mineralology of the material from which the soil has formed and the nature and duration of the weathering and other soil processes. Clay minerals are formed by the weathering and breakdown of primary, rock derived minerals.

The organic constituents are derived from dead plant material which falls onto soils and from roots, plus organic compounds removed from leaves of living vegetation by rain and exuded from roots. The organic debris is gradually decomposed and transformed and incorporated into the soil. These processes can be seen most clearly in soils that have been uncultivated for a long time, such as old forests, old heathlands, and old grasslands. Such soils have characteristic distributions of undecomposed and decomposing litter and humus on the surface and mixed with the surface mineral soil horizons. These distributions are called humus types or humus forms. The nature of the humus form at a given site will depend upon the vegetation type and the soil organisms, which themselves are controlled by the soil parent material and climate. These organic-rich layers are zones of high levels of activity of soil organisms, and produce substances which move down the soil profile in percolating water and bring about chemical changes (e.g. Russell 1973).

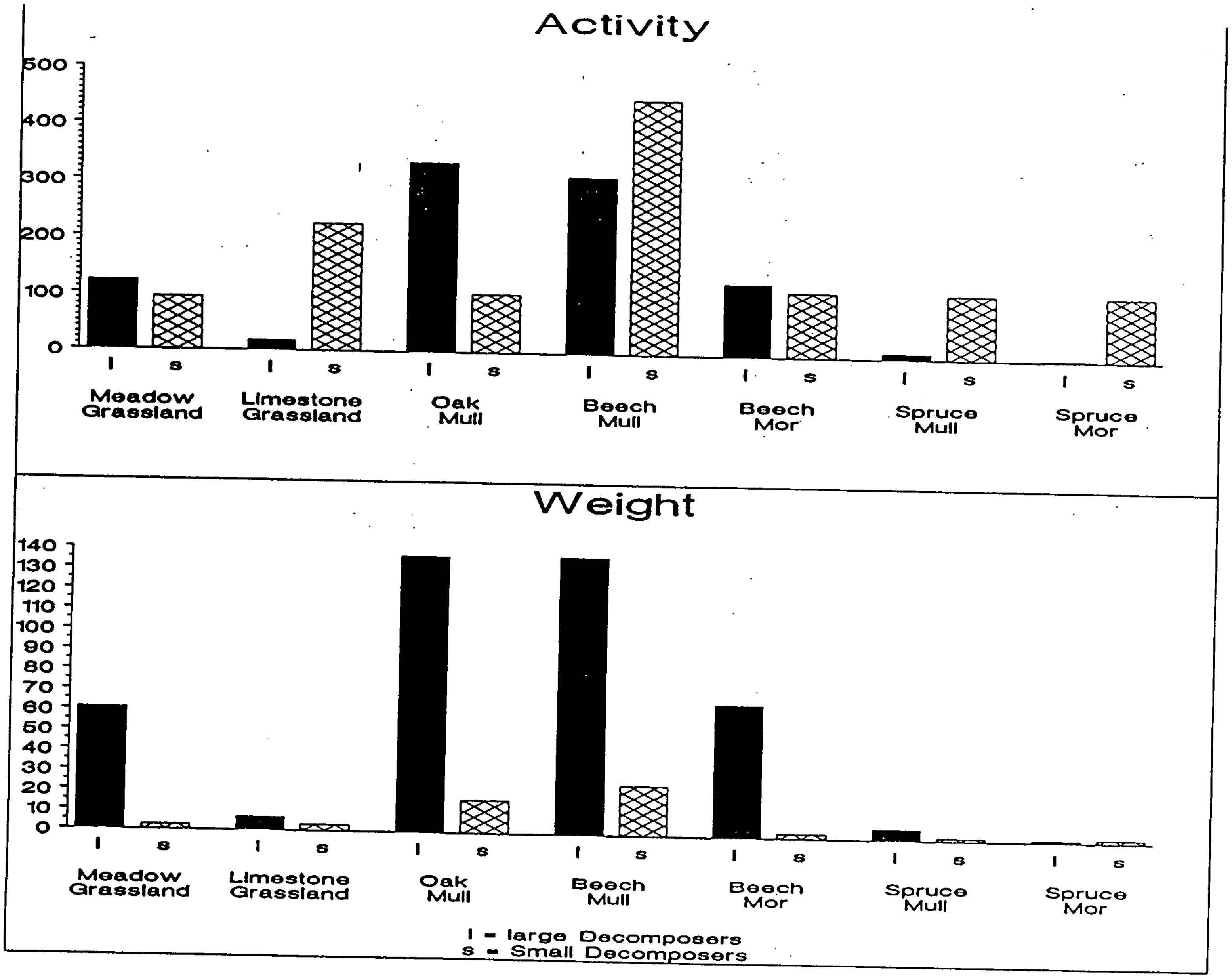


Figure 1 Activities and weights of soil invertebrates in various types of ecosystem (after MacFadyen 1963).

Changes in vegetation will lead to changes in the organic inputs to soils, in the humus form and in soil organic matter. Changes in management can lead to changes in the rates of breakdown of organic debris and its incorporation into the soil. The mineral constituents of soil are much less sensitive to changes in vegetation/or management.

The chemical and physical properties of soils are controlled largely by humus and clay, they are centres of activity around which chemical reactions and nutrient exchanges occur. By attracting ions to their surfaces they can protect them temporarily from leaching, releasing them slowly for plant use.

1.4.3 Soil organisms

Soils contain varied assemblages of living organisms whose activities range from the largely physical comminution of plant residues by soil animals to their transformation and eventual complete decomposition by micro-organisms. Accompanying many of these activities is the release of several plant nutrient elements including nitrogen, phosphorus, and sulphur from organic components. Organisms also need those elements for growth, and a proportion of the released elements is converted into forms not available to plants. Blum (1988) suggested that the top 30 cm of a one hectare area of agricultural soil contains approximately 25 tonnes of soil organisms comprising c. 10 tons of bacteria and actionmycetes, 10 tons of fungi, 4 tons of earthworms and one ton of other soil organisms such as spring tails, mites, isopods, spiders, coleopterus, snails and mice. However, the total faunal biomass, the species composition of the soil fauna, and the activities of the various groups depend on the type of ecosystem and the type of management (Petersen and Luxton 1982; Lagerlof 1987, and Fig 1).

Earthworms are important in mixing mineral soil and organic matter and developing soil structure and aeration, and organic matter is important because it stabilizes soil aggregates. This was demonstrated when earthworms were introduced into apple orchards on reclaimed polder soils in Holland. Compared to plots without earthworms, plots with the earthworm Aporrectodea caliginosa showed an increase in large and capilliary pore space and aggregate stability and an increase of about 40% in water available for plant growth (van Rhee 1969). Conversely, in old Dutch orchard soils that had been treated with fungicides for many years, destroying all the earthworms, there was a deterioration of structure in the 0-40 cm horizons, with a sharp boundary between mineral soil and an organic mat (A_0 horizon) (van de Westeringh 1972).

Although only 10% or less of the carbon dioxide produced by decomposition of plant material has been attributed to soil animals (Persson et al. 1980; Peterson & Luxton 1982), micro-arthropods may have a large effect on litter decomposition, increasing the loss of mass by up to 70% over that attributed to microbial effects (Vossbrinck et al. 1979; Seastedt 1984). The possible effect of soil animals on element flux has been examined in several ecosystem studies (Witkamp & Ausmus 1976; Reichle 1977; Persson et al. 1980; Anderson et al. 1981). Mineralization rates have been shown to increase in the presence of various faunal groups both in field experiments in varying conditions and in laboratory microcosms (Cole et al. 1978; Anderson et al. 1983; Verhoef and de Goede 1985). Ammonium ions are often mobilized from the litter and humus layers by animal activity, and different groups of soil fauna contribute to the nitrogen mineralization to different extents, with lumbricid earthworms usually being the most important group quantitatively. Population density is also important (Anderson et al. 1983), as is temperature.

1.4.4 Depth - the problem of the lower limit of soil

As has been pointed out above (Section 1.4.1), the lower limit of soil could be drawn at a very different depth depending on the particular use which is made of soil or the function which is exploited. Extreme examples might be the gardener interested in the top 20-40 cm and the civil engineer who might regard tens of metres of overburden as soil. The approach suggested here is that soil must include all the layers, horizons, which allow it to perform a range of functions or uses, which allow the soil to function as a dynamic, living system and which allow it to be characterized and defined. This is the approach of the soil scientist who would include as soil, all layers which had been changed from their original state by the processes of soil formation and which are now part of the living dynamic system. The depth of material thus regarded as soil would vary from a few centimetres in parts of the uplands to perhaps a maximum of 1.5 or 2.0 m in areas of the lowlands. The depth of the soil would also change gradually over time as processes such as weathering altered the upper parts of the soil forming material. The depth can also be changed by man, e.g. by ploughing up some of the soil forming material and incorporating in into the soil profile.

1.4.5 Soil pores, gases and solutions

Most peoples concept of soil concentrates on its solid constituents, the mineral particles and the organic materials. However, soils incorporate a large amount of space, as voids of various sizes which contain gases and liquids. The proportion of voids, their spatial and size distributions are influenced by other physical characteristics of the soil and by the activities of soil flora and fauna, and by plant roots. The pore system is not stable but changes continually under the influence of natural wetting and drying, freezing and thawing, the activities of soil organisms and plant roots, and in agricultural soils, of cultivation.

The voids in soils are extremely important as they form the site of the dynamic interactions between gases, liquid and solid phases of the soil, i.e. between the pore content and the pore walls. The proportion of the voids of a soil occupied by liquids as opposed to gas will reflect climate, vegetation and other physical properties of the soil. The solutions and gases are, however, an important part of the soil with the distribution and composition being influenced by, and influencing, the rest of the soil system. The importance of the soil solution and of soil-solution interactions is most clearly seen in the present concerns about the leaching of nitrates and pesticides to groundwaters and the ability of the soil to buffer groundwaters against pollution.

The definition of soils used in the Dutch soil protection policy explicity includes soil waters and gases, while in the German policy the link between soil protection and protection of groundwater quality is stressed. The Dutch policy goes even further by defining 'groundwater' as part of soil. This is understandable in the context of the Netherlands where a large proportion of the country has a very shallow water table which in many cases lies within what most soil scientists would regard as 'soils'. However, it does not seem sensible to follow this approach in the UK where the upper surface of the groundwater is at a depth of tens of metres in places and may even be within the bedrock. A practical approach in the UK would be to consider 'groundwater' per se as part of soils only when it comes within the soil profile; the 'groundwater' would then be soil water. This situation would arise in valley bottoms. In other situations, groundwater should not be regarded as part of soil; groundwater quality would, however, still be protected through protection of soils and their role as a buffer of drainage water quality.

1.4.6 Soil heterogeneity

Soils are anisotropic, i.e. their properties vary with depth. A vertical section dug through all but the shallowest and youngest soils reveals a series of visibly distinct layers, or horizons, which differ in physical, chemical and biological properties. This variation reflects the influence of plant remains added to the surface and the influence of soil-forming processes, including the effects of percolating waters and the substances dissolved and suspended in it, mineral weathering, the action of soil animals and plant roots. The sequence of horizons, and their properties are used to classify soils (e.g. Avery 1980, Clayden & Hollis 1984).

Soils also exhibit lateral spatial heterogeneity at different scales, from millimetres (Bullock & Murphy 1983), through metres (Ball & Williams 1968; Webster & Cuanalo de la C. 1975; Robertson et al. 1988) to kilometres (e.g.any Soil Survey of England and Wales Memoir). Large variation can be expected on a regional scale with soils derived from different types of parent material and experiencing different climates. Even on the same parent material, soils may be heterogenous on a local scale because of the influence of factors such as vegetation type, land use and topography.

The spatial heterogeneity, at a variety of scales, provides a range of habitats for plants and associated fauna. This heterogeneity may be due to variations in, for example, nutrient status or water-holding capacity. Variation in soil properties at scales of a few metres may be associated with changes in plant species distribution (e.g. Snaydon 1962; Pigott & Taylor 1964; Turkington & Harper 1979). Whether spatial complexity affects or mainly reflects plant community structure is not known, but this heterogeneity may influence existing plant and microbial population dynamics and needs to be considered in studies of community and ecosystem dynamics (Robertson et al. 1988). It is also important for the appearance of the landscape. Agricultural activities and eutrophication as a result of pollution tend to reduce the natural heterogeneity and hence the range of available habitats. Soil heterogeneity has important consequences for discussions of soil degradation (section 1.8) and soil quality (section 1.7).

1.4.7 The dynamic nature of soils

Soils, as they exist in their natural setting, are dynamic systems which are always in a state of development. The rate of development is greatly influenced by the nature of the material from which the soil is formed and the climate. The rate of change of soils varies through time and different characteristics of soil change at different rates, as the many processes operative in soils proceed on different time scales. The development of the sequence of characteristic horizons of a podzol or brown soil, for example, may take hundreds or thousands of years, the development of lateritic soils, characteristic of some areas of the tropics, tens of thousands of years. The soils of the British Isles are relatively young, having developed over c. 10 000 years since the end of the Plaistocene glaciation, and are still evolving. The generally very slow rate of development and evolution of soils at a given site can increase dramatically as a result of management or changes in vegetation.

Proudfoot (1958) studied soil history and podzol development in Co. Antrim, N. Ireland, and used archaeological evidence to show that tillage in Neolithic times helped to accelerate the rate at which podzolization occurred on boulder clay. In the Forest of Dean, the planting of Norway spruce and European larch, on ancient deciduous woodland sites led to significant leaching of iron, and the shift, in 50 years, from a brown earth to a soil showing evidence of podzolization. On a larger scale, the clearance of deciduous woodland from the uplands by early man is thought to have led to the development of podzolic soils and, in some cases, peat.

Data from Scandinavia and West Germany (Berdên et al. 1987) suggest a marked increase in the rate of soil acidification as a result of increased acidic deposition.

The addition of plant debris to soils, its decomposition, and the subsequent release of the contained nutrients for uptake by plants, is a clear demonstration of the dynamic nature of soils. This cycling of nutrients is an important mechanism in the maintenance of the fertility of the soils of natural and semi-natural ecosystems. Disruption of the cycle can lead to a reduction in site fertility as evidenced by the impact of the removal of tropical rain forest.

In addition to the longer-term changes in soils as they evolve, there are many short-term oscillations in characteristics in response, for example, to seasonal variations in climate. Thus, there are seasonal variations in soil water content, soil animal populations and root activity which lead to annual cycles in soil chemistry.

Iversen (1969) has studied soil development at a site in Denmark. In Mesolithic times the site had a brown soil with a mull humus. The forest vegetation at the site gradually changed from a lime forest with hazel and oak to one of oak, beech and holly; this change was paralleled by an increase in soil acidity and a change from mull humus to mor. A further change took place about 1000 years ago when beech spread into the site as a result of man's activities; the humus became still more acid and changed from one containing small soil animals to one dominated by soil fungi.

1.4.8 Soils as parts of ecosystems

Soils form parts of ecosystems, and should not be considered in isolation. An ecosystem consists of (i) a biological community composed of populations of plants, animals (including man), and micro-organisms, and (ii) its environment of physical and chemical factors. Green vegetation is the foundation of terrestrial ecosystems, it captures solar energy and by the process of photosynthesis incorporates it into chemical substances which sustain organisms at other trophic levels. In doing so, it absorbs mineral nutrients from soil. Vegetation modifies the physical environment and determines, directly or indirectly, what other organisms can exist in the ecosystem. The type of vegetation influences, and is influenced by, the type of soil. There is an exchange of materials between living and non-living parts (Odum 1971; Billings 1983). Man-induced changes in vegetation or the physical environment will lead to changes in soils.

Studies of the development of soils in natural, unmanaged situations are really studies in the development of ecosystems. Thus, in Britain, following the retreat of the Pleistocene glaciers, the soils evolved as the vegetation changed from tundra, through coniferous forest to deciduous forest, as the climate changed (Godwin 1975).

In the absence of major disturbance, ecosystems, including their soils, tend to show a consistent pattern of change in structure and function through time. Few, if any, ecosystems reach a perfect steady-state condition in which the structure and function of the system remain constant through time. Long-term climatic fluctuations, and trends in regional climates, together with processes such as leaching, erosion and deposition, cause slow but continual changes in ecosystems (Collier et al. 1973). When changes in environmental factors are small and occur over long time scales, the ecosystem may be said to be in a 'quasi-steady state' or 'quasi-equilibrium'.

Natural ecosystems and their soils evolve over long time scales which are often studied in dated sequences of soils known as chronosequences. Jenny (1980) found that soils developing on moraines of the Rhone glacier were still accumulating organic nitrogen after 300 years, and calculated that it would reach a maximum at or after 2000 years. In a chronosequence of soils and vegetation at Mt. Shasta (California) surface organic matter (forest floor) increased rapidly to a maximum at 205 years, then declined to half the maximum amount at 566 years. Soil organic matter increased rapidly up to 60 years, then less rapidly to 566 years (Dickson & Crocker 1953). In Norfolk, Ball and Williams (1974) found marked accumulation of organic matter in quartz sand dunes over 70 years.

When heather moor was colonized naturally by birch, the soil organic matter content fell from 194 g dm^{-3} under heather to 120 under 38 year old birch and 97 under 90 year old birch, as a result of changes in soil organisms and their activities (Miles 1981). When arable land at Rothamsted was laid down to grass, the soil nitrogen content increased for 150 years. It took about 25 years under grass for the organic nitrogen content of the soil to increase half way from the arable level to the level in old pasture (Russell 1973).

Man can alter or destroy natural ecosystems directly or indirectly. Examples of direct alterations are cutting down vegetation, changing vegetation, ploughing natural grassland, draining peatlands. An extreme example is the complete destruction of the ecosystem by urbanization and road building. Indirect effects are initially less dramatic, and involve changes in one or more factors which then trigger other events with long term, often unpredictable effects on the system. An example of an indirect cause of change is increased acidic deposition. A problem with long term indirectly produced changes, is that the ecosystem may not show signs of change for some time after the initial perturbation, and irretrievable damage may have been done before the problem is recognised (Billings 1983). The important point is that all alterations to ecosystems, whether resulting from direct or indirect effects, will produce linked changes in soils.

The energy derived from sunlight via plants enables the complex structure of natural ecosystems to be maintained. Agricultural ecosystems are very much simpler than natural ecosystems. In order to keep such ecosystems simple and productive, energy inputs are required to counteract the natural processes. In Europe, this is mostly from fossil fuels used in agricultural machinery and the manufacture of fertilisers. Without this input of energy an agricultural ecosystem would revert to some form of semi-natural ecosystem, albeit very different from that which occupied the site originally (Billings 1983).

1.4.9 Soil fertility

Discussion of different types of soil, and the effects of stresses on them often refer to 'soil fertility'; for example, the term is used in the FAO 'definition' of soil quoted earlier. There is no generally-accepted definition of soil fertility. One definition may refer to the soil nutrient status, including quantities and availability of, and ratios between, different elements. By this definition, a fertile soil is one which has, or is capable of providing, an adequate and well-balanced supply of essential nutrients in an available form to meet the requirements of a growing plant during the various stages of its growth. However, that is not enough. A soil may have all the necessary plant nutrients readily available, but may not be fertile because of its poor physical condition. Its physical properties determine its water-holding capacity, ease of penetration of plant roots, degree of aeration, and stability of soil structure.

In fertile soils, soil structure is stabilized by bacterial polysaccharides and humus substances which help to develop aggregates. In light soils there is usually little aggregation, and the main function of humus substances is to act as the predominant agents for nutrient exchange to plants. However, these functions of humus last only as long as the balance of humus substances remains unchanged. Because of the dynamics of formation and breakdown, this depends on (i) a regular supply of organic residues, and (ii) suitable conditions for the activities of soil organisms. Soil management operations often reduce the volume of pore space and consequently of soil air, resulting in a change in the quantity of humus and its composition. If the soil is loosened, enlarging the air spaces, humus substances are transformed or decomposed and soil aggregates tend to disperse. The magnitude of these effects depends on the degree of cultivation, so that grassland soils develop a better structure than do soils under continuous cultivation.

1.4.10 'Soil' vs. 'Land'

In the UK the use of the term 'land', as in 'land use', can cause some confusion. One definition of 'land' is a part of the solid portion of the earth's surface either of undefined extent or marked off by natural or political boundaries. However, another definition of 'land' is 'ground or soil', especially as having a particular use or properties, e.g. arable land, plough land, corn land. Even 'urban development' as a form of land use carries some implicit definition of the soil properties, for example no responsible person would carry out urban development on a peat bog. Similarly, in Germany the noun 'Boden' can mean soil or ground. In English, the term 'ground' can mean a portion of the earth's surface, a piece or parcel of land. These uses of the various terms emphasize that for practical purposes soil has been thought of as part of the landscape. In OECD (1985) the French 'sol' is used as being equivalent to both 'land' and 'soil'.

1.4.11 Summary and conclusions

The definition of soils will vary depending on the viewpoint, the use to which soil is put or the functions of soil which are exploited. In the context of a soil protection policy, the philosophical basis of the policy will be a major influence on what is regarded as soil. In a multiuse- or multifunction-based policy, which also recognizes soils as natural bodies worthy of study, it is important that any 'definition' recognizes those characteristics of soils which enable them to perform a variety of uses and functions.

Soils are dynamic, living systems which comprise a skeleton of organic and mineral constituents enclosing a network of voids and pores which contain liquids and gases; soils contain a population of living fauna and flora ranging from bacteria and fungi to worms and rodents; the chemical, physical and biological properties of soils vary both vertically and horizontally at a variety of scales - this variation produces a range of habitats for plants and animals; soils vary in depth from millimetres to metres, the lower limit of soil is material which has not been modified by soil forming processes;

organic, chemical and physical processes operative in soils produce long and short term changes in soil properties; the organic (living and dead), mineral, solid, liquid and gaseous fractions of soils form a complex interlinked system, such that a change in one of the components of the system will result in linked changes in others and an alteration in the functioning of the system; soil systems form part of ecosystems, any alteration to other components of the ecosystem will result in changes in the soils.

1.5 WHY PROTECT SOIL?

"The soil, water, range, and forest resources of the United States are the natural foundation of our national economy. From them come our food, most of our clothing, and much of our shelter. How well we protect and improve these resources will have a direct bearing on the future standards of living of the whole nation".

Secretary of Agriculture Benson
(in J. Soil & Water Conserv., May 1954)

1.5.1 Practical considerations: Uses and functions of soils

Soils are capable of fulfilling various functions which in turn enable them to be put to various uses by man (Table 1).

The functioning of soil as a rooting medium and a source of nutrients and water is the basis of human and animal life supporting the production of food, fibres and fuel both directly and indirectly. These functions have always been important but the functions of being a filter, buffer, and transformation system have become increasingly important.

Soil acts a filter to remove solid matter from percolating water, and as a buffer to absorb rain water and control its transport to the groundwater table or streams, rivers and lakes. Water stored in the soil is used by the vegetation. Another important buffering activity is the protection of groundwater and food chains against pollution by means of physico-chemical and chemical processes. An important example of this is the biological/ biochemical transformation and decay of toxic organic compounds such as pesticides.

Blum (1988) has suggested dividing the various functions of soils into ecological functions and technical-industrial and socio-economic functions:

Ecological functions -production of biomass, filter, buffer and transformation system, gene reserve and protection medium (in this context "protection" of historial and archaeological materials is being considered).

Table 1. The functions and uses of soil

FUNCTIONS OF SOIL
Plant anchorage medium
Supply of plant nutrients
Substrate/habitat for soil organisms
Filter, buffer and transformation system
Food supply for ground feeders
Heat exchange
USES OF SOIL
Agriculture
Forestry
Natural ecosystems
Recreation
Building
Waste disposal
Raw material
Fuel (energy)

Technical-industrial/ socio-economic functions	-foundations for urban and industrial development, transport systems, sporting facilities
	-sources of new materials eg sand, gravel, clay, water.

This division cannot be applied rigidly as man exploits the buffering function of soils as part of his 'technical-industrial' activity. The function as a gene reservoir might also be better expressed as a function as a habitat for a diverse population of flora and fauna. The function as a 'protective medium' might be best seen as a third type of function i.e. 'cultural'.

Problems arise when a particular use destroys one or more of the functions of soils. The expansion of settlements, industrial estates, and the infrastructure of roads, railways, and airports has effectively limited the functioning of large areas of soil. Pollution resulting from this expansion has placed increasing loads on the ability of the remaining soils to act as filter, buffer, and transformation systems. These systems have also been strained by the excessive use of plant protection products, resulting in the appearance of these substances in groundwater, streams, rivers and lakes. Such problems are discussed in the following section.

Blum (1988), has also expressed the view that "The use of technical, industrial and socio-economic soil functions precludes ecological functions totally, partly and/or temporarily."

The subdivision into ecological and socio-economic functions of soils has some similarities to the division of functions (human uses) of the natural environment proposed by van der Maarel (1978). He suggested that man makes use of various functions of ecosystems: biotic production (agricultural production); as a carrier (of urban activities, rural activities, waste, outdoor recreation); as an information source; for regulation. Van der Maarel (1978) suggested that usually, a particular area has a potential for many functions, but the fulfilment of one function will reduce the capacity for most of the others. From an ecological viewpoint, van der Maarel (1978) distinguished between functions provided by the more or less unchanged 'natural' environment versus functions whose fulfilment may include a considerable change in the original characteristics. The first type includes particularly information and regulation functions, while the second includes particularly the carrier, storage, and most of the production functions.

'Natural' functions are linked to the productivity, structure, and species composition of ecosystems. These are defined by geological and geomorphological conditions, soil and soil water conditions, vegetation type, flora and fauna, and climate.

1.5.2 Philosophical and ethical considerations

The history of soil conservation in the USA has been characterized throughout by two interlinked trends, one aesthetic, philosophical and religious the other practical and technical (see Appendix 2). Thus, Forred (1956) discussed religious/ethical/philosophical aspects of conservation and emphasized the concept of our stewardship of soil, water and natural resources.

The theme of stewardship is echoed in the Report of the UN World Commission on Environment and Development, 'Our Common Future' which discusses, and endorses the concept of 'sustainable development' or 'development without destruction'. Sustainable development may be defined as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs.' Thus, development must not endanger the natural systems that support life on earth: the atmosphere, the waters, the soil and the living beings ('Our Common Future'). As pointed out in the UK perspective on 'Our Common Future' the basis of the concept of 'sustainable development' is not new, indeed it has been the essence of the approach adopted for centuries by rural societies in working the land and its soils, the forests and woodlands, as well as the fresh- and sea waters (DoE 1988).

In a similar vein, the Dutch soil protection policy (Appendix 2) stresses the view that soils should be kept in a condition which gives the widest possible range of use options and which does not constrain their use by future generations. The aim is to do nothing which would impair any of the soil's functions now or in the future. Thus, the exploitation of one function of soils should not impair the operation of other functions. This is the so-called 'multifunctionality' concept which, as noted earlier, forms the philosophical basis of the Dutch soil protection policy.

The German environmental protection policy (Appendix 2) stresses that soils are a fundamental part of terrestrial ecosystems and that, even if they are not exploited by man they are natural objects worthy of study in their own right. This leads to the view that soil systems are worthy of conservation and protection in the same way as rare plants and animals, or particular ecosystems or plant communities.

One of the three themes of the Swiss research programme (Appendix 2) is "Soil as an economic and a legal object". In this theme there is a project "Proper rights of soils" which is being carried out by a law professor at the University of Bern. For centuries there has been an anthropocentric view of the world, but it may be argued that although man has a right to live, he has no right to dominate the ecosystem. Man should therefore prove that any of his activities which impinge on the environment are essential. In Switzerland, nature protection groups already have the right to oppose building and other developments, so this new viewpoint is not that far ahead of the present. There may be other projects on ethical/religious aspects. There will undoubtedly be interesting discussions, perhaps involving the concepts of multifunctionality and inputs-outputs.

The concepts of 'stewardship' of soils, of not impairing the options of future generations, of 'sustainable development' will require a re-education of many involved in the highly intensive, exploitation of soils. On the family farms which predominate in Europe, one of the greatest gains has been the maintenance and improvement of soil structure and fertility over the centuries. This can be explained by the family farm structure, which aims to hand down the inheritance from one generation to the next in the same family. Hence, the farmer is motivated not to over-exploit his plot of land. To be effective, soil conservation and soil protection policies must find acceptances by landowners and land managers. Hence, peoples attitudes to soil and the environment are important. For this reason, education and public awareness are an important part of the soil conservation and protection programmes of the USA, Switzerland, the Netherlands, and West Germany.

1.5.3 Summary and conclusions

There are both ethical and practical reasons for protecting soils. Soils perform a wide variety of functions; man exploits these functions when he uses soils. Different uses exploit different functions. A soil protection policy which aims to maintain use-options for present and future generations will aim to retain, and protect all the various functions soils perform, i.e. it will be multifunctional. This leads to the principle that exploitation of one function, by man, should not inhibit the operation of the other functions of soils. In practice, this aim or ideal is not achievable in all cases: thus, the use of soils as a foundation for buildings or transport systems is incompatible with its use as a growth medium; the exploitation of sand and gravel, for example, may physically remove soils thus preventing its use as a foundation or a growth medium.

A multifunctional-, and multiuse-, based soil protection policy should aim to limit those uses of soils which interfere with their functioning as natural systems and which are incompatible with other functions of soils; if soils are used for any of these uses, the aim should be to restore the soil, following exploitation, such that it can perform as wide a range of functions as possible, and hence be available for a wide range of uses.

A multifunctional-, and multiuse-, based soil protection policy has implicit in it an acceptance of the principle of the 'stewardship' of the soil by present generations; the recognition that resources, including soils are finite. This will require a change in attitudes of many people involved in using soils and in society in general.

Soils are natural objects worthy of study in their own right. Acceptance of this principle, leads to the conclusion that soils are worthy of conservation in the same way as species of plants and animals. Conservation of soils in this sense would necessitate protection of whole soil systems, indeed, of whole ecosystems.

1.6 CURRENT THREATS TO SOILS AND ECOSYSTEMS

Although there are differences between countries in the relative importance of the various threats, there seems to be general agreement on the nature of the important threats. These are sometimes spoken of in terms of local and 'global' effects, but for some threats there is no clear distinction and in any case the term 'regional' is preferable to 'global'.

The important threats are:

	local	regional
urbanization and infrastructure	x	
erosion	x	
acidification	x	x
accumulation of pollutants	x	x
nitrates in groundwater	x	x
loss of organic matter (deteriorating soil structure)	x	x
compaction	x	

1.6.1 Loss to urbanization and infrastructure

The covering of soils by urbanization and industrialization is a matter of concern in many European countries. Not only does this seal the soils, but usually the topsoil is removed beforehand. The availability of land for agriculture, forestry, nature conservation, and other uses is threatened by such developments. The urbanized landscape covers some 15% of the total land area in the Netherlands, 12% in the Federal Republic of Germany, only 5% in France, 8% in the UK, and nearly 7% of the EC as a whole (Best 1981). Nearly 78% of the land in the UK is used for agriculture. In Belgium the figure is 46%, in France 62%, and in the Federal Republic of Germany 56%. There is a considerable lack of agreement on statistics for the amount of agricultural land lost each year to non-agricultural uses, notably building, in the UK. In the UK, the annual loss since 1945 is estimated at between 13,000 and 20,000 ha, or 4.6% of good agricultural land, which itself accounts for 65% of land classed as agricultural (Kromarek 1984). Data updated by DoE to 1985 show that the average annual transfer of (all) farmland to urban uses in England and Wales fell from 17 500 ha in 1946-50 to 14 000 ha in 1955-60, rose again to 16 800 ha in 1965-70 and then declined rapidly to 4800 ha in 1980-85. Moss and Neate (1987) noted that in recent years concern has been expressed over the paucity of reliable and comparable land use data. The available information is held in various degrees of detail and accuracy by a host of organizations using a variety of definitions of use, type and condition. Data collected by the Second Land Utilization Survey at King's College London, which are not accepted by the UK Government, stress that an alarmingly high level of land is lost to urban development each year. Whatever the actual figures may be, it is generally accepted that in the UK, urban development is the greatest single threat to soil. Members of the Council for the Protection of Rural England, when asked what were the main pressures on the countryside, identified five causes: new house building, new roads/motorways, industrial development, mineral extraction, tipping of waste. It may not be possible to reduce such pressures but it should be possible to reduce their impact on environment and soil, partly by enabling land-use planning decisions to be based on better information concerning soil quality.

1.6.2 Erosion

Soil erosion is a process which occurs naturally, although generally the stabilization of soil by vegetation reduces its rate. The rate of erosion increases to the point where it becomes a problem when the vegetation cover is disturbed and, as in intensive agriculture, the soil surface is bare for varying periods of time. Then the rate of loss of soil becomes greater than its rate of formation. It is estimated that 1 cm of forest soil can form in 200 to 400 years (Graziani 1987).

Soil erosion is reviewed in Vol II section 2.5 of this report. The physical loss of mineral or organic particles from specific soils is regarded as a gross physical change and has implications for dependent properties such as water and nutrient retention capacities. With wind and water erosion, one soil's loss can be another's gain. Wind erosion deposits particles on soils in the lee of obstacles such as field boundaries, causing deepening of the surface horizon. Water erosion commonly sorts material, depositing coarser fractions on less sloping ground where they dilute the organic fraction and alter the particle size distribution of surface horizons. Finer fractions and organic particles are carried further to either areas of standing water or the river network.

The degradation of agricultural land through the loss of topsoil by erosion in European countries is a matter of some concern, although it is difficult to identify the scale of the problem with any accuracy. In France 5 million hectares of land are subject to erosion, while in Belgium the figure is 600 000 hectares. The problem is greater in many Mediterranean countries (Graziani 1987). In the Federal Republic of Germany soil erosion has long been recognized as a problem and has been the subject of advice, especially over the period 1850 to 1930. More recently, the introduction of heavy machinery resulted in up-slope ploughing and the removal of hedges, resulting in increased erosion which has become especially noticeable over the last 10 years. The growing of maize leaves soil bare until late in the year, with consequent risk of erosion. In the uplands, forest death and tourism are also increasing the erosion problems.

In Switzerland, erosion has become a problem in the settled areas over the past 15 to 20 years, and there is visible and measurable erosion even on fields with 10% to 15% slopes. In places, the soil loss is 20 to 30 tonnes ha^{-1} while soil production is only 5 t ha^{-1} (Häberli pers. comm.).

About 37% of agricultural land in England and Wales (2 million hectares) is threatened by an unacceptable degree of erosion (Graziani 1987). Wind erosion is confined largely to sandy soils and to lowland peaty soils. Water erosion is a problem in the main arable areas of Britain, in upland areas, and in areas of intensive recreation such as those associated with footpaths in National Parks. Off-site effects of erosion are also very important, involving the silting-up of watercourses, reservoirs, and filtration equipment, and associated eutrophication. Soil erosion represents the most extreme form of soil degradation. It results from decreasing shear strength, decreasing infiltration rate and increasing run-off that follow loss of soil structure, especially under continuous arable farming. Crop rotations based on grass leys restore soil structure and organic matter.

Most attempts at assessing the long-term implications of erosion on soil productivity in Europe have been based on comparisons of the mean annual erosion rate, estimated or measured, with a maximum acceptable rate called the soil loss tolerance, or T value. The T value is intended to represent the rate of formation of new soil as a result of pedogenic processes, the addition of manures and fertilizers, and the mixing of topsoil and subsoil during tillage. Because crop yield is related to the depth of the soil, the loss of soil by erosion can be expressed in terms of reduced crop yield.

Johnson (1987) considered that T values currently assigned to cropland soils in the USA are based on faulty premises concerning rates of topsoil development and mineral weathering processes. The concept of soil loss tolerance rests upon two assumptions: (i) that soil scientists can assess reliably and objectively the maximum rates of soil erosion that can be tolerated, and (ii) that policy makers can weigh that assessment objectively against countervailing interests or needs, however they may be defined. Johnson challenged both assumptions. He noted that short-term political considerations may demand that public policy allow soil resources to degrade. McCormack et al. (1982) also concluded that the rate of soil formation will not compensate for soil erosion at the rate of T values currently accepted in the USA. Larson (1981) proposed a two-level approach to setting T values. A T1 value would reflect on-site soil productivity maintenance objectives and a T2 value would reflect broader social purposes and off-site concerns such as water pollution or reservoir sedimentation. The T1 values would be set by scientists and the T2 values would be set by economists, environmental scientists, planners and policymakers. Nowak et al.(1985) suggested that T2 might be set temporarily greater than T1 where the economic, social, or political costs of reducing current erosion rates to a crop productivity maintenance level were deemed to be excessive. However, such a temporary relief could easily become permanent, and Johnson (1987) concluded that acquiescence in unceasing soil resource degradation is not an acceptable public policy choice.

Although off-site effects of erosion such as the pollution and silting-up of watercourses and reservoirs are not threats to soils, they are important consequences of soil changes resulting from such threats, and so need to be borne in mind.

1.6.3 Acidification

Soil acidification is seen as one of the major current threats to soils in northern Europe. It is discussed in more detail in section 1.13 and Vol. II section 2.8. Acidification of soils is a process which occurs naturally at rates which depend on the type of vegetation, soil parent material, and climate. However, man's activities can accelerate the rate of soil acidification. Long-term, gradual soil acidification can occur as a result of planting certain tree species. Exotic conifers vary in their tendency to acidify soils, and some broadleaved species may acidify soils more than some conifers (e.g. Howard & Howard 1984a,b,c,d). Acidification may also be caused by fertilizers and the draining of soils. However, the acceleration of soil acidification by inputs of oxides of sulphur and nitrogen, produced by the burning of fossil fuels, is the major concern in Europe. It is implicated in forest decline, especially in central Europe, and can also have adverse effects on poorly-buffered surface waters. One effect of soil acidification is the mobilization of aluminium from clay minerals and the mobilization of any heavy metals which the soils might have accumulated.

The soils most at risk from acidification are those on parent materials which are poor in bases such as calcium and magnesium and in readily-weatherable silicate minerals. Acidification is favoured by high rainfall, which leaches bases from the soils. Soil acidification is accompanied by changes in the whole ecosystem. Falling soil pH and base status are followed by changes in the vegetation, eventually favouring the more acid-tolerant and acidophilous species. Similar changes occur in populations of soil organisms.

1.6.4 Pollution of soils

Heavy metals

Heavy metals, chiefly zinc, copper, nickel, lead, cadmium, chromium, and mercury, are found in domestic sewage sludges and wastes. Over the last 10 to 15 years, every EC member state has been considering seriously the maximum heavy metal content which is tolerable in farmland, or what quantities can be added to farmland in sewage sludges without further concern (Sauerbeck 1987).

Heavy metals may also be added as contaminants in fertilizers (see also Vol II section 2.2).

Sewage sludge is not much used for agriculture in Belgium, and it does not seem to be a problem in the Netherlands. The Swiss Sewage Sludge Order governs the use of sewage sludge on agricultural land and stipulates maximum limits for heavy metals. In the Federal Republic of Germany, a Federal Decree of 1982 controls the use of sewage sludge. France is in the process of working out technical standards for the use of sewage sludge and standards for determining the levels of trace elements in soil before the first spreading and every 10 years thereafter. In the UK, about half of the domestically-produced sewage sludge is used for agricultural purposes according to a code of practice which aims to control heavy metal inputs to soils by requiring compliances with guidelines which in future will be in line with the EC Directive (Kromarek 1984).

The CEC Directive of 12 June 1986, instead of setting strictly-defined maxima, lays down maximum ranges which may be exceeded only in exceptional conditions but should generally not even be reached (Sauerbeck 1987).

Heavy metals are also deposited on soils from industrial emissions to the atmosphere. They are controlled through air pollution legislation. Solid refuse (landfill) can also be a source. Locally-high concentrations of heavy metals in and around mining areas and some industrial sites have existed for many years and are often the subject of clean-up operations. Some natural geological deposits produce locally-high concentrations of heavy metals.

Heavy metals become bound to organic and clay fractions of soils and are extremely persistent. McGrath (1987b) studied soils which had farmyard manure and sewage sludge applied from 1942 to 1961. Recoveries of zinc, copper, nickel, cadmium, lead, and chromium ranged from 55% to 85% in 1960, and from 32% to 42% in 1980. However, this apparent decline in recovery was due to lateral movement of metals due to cultivation, and if this is taken into account the recovery was 80% or more after 45 years (McGrath pers. comm.). Giller and McGrath (1988) stated that for all practical purposes, once heavy metals are added to soil they remain there for thousands of years.

In the UK current controls on the contents of heavy metals in soils appear to centre on their toxicity or on the possibility that they may find their way into the human population. Their possible effects on the environment will be covered when the EC levels are adopted. It is now well established that the majority of urban soils in the UK are contaminated with metals to varying degrees. Areas where the mining and smelting of metals have continued over several hundred years present a special case. A study of metals in urban soils and dusts was commissioned by the Department of the Environment in 1981 to establish the usual ranges of metal concentration to which the population may be exposed in the house and urban environment (Thornton 1986). The methods used were discussed by Culbard et al. (1983) and Thornton et al. (1985). The results were given in Thornton et al. (1985). Amounts of lead, zinc, and copper in urban garden soils were appreciably greater than those normally found in agricultural soils, confirming the results of several other studies in individual urban locations.

Biological effects of heavy metals

Zinc, copper, and nickel have high toxicity to plants and are likely to affect crop growth before causing food-chain effects on animals, including humans. Lead is only taken up to a small degree by plants but may be deposited on plant surfaces in significant amounts; lead in soil ingested by animals is toxic. Cadmium is a special case, as it is considered to be dangerous in the food chain below phytotoxic thresholds.

Urban gardening is common in the UK, and vegetable growing is for many both a source of fresh produce and a leisure pastime. Thornton (1986) studied (i) lead, zinc, and cadmium contents of garden soils and radish, lettuce, and carrot crops grown in some typical urban/city areas, and (ii) the content of arsenic in soils, vegetable and salad crops in Cornwall. He concluded that although many urban soils are contaminated with heavy metals, this is reflected to only a small degree in edible tissues of garden crops. However, the role of air-borne heavy metals deposited on to plant surfaces needs further study. The statutory limits for lead and arsenic in food offered for sale for human consumption in the UK is 1 mg kg^{-1} fresh weight.

There is no legal limit on cadmium, but amounts in vegetables can reach undesirable levels. Ottevanger (1986) found that in a contaminated area in

Belgium, a 'provisional tolerable weekly intake' of 400-500 μg of cadmium per person could be exceeded at a normal average consumption of contaminated vegetables. The 'provisional tolerable weekly intake' was based on the critical concentration in the kidney cortex of 200 μg cadmium per kilogram of kidney cortex, which can be the result of long-term uptake exceeding 400 μg $person^{-1}$ (FAO, WHO).

Apart from the possibility that heavy metals may get into the food chain, there is also the problem of the effects on plant growth and soil organisms and processes. Heavy metals have been shown to cause complete suppression of symbiotic nitrogen fixation in clover, with yields reduced by up to 40% in the field (McGrath et al. 1988a). Heavy metal contamination may also halve the size of the microbial biomass (Brookes & McGrath 1984). These effects have implications for land which is taken out of agriculture, as such land will depend on biological fixation of nitrogen and cycling of nutrients through the microbial biomass (Giller & McGrath 1988).

Heavy metals inhibit activities of soil micro-organisms, for example respiration, nitrogen mineralization and nitrification, and some enzyme activities (Doelman 1986). Litter decomposition has been found to be linearly related to contents of copper and zinc (Tyler 1976), and litter accumulates in the presence of increasing cadmium contents (Coughtrey et al. 1979). In the latter case, it was noteworthy that the proportion of small organic matter particles increased, suggesting that a soil fauna adapted to the changed conditions was active. Domsch (1984) emphasized that heavy metals have selective effects on populations of soil organisms. Under continuing stress, heavy metal tolerant and/or resistant micro-organisms will emerge (cf. McGrath et al. 1988a,b). Metal pollution around smelters has been shown to reduce the abundance and species numbers of the soil fauna and their activities (Bengtsson & Rundgren 1982, 1984; Bengtsson et al. 1983; Bengtsson et al. 1988).

A major problem with heavy metals is how to reduce the levels. Metals are not removed from soil by normal cropping, nor are they leached from near-neutral topsoils. A maximum of only 0.5% of the amount of each of zinc, copper, nickel, cadmium, chromium, and lead which had accumulated in a sludge-treated soil is removed after 20 years of harvesting. For all practical purpose, once metals are added to soil they remain there for thousands of years (McGrath 1987b; Giller & McGrath 1988).

Organic pollutants

The development and widespread use of synthetic and natural organic compounds in industry and agriculture has led to concern over the possibility of environmental pollution by these chemicals. Not only are pesticides known to pollute soil directly by affecting soil organisms, but soil acts as a vector for the pollution of water.

Long-term studies at Rothamsted Experimental Station (UK) have shown that since the 1860's, there have been large increases in the soil burden of polynuclear aromatic hydrocarbons (PAH's), the latter mainly being derived from combustion of fossil fuels. PAH's are excluded from cereal grain, but accumulate on or within herbage, where they are a source of dietary intake for herbivores. Their effects on soil microbial processes are unknown, but if they do have adverse effects there is a need to quantify both inputs to, and outputs from, sites of ecological importance. There is some suggestion that for PAH's residence times in soils may be long (Johnston, in press).

Attitudes to the use of pesticides vary. In 1984, in the UK and the Federal Republic of Germany, there was a tendency to think that as long as the fertility of the soil was not affected it was not necessary to take any more restrictive measures than those in operation at the time. There appeared to be little concern about the problem in Belgium. In France some avenues for research had been defined to study the way in which pesticide residues act in certain types of soil corresponding to certain typical situations, and in particular to follow the effects of run-off (Kromarek 1984). However, recently pesticides have become a problem in the Federal Republic of Germany and it has become difficult to fulfil the requirements of the EC Directive of January 1984 (A. Grafen pers. comm.). Some 300 organic compounds are applied on a large scale in EC Member States (de Haan 1987). In the Netherlands, 31 compounds have been placed on the 'black list' of compounds which must not be used in the protection zones for drinking water supply. In addition, there is a 'white list' of 206 compounds which may be used in drinking water areas if the directions on the label are followed strictly.

The rate of transfer of pesticides through soil systems depends on the physical and chemical properties of the pesticides, the regional climate and geomorphology, and soil properties such as permeability, cation and anion exchange capacities, redox potential, pH, and organic matter content (Yassoglou 1987). Micro-organisms are responsible for most of the pesticide degradation in soils, and high rates would be expected in soils with well-aerated, thick surface horizons with high organic matter contents, base-saturation, and adequate moisture.

Biological effects of organic pollutants

There are two problems with the use of organic pesticides. The first concerns their selectivity, i.e. whether a compound is toxic to only the specific target organism(s). The second concerns undesirable side-effects to soil organisms or human beings. While toxicity constitutes the basic problem, the way in which undersirable effects are brought about depends largely on the behaviour of the compound in a soil system. One of the most important aspects is biodegradability, because it governs the persistence of a compound. Other important properties are the solubility of a compound and its degree of bonding onto soil constituents, especially clay and organic matter (de Haan 1987).

Domsch (1984) reviewed the effects of pesticides on biological processes. He noted that if the user follows the recommendations and restrictions given for registered pesticides, the actual quantity applied per unit area is small, usually much less than 10 kg ha^{-1}. In contrast to the rather persistent chemicals previously used, recently-released pesticides have considerably shorter half-lives in soil. However, it is still not known to what extent a postulated lasting flux of bound pesticide residues into the soil solution might affect sensitive microbiological processes and produce a persistent effect. He gave examples of microbiological processes which are sensitive to pesticides, but stated that the ecological significance of an induced change cannot be estimated without taking into account the natural variations within a soil system.

Insecticides tend to upset the balance between groups of invertebrates, and create increases in populations of some species. Organo-chlorine insecticides are not very toxic to soil invertebrates, but they do tend to depress overall population sizes. Organo-phosphate insecticides are more selectively toxic, decreasing populations of some invertebrates at the expense of others. Carbamates are more harmful to most groups of invertebrates. Contact and fumigant nematicides have drastic effects on all species, from which they may take more than a year to recover (Edwards 1984). Herbicides have little direct effect on soil invertebrates, but they do affect the availability of organic matter.

1.6.5 Pollution of groundwater by nitrate and phosphate

Although heavy metals and persistent organic pollutants are the main potentially-harmful components in municipal wastes, and especially sewage sludges, the main problem with liquid manures and other agricultural residues lies in their content of plant nutrients, which can have an adverse effect if excessive quantities are applied. There are two main problems: (i) the risk of losses of nitrates into shallow groundwater, and (ii) saturation of the soil with phosphate, which may also move into the groundwater. These problems were discussed briefly by Sauerbeck (1987), and are discussed in Vol II section 2.3 of this report.

The problems of excessive application of nitrogen and phosphorus, in whatever forms, were discussed by de Haan (1987). The Dutch definition of soil includes groundwater, and the movement of nitrate and phosphate into the groundwater is a matter of some concern. Important factors in the nitrate leaching problem are:

i. nitrogen application rate and type (mineral or organic)
ii. land use (arable, pasture)
iii. soil type (sand, clay, peat)
iv. water management (groundwater level, irrigation)

The nitrate leaching problem is caused by incomplete use or uptake of mineral nitrogen present in the rooting zone in soil water. There may be various reasons for this, for example the absence of roots after harvesting, when nitrate is released by mineralization of organic matter.

The current EC standard for drinking water (Directive 80/778) is 11.3 g nitrogen per cubic metre, which corresponds to 50 g nitrate per cubic metre (50 mg litre^{-1}) and member states are advised to aim for half that amount.

Nitrate moves freely in soil water because it does not bond on to soil constituents. Phosphate, on the other hand, bonds strongly on to soil constituents. This limits its availability to plant roots. Different soils vary in their ability to fix phosphorus. If phosphate is added in excess of the fixation capacity, it will move in the soil water. The main soil components responsible for phosphate bonding are organic matter, clay minerals, and hydrous oxides of aluminium and iron (see Beek and van Riemsdijk 1979 for an extensive review). A model was developed by van Riemsdijk et al. (1984) and van der Zee and van Riemsdijk (1986) for sandy soils. For many soils, a good correlation exists between the total amount of phosphorus that can be bound and the amount of reactive iron and aluminium as determined by oxalate extraction. De Haan (1987) discussed a method for assessing the currently-remaining phosphate-binding capacity of a soil, and hence the evaluation of the risk of phosphate leaching.

The problem of nitrate pollution is recognized internationally, and is usually associated with intensive agricultural practices. In the UK, the areas affected are those on permeable rocks such as chalk and Triassic sandstones. There is a voluntary approach based on a code of good agricultural practice. Every incident of water pollution in accordance with the Control of Pollution Act definition is not considered as pollution if it corresponds to good agricultural practice.

It is often claimed that the blame for nitrate pollution falls on farmers who, seeking ever-increasing yields, use too much nitrogenous fertilizer. However, research at Rothamsted Experimental Station (UK) and elsewhere has shown that this idea greatly over-simplifies a complex problem. Hence, control measures based on this misconception might prove not only ineffective, but also very costly to farmers and to the community in general (Addiscott 1988). All of the nitrate in British soils is dissolved in the soil water and is vulnerable to leaching. Ammonium is less vulnerable because it is adsorbed on soil particles. Except in some very acid soils, micro-organisms convert ammonium to nitrate, and any nitrate not used by growing plants is carried away in percolating water. This nitrate might come from a chemical fertilizer, an organic manure, or the breakdown of soil organic matter.

Soil contains large quantities of nitrogen tied up in organic forms. Some of this organic nitrogen is very resistant to microbial decomposition, some is readily broken down by micro-organisms with the release of ammonium. This, and the subsequent conversion of ammonium to nitrate, occurs in arable soils in autumn, when the soil is either bare or carrying a small growth of newly-sown crop. Researchers at Rothamsted believe that nitrate released from soil organic matter decomposition is responsible for more of the nitrate in groundwater than are direct losses from chemical fertilizers (Addiscott 1988). Little is known about the dynamics of nitrogen through different components of soil organic matter and its relation to soil ammonium and nitrate. This is one area in which more research is needed.

The nitrate problem is relevant to the question of 'set-aside', i.e. taking agricultural land out of production. As soil cannot be left bare because of the problem of nitrate leakage, a good option would be to put the land under grass; grass roots scavenge nitrate effectively. However, nitrate would be released from organic matter if ever the grass had to be ploughed. Another option would be to use the fields for forestry. Mature woodland leaks little nitrate but there are periods, particularly after felling, when nitrate leakage is likely.

In the Federal Republic of Germany alternative ways of maintaining nitrate pollution of groundwater below permitted maximum levels are being evaluated economically. Cost-benefit analysis is being used to study the possiblities of reducing emissions or eliminating them completely so as to keep the nitrate content of drinking water within permitted limits (BELF 1987). In Belgium, for the Flemish region, the first draft regulation of the decree for the protection of ground water will deal with the use of fertilizers (Kromarek 1984).

In the Netherlands, ground water is included in their definition of 'soil'. The western part of the Netherlands is very low, with peaty and clayey soils. The eastern part is somewhat higher, with poor sandy soils. The most intensive stock breeding is in central and eastern parts. The latter areas were formerly occupied by small, poor farms. With increased fertilizer use grass production improved and stock numbers increased, producing more manure. Almost everywhere there the ground water is 1 to 2 metres below the soil surface. Shallow aquifers lead to small brooks and rivers, and produce the main 'natural' ecosystems. In such systems, nitrate from manure and fertilizers is a particular problem because it moves quickly in percolating water. Dutch scientists think that the sandy soils will soon become phosphate-saturated, creating more problems. Surface run-off from water-saturated soils can carry manure and slurry, also polluting water courses. The Manuring Order restricts the time of application of manure, which is different for different crops. Over the next few years, the permitted quantities will be reduced. Legislation on manure application is also used to reduce the likelihood of phosphorus saturation. Some 40 to 60 kg ha^{-1} of nitrogen is input in rain. The amount leached from arable land or grasslands is similar.

The Dutch try to solve the groundwater nitrate problem by creating, around the 'natural' vegetation, buffer zones in which the spreading of manure is prohibited. The problem is how wide each buffer zone should be. The farmers and authorities want the buffer zones to be as small as possible, conservationists want them to be as large as possible. Provinces are encouraged to declare such areas, but are reluctant to do so because of the resulting economic constraints.

The approach is to model groundwater flow in selected transects. Most rainwater drains into the surface soil layers, only 10% to 20% of the surplus water goes to deeper aquifers, and there it moves very slowly. A series of zones with different penetration times can be constructed round the area of interest. This can be tied in with models of nitrogen behaviour, such as ANIMO (Berghuys-van Dijk 1985), so that the arrival of nitrogen into the protection areas in different flows can be calculated for the unsaturated zone (say to 2 metres depth). The model suggests that application of less animal manure will reduce the time required for denitrification. At the same time, if farmers have to apply less manure they will apply more inorganic fertilizer nitrogen, which will make the nitrate problem worse, especially in grasslands. It is easier to monitor the application of artificial fertilizer than to monitor manure application.

Fortunately, in certain locations the aquifers are composed of material which contains some peaty layers. They thus have a sufficiently large denitrification capacity to remove known contents of nitrate in relatively short times, about two years. The time for denitrification can be used to define the buffer (protection) zone. However, the heterogeneity of the material presents some problems. In some areas, organic matter is lacking and nitrate is not removed. The next phase of the Dutch work is to produce some simple rules for using these conclusions in other areas, and to examine the problem of soils lacking significant organic matter contents. Research is also being done on models for optimizing crop use of nitrogen by ensuring that factors which affect plant uptake of nitrogen, such as soil moisture content, are not limiting (Steenvoorden & Bouma 1987).

Phosphate does not appear to be a problem at the moment, particularly as the use of phosphates in detergents is now controlled. However, unlike nitrate, phosphate binds to soil particles and if a soil becomes phosphate-saturated then phosphate will remain in solution along with nitrate. In the Netherlands the capacity of soils to adsorb phosphate is already exhausted at several locations (Moen & Cramer undated), and provisional quality levels for phosphorus in fertilizers were given in IMP-Environment 1986-1990 (p 39).

Biological effects of fertilizers

Organic manures are bulky relative to their nutrient content, and in relation to their nutrient value they are costly to transport. Hence, the use of inorganic fertilizers, especially as nitrogen sources, has increased rapidly. Little is known about the effect of fertilizer nitrogen on soil organisms, and the available evidence is conflicting. Working on the Park Grass Plots at Rothamsted, Edwards and Lofty (1975, 1977) found that decreases in numbers of total invertebrate fauna, earthworms, enchytraeid worms, myriapods, mites, springtails, and beetle larvae were inversely proportional to the amount of nitrogen applied.

However, in arable soils inorganic nutrients have been shown to increase numbers of invertebrates (Edwards 1984). Edwards concluded that the available data suggest that:

i. Where there is abundant organic matter, as in grassland or forest soils, nitrogenous fertilizers tend to depress invertebrate populations.
ii. Where there is much less organic matter, as in arable soils, nitrogenous fertilizers appear to increase invertebrate populations, probably because the increased crop residues remaining on the soil after harvest provide food for these animals.

1.6.6 Soil organic matter: Losses and additions

Soil organic matter is important in maintaining soil structure, in retaining water, and as a nutrient reserve and chemical buffer. Soil organic matter is lost if outputs from the soil exceed inputs to it. Thus, the draining of fenlands increases soil aeration, which stimulates the activity of soil organisms resulting in organic matter decomposition. Agricultural cropping systems and cultural practices have been shown to affect organic matter levels because (i) inputs to the soil are less than occurred prior to cultivation, and (ii) through excessive tillage, and consequent erosion, losses of soil and of soil organic matter have been accelerated (McGill et al. 1981). Tillage may also cause soil organic matter loss by increasing aeration and organic matter decomposition.

Many of the changes in agricultural practices which have occurred over the past 50 years have reduced the amounts of organic matter in soils. Many people have identified the causes as being related essentially to economic and fiscal policies, linked to the Common Agricultural Policy. It has been noted that the proportion of carbon in some Belgian soils is decreasing. In France, the phenomenon is noticeable particularly in the south.

In the UK, the weakening of soil structure due to loss of organic matter is a fairly general problem of arable land. It has been estimated that the critical organic matter level in such soils is about 2%, but in many cases the actual level is 1% to 1.5%. Fenlands represent a different type of soil system, which is naturally waterlogged and consists largely of organic matter. Drainage and cultivation cause loss of organic matter and consequent shrinkage, as well as deteriorating structure which makes the soils prone to wind erosion.

Newbould (1982) summarized factors that influence changes in soil organic matter content, and reviewed studies aimed at understanding its turnover in soil. He concluded that in soil under modern farming systems in temperate climates, organic matter levels tend slowly towards equilibrium levels determined by the system, climate and soil type (cf. Johnston 1982; McGrath 1982). For a particular system and site, equilibrium levels increase in the order: fallow no nitrogen, phosphate, and potassium (NPK) fertilisers or farmyard manure (FYM), or residues NPK alone, FYM or residues alone NPK and FYM or residues. Organic matter levels can be increased slowly by the use of leys, return of straw with added fertilizer, heavy use of FYM and addition of other organic materials. However, there were no grounds, either in terms of yield or soil structure, to change farming systems if it lowered their profitability.

In general, loss of soil organic matter favours aggregate disruption, soil compaction, erosion, reduced rate of water infiltration and storage, and crusting. The reverse is true within certain limits. The question, "How much soil organic matter is enough?" is difficult or impossible to answer. Newbould (1982) concluded that it was not possible to predict an ideal or target level of organic matter. It may be that the degree of association, and the nature of complexing, in organo-mineral particles, rather than the total organic matter content, is the major criterion controlling physical properties. Sauerbeck (1982) thought that it is organic matter turnover, rather than a particular content of soil organic matter, that should be aimed at. Most of the effects of organic matter are indirect, through its influence in soil organisms and processes.

Soil organic matter turnover can be improved by the application of organic residues. Much information concerning the effects of farmyard manure has been obtained in classical experiments carried out at Rothamsted Experimental Station. Regular dressings can usually increase crumb stability in arable soils, though the amounts required may be very large. Annual applications of 35 t ha^{-1} for a century have produced a measurable increase in the crumb stability of Rothamsted soil. However, 70 annual dressings of 15 t ha^{-1} on the Saxmundham boulder clay had no measurable effect on structure stability, and 18 annual dressings of 75 t ha^{-1} on the Woburn sandy loam and 28 annual dressings of 40 t ha^{-1} on a loam soil in Ohio gave only small improvements. Application of farmyard manure also increases the water-holding capacity of soil (Russell 1973).

Application of slurry seems to have variable effects. On a silty clay soil, the spreading of pig slurry significantly increased the total porosity of the soil and modified the size distribution, shape, and arrangement of the pores. Microscopic examination revealed an angular or subangular blocky microstructure which was better for plant growth than the large, fairly compact, soil aggregates of the control. The improvement was proportional to the application rates of the slurries, but it depended also on their time of application (Pagliai et al. 1985).

Results of various long-term experiments in France suggest that the evolution of soil organic carbon is governed by environmental conditions such as climate and soil type, and the availability of mineral nitrogen (Muller 1972).

Biological effects

Edwards (1984) reviewed the effects of agricultural practices on soil organisms. He concluded that some of the changes in agricultural practice which have occurred over the past 50 years favour soil organisms, but because many of the changes reduce the amounts of organic matter in soils, the overall tendency is to reduce populations of soil organisms. The change from organic to inorganic fertilizers has tended to decrease the diversity and size of populations of most groups of soil invertebrates, particularly earthworms. Where more plant residues are left behind, this effect can be alleviated.

Practices which reduce the amount of organic plant residues entering the soil have drastic effects on soil organisms. Straw burning results in decreased invertebrate populations. The drilling of crops such as sugar beet or vegetables tends to remove the need for singling and leaves less plant residues as food for soil invertebrates (Edwards 1984).

The density of most groups of soil fauna is lower in Swedish arable soils than in grassland or forest soils. Biological activity decreases steadily with decreasing organic matter levels when annual crops are grown regularly in the same soil. Negative effects of intensive arable farming on such beneficial organisms as earthworms can be minimized by practices which conserve or increase the soil organic matter content. Legumes and well-fertilized grass leys in the rotation also have high abundances of soil fauna compared with cereal cropping only. Herbicides caused a reduction in faunal density of grassland soil as an indirect effect of vegetation change (Steen 1983).

Levels of organic matter can be maintained by additions of manures or sewage sludges. These applications would be expected to have an effect on soil organisms. On Rothamsted Broadbalk plots, a plot receiving farmyard manure dissipated 15 times as much energy as an unmanured plot or neighbouring plots receiving fertilizers only, yet it had scarcely twice as many bacteria or protozoa and only about the same number of fungi. Presumably the organisms in the manured plot lived more actively and spent a smaller proportion of their time in resting stages (Russell 1973).

Total numbers of earthworms, and numbers of deep-burrowing species, were greater on plots receiving large applications of pig slurry (5528 m^3 ha^{-1}) than on controls receiving inorganic fertilizer (Unwin & Lewis 1986). However, Bieri and Besson (1986) studied the influence of three types of cattle and pig slurries on temporary grass. Only the methane slurry favoured earthworm populations, particularly L. terrestris. By contrast, a large pig slurry application had a negative influence on earthworms.

Tomati et al. (1985) found that sewage sludge stimulated soil oxygen consumption, which may be considered to be an indication of increased microbial activities. A high content of available ions, especially nitrate followed. Crop yield and quality increased after treatment. Appreciable increases in humus content, nitrogen content, pH, contents of aerobic bacteria, and "biological activities" occurred on a sandy loam soil receiving five tons of sewage sludge annually (Stadelmann & Furrer 1985). However, heavy sludge applications can depress mineralization, especially in soils of low clay content, and may also have an unfavourable effect on other microbial processes such as ammonification and nitrogen fixation. As the extent of the effect depends on soil properties and on the micro-organisms involved, quantification of the phenomenon requires specific bioassays (Coppola 1986).

1.6.7 Soil compaction

Many soils under agriculture and other uses are at risk from soil compaction, which is reviewed in Vol II section 2.6 of this report. In the UK, moderate or severe compaction is common on heavy land under arable and intensive grassland cropping systems. Other lighter, but intensively-used, land is also susceptible to compaction though in such soils corrective measures are easier. The tendency to compaction associated with building, mineral working, and other civil engineering works is a consequence of the heavy machinery used and the lack of flexibility in the timing of operations. Conditions imposed on mineral extractors regarding the timing of soil stripping are a move in the right direction.

Active soil systems, and the ecosystems of which they are a part, are easily destroyed or degraded when industrial processes produce derelict land. Often the topsoil is removed from the site to obtain access to materials at depth, as in the gaining of brick clay, in operations where land is stripped for peat, sand, and gravel, and where quarries are opened up to obtain stone, slate, and shale. In modern mining procedures, such as opencast or strip-mining for coal, ironstone, or other metalliferous ores, much of the soil may be stored. However, the topsoil may well become buried under huge piles of waste. Handling and tipping very often result in compaction and loss of soil structure. The restoration of such derelict and degraded land was discuseed by Bradshaw and Chadwick (1980).

Powerful tractors and other heavy machinery such as that operating on construction sites and reclamation of land after open-cast mining compress the soil and increase its bulk density not only at the surface but also in deeper layers. This will also change the void structure, and hence the soil's aeration and water-retention. These, in turn, will have effects on soil organisms.

Soil structure is influenced by soil organisms, the nature of the soil parent material, land use and management, and climate. Complex changes in the structure of soils result from atmospheric pollutants, applied pesticides, changes in the use of land from moorland or forestry to agriculture, and from more subtle alterations in the everyday management of land. The main causes of soil compaction at the present time are considered to be wheeled vehicles and animal hooves. The main problems arising from soil compaction are decreased crop performance, caused by decreased root penetration, air permeability, and water movement, on one hand, and on the other increased soil erodibility and surface water run-off. Soil compaction and other forms of structural degradation act in many soils to increase waterlogging.

Biological effects of compaction

Soil micro-organisms are influenced by a vast complex of factors associated with soil texture, structure, water and gaseous exchange. Spore formation by fungi is related to the size of soil voids. Water potential, which is an expression of a number of forces acting on soil water, affects germination of fungal spores. Fungi differ greatly among themselves with regard to their vegetative growth at different water potentials. Some are unable to grow at high potentials and are exceptional in their ability to grow at very low potentials. For reasonably rapid growth, most fungi are restricted to potentials exceeding -60 or -80 bar. In a clay soil, -100 bar would be about 10% water content and -1 bar would be about 45% water content. Like germination, growth is affected by temperature and nutrient concentration, and occurs at lower potentials if temperature is optimum and nutrients are not limiting (Griffin 1972). In general, bacteria are limited to potentials greater than -100 bar.

The effects of soil compaction on micro-organisms will depend on the species, and may differ for survival of spores, germination, and vegetative growth. For example, in all 22 soils studied by Kraft and Allmaras (1985) there was a tillage pan at about 20 cm depth. Fusarium solani f. sp. pisi propagules were present everywhere in the top 60 cm except in the tillage pan, whereas Pythium ultimum propagules occurred only in the tillage layer. These propagule distributions were related to the moisture conditions and the comparative optima for the organisms.

Effects of compaction on soil fauna depend on the type of animal. Usher (1976) suggested that the aggregation of soil arthropods in favourable microhabitats could be caused by two major factors, the location of food sources and the physical environment. However, little appears to be known about the relationships between pore structure and micro-arthropods because of practical difficulties in establishing a relationship between the two types of information. In a laboratory experiment with soils having artificial pore structure, Didden (1987) found that Onychiurus fimatus (Collembola) could not migrate in compact soils, which strongly repelled the animals.

Lumbricus terrestris and Aporrectodea longa are the two main burrowing earthworm species in Britain. Both species occupy similar ecological niches and may be direct competitors in some circumstances (Edwards & Lofty 1982). They have similar feeding habits and create permanent burrow systems, but A. longa does not burrow as deeply as L. terrestris (Edwards & Lofty 1978). The latter species can survive for long periods in soil submerged below aerated water.

Any management operation that would decrease the population densities of deep-burrowing earthworm species should be avoided if possible, as these species improve the drainage. Where compaction occurs below the effective burrowing depth of A. longa (approx 45 cm) the improvement of drainage by earthworms will probably rely on the presence of L. terrestris, which will be present only when there is limited disturbance (Rushton 1986a). In laboratory studies, Rushton (1986b) found that survival of L. terrestris was not affected by waterlogging, but tunnelling activity was negatively related to bulk density. Analysis of soil profiles on sites reclaimed from opencast coal mining showed that on sites where L. terrestris was absent the soil bulk density was greater than that in which the species was capable of burrowing.

A. longa and Lumbricus species are not found in very compacted and waterlogged soils such as result from the restoration of some opencast coal workings. Shallow-burrowing A. chlorotica may be the pioneer in such soils and other species may follow as the soil physical conditions improve and organic levels increase (Armstrong & Bragg 1984).

In experiments on soils of different densities (1.1, 1.3, and 1.5 g cm^{-3}), Atlavinyte and Zimkuviene (1985) showed that Nicodrilus caliginosus decreased the soil density and increased its porosity. Associated with this effect, germination of barley increased up to 20 times, the earing of barley was accelerated and the number of grains in an ear and the mass of 1000 grains were increased, and there was a slight effect on barley stem height.

1.6.8 Summary and conclusions

There seems to be general agreement that in the UK, as in many other EC countries, the main threats to soils are (i) the extension of urbanization, roads, motorways, and industrial zones; (ii) erosion; (iii) acidification; (iv) accumulation of pollutants; (v) nitrates in groundwater; and (vi) loss of organic matter and deteriorating soil structure.

At present some 8% of the total land area of the UK is classed as urban land, although there is a considerable lack of agreement on statistics for the amount of agricultural land lost each year to non-agricultural uses. It may not be possible to reduce the pressure for extension of urbanization and industrial development, but it should be possible to reduce their impact on environment and soil, partly by enabling land-use planning decisions to be based on better information concerning soil quality. There will be some constraint on this option, due to the fact that the most productive agricultural soils are in the south and south-east of Britain, where the pressures are likely to be greatest.

About 37% of agricultural land in England and Wales is threatened by an unacceptable degree of erosion. Wind erosion is confined largely to sandy soils and to lowland peaty soils. Water erosion is a problem in the main arable areas of Britain, in upland areas, and in areas of intensive recreation such as those associated with footpaths in National Parks. Because the factors affecting soil erosion are now fairly well established, it is possible to develop a number of models for predicting the likelihood of erosion in a given area, and maps could be prepared.

Soil acidification is seen as one of the major current threats to soils in northern Europe. The soils most at risk are those on parent materials which are poor in bases and readily-weatherable silicate minerals. Acidification is favoured by high rainfall. The process is sufficiently well understood for the development of models to predict the risk of soil acidification in a given area.

The problem of pollution by heavy metals and organic compounds such as pesticides is more difficult, but fortunately these do not seem to be a serious problem in the UK at present. They are of greater importance in the

Netherlands, the Federal Republic of Germany, and Switzerland, where they are the subject of research. A major problem with heavy metals is that once they get into soils they may persist for thousands of years.

The problem of nitrate pollution is recognized internationally, and is usually associated with intensive agricultural practices. In the UK, the areas affected are those on permeable rocks such as chalk and Triassic sandstones. Although it is often claimed that the blame for nitrate pollution falls on farmers who use too much nitrogenous fertilizer, nitrate is released naturally from soil organic matter in some ecosystems.

Many of the changes in agricultural practices which have occurred over the past 50 years have reduced the amounts of organic matter in soils. This has resulted in deteriorating soil structure, water-holding capacity and biological activity. It also reduces the capacity of the soil to absorb and inactivate heavy metals in the soil solution.

In the UK, moderate or severe soil compaction is common on heavy land under arable and intensive grassland cropping systems. Other lighter, but intensively-used, land is also susceptible to compaction though in such soils corrective measures are easier. The main causes are wheeled vehicles and animal hooves. The problem is well understood, and the susceptibility of soils to compaction can be predicted.

The threats discussed have effects, usually adverse, on populations of soil organisms which are necessary for carrying out functions which are necessary for the maintenance of the soil system, and the ecosystem of which it is part. Because the spatial arrangement of ecosystems gives the form of landscape, the latter is affected by the threats in soils. This is already a major concern in the Federal Republic of Germany, where differences between ecosystems are being reduced by pollution and eutrophication of soils.

In the past, European agriculture has been largely successful in maintaining the landscape, soil fertility, and the rural scene in general. However, this task is becoming more difficult because of the high pollution from urban and industrial areas. Acid rainfall, heavy metals, and water pollution from urban areas and industry cause widespread negative effects on soil quality, reducing the soil pH and breaking up the micro-aggregates which provide soil structure. The natural mineralization of organic matter to release nutrients for vegetation can continue only by the maintenance of a correct balance of water, air, nutrients, and soil flora and fauna (Huber 1984).

The Dutch are concerned that an acceptable equilibrium between input and output of substances must be reached, and this may only be possible with non-persistent substances. Most heavy metals and many organic pollutants which do not meet specified requirements concerning peristence and biodegradability are placed on a 'black list' of substances that should not be allowed to enter the soil.

This view is unlikely to commend itself to the UK, where these problems are not so acute, where geological and hydrogeological conditions are different, and attitudes to land use controls are different. The UK view, though not yet formally incorporated in statements of policy, is that the soil needs only to be fit for the immediate use. When that use changes the condition of the soil may constrain the choice of future use. If it does so constrain the future use, then appropriate remedial action can be carried out within the context of land reclamation or site development proposals to fit the land for the intended new use (CDEP 478/53). However, remedial action may be too expensive or impossible in practice. For example, reclaiming land contaminated by heavy metals for agriculture is completely uneconomic if soil has to be removed and replaced. The potential of such land is therefore limited.

Before the industrial revolution, soil pollution occurred on only a local scale, around mines and small industrial sites. A characteristic of the present time is the great increase in the extent of pollution to regional and global scales. Transboundary pollution increases the problems of indentification and control.

1.7 SOIL QUALITY

1.7.1 Definition of the concept

The concept of soil quality forms a central part of soil protection policies being developed in Europe. Various EC countries, notably the Netherlands, have set out to develop standards for soil quality not only for their national soil protection programmes, but particularly for use in operations to clean up contaminated sites. In the Netherlands, de Haan (1987) stated that the principal aim of soil protection is the maintenance of 'desirable' soil quality. Such an approach requires the definition, preferably in quantitative terms of 'soil quality' or 'good quality soil'. Moen et al. (1986) suggested that reference values for 'a good soil quality' should be set such that the soil:

- poses no harm to any use by human beings or animals
- can function without restriction in natural cycles
- does not contaminate other parts of the environment

The CORINE programme, which concerns the co-ordination of information on the state of the environment, is currently attempting to define soil quality and rank soils in terms of quality, with the aim of producing a soil quality map of the EC; this is in fact a ranking of soils in terms of their potential for agricultural use.

1.7.2 Application of the concept

To date, soil quality has only been defined in terms of acceptable levels of pollutants, in particular heavy metals and organic residues (e.g. de Haan 1987, Vegter, undated).

Pollutants

Vegter (undated) noted that reference values for 'a good soil quality' should represent acceptable levels for the more important 'diffuse' pollutants. He divided the possible range of values of a soil parameter (presumably a pollutant in this case) into ranges of various degrees of desirability (Fig. 2). The reference value should be as near as possible to the value at S

(Fig. 2). De Haan (1987) also discussed soil quality in relation to the contamination of soil with pollutants; he suggested that any quantitative evaluation of soil quality, with respect to a given pollutant, should take the expected effects of the pollutant on the soil system, and its functioning, as a starting point.

Figure 2 Degrees of desirability of a soil reference parameter (after Vegter undated)

'good soil quality'	S	uncertainty about soil quality	U	possible harmful effects for human health or the environment	C	soil heavily affected

low — parameter value (e.g. concentration in soil) → high

The assessment of the impact of pollution is a prime consideration in soil quality evaluation, and a basic problem in impact assessment is the establishment of the quantitative relationship between exposure and effect. Hence, the behaviour of a compound of interest in the soil system is central to soil quality evaluation. This behaviour is controlled by a large number of variables which may be compound-related and soil-related. Important aspects are the soil's buffering capacity towards the compound of interest, compound speciation, soil heterogeneity, and the bio-availability of the compound.

The effects of a pollutant in soil will depend on other properties of the soil environment. Hence, a concentration which might be hazardous in one soil might be relatively harmless in another, and a single 'safe' value cannot be chosen for all soils. How this should be taken into account is a major problem in setting quality standards for soils, especially when one considers the heterogeneity of soil. This heterogeneity occurs at all spatial scales (see Section 1.4.6).

Heavy metals and organic pollutants: the Dutch approach

Given the heterogeneity of the soil environment, Dutch workers are developing a continuous, scale-invariant, approach instead of giving different reference values for a number of well-defined soil types. The first step in this approach is to specify a reasonably simple relationship between the hazards or risks associated with a given concentration of a substance and soil characteristics that can be measured at the same scale as the substance concerned.

The Dutch policy-makers, developing quality reference values for heavy metals and organic chemicals, started from the view that the main part of rural Holland is still multifunctional, or at least 80% is, by ministerial decree. Starting from this viewpoint, Vegter (undated) developed an approach based on a limited amount of information from a survey of 40 (mainly nature reserve areas) topsoils (0 to 10 cm) carried out by Edelman and de Bruijn (1986). Only mineral soils were studied and they were thought to be uncontaminated. As a first approximation, Vegter assumed a linear relationship (which was forced through the origin) between the amount of a heavy metal and the soil clay and organic matter contents. This enabled a reference value Ys for an 'average' soil to be calculated (Table 2).

Two important points were stressed:

i. These formulae should not be regarded as mechanistic adsorption-desorption models, but are merely probablistic conjectures concerning 'risk', i.e. the chance that a given concentration might result in an adverse effect. The risks associated with the presence of a given concentration of heavy metals in soil are generally considered to be lower in soils with a high organic matter content and a large clay fraction.

ii. These formulae are only provisional, and several modifications may be necessary. For example, it may be necessary to change the constants A and B, to include more soil properties such as pH, or to include a constant.

Table 2. Calculation of reference values for soil parameters (after Vegter undated)

---

1 HEAVY METALS

Reference values Y (concentrations) are linearly dependent on percentage organic matter (OM) and clay (C)

$$Y = A *(OM) + B * (C)$$

A and B are tentatively set at 1.5 and 0.5 respectively

2 ORGANIC CHEMICALS

Reference values (concentrations) are linearly dependent on percentage organic matter (OM). The clay fraction is considered less relevant with respect to organic chemicals and is therefore omitted in the standardisation for these substances

$$Y = (OM)$$

3 Reference value for 'average soil', where 1.5 *(OM) + 0.5 *(C) = 27 and (OM) = 10, is specified as Y_s.

4 Reference values (Y) for other soils can be obtained by linear extrapolation

$Y = Y_s/27 * 1.5 *(OM) + 0.5 *(C)$ for heavy metals

$Y = Y_s/10 * (OM)$ for organic compounds (For soils containing more than 30% or less than 2% organic matter, H values of 30 and 2 respectively are used)

5 Y_s is estimated from data on concentrations actually occurring in 'good quality' soils.

Although the term 'risk' is sometimes used in discussing such approaches, this is not strictly risk assessment. Correctly used, risk assessment yields not only an absolute measure of risk from a given chain of events, but also an estimate of the uncertainty of that measure.

In a discussion paper circulated by the Dutch Ministry of Housing, Physical Planning and Environment, the maximum of the range of Ys values for a given substance was proposed as a provisional reference value for a 'good soil quality'. However, the basic linear regression on which this approach rests is a considerable over-simplification. Lexmond et al. (1986) compared published values of heavy metal contents in Dutch soils with Vegter's reference values (which they called C-values or C-factors), and found that even in 'unpolluted' nature reserve soils the reference values were often exceeded. In very organic and peaty soils the differences were "collossal".

Lexmond et al. concluded that the values proposed by Vegter are of little significance. The explanation is clear for chromium, for which an increase in C-value is related mainly to an increase in clay content in one part of the range and organic matter in another part. The quantity of an element is not related in a simple way to clay and organic matter because it is not in equilibrium. Lexmond et al. suggested that binding capacity is not related directly to clay content. The natural heavy metal content of a soil depends on its mineralogical composition, and is inversely related to its quartz content which itself is inversely related to clay content.

The Dutch soil clean-up guideline (Leidraad Bodemsanierering) defines three values:

A value = average background value
B value = indicator value for further investigation
C value = action value

Lexmond et al. found that soil samples with large organic matter contents were above the A value. In raised bogs, a high cadmium content can come only from the atmosphere. Any increase in the heavy metal content will depend on the amount of soil, as organic matter decreases the density, and results should be expressed per soil volume or per gram organic matter. Some of the sites which had been used by Vegter appeared to have been cultivated and contaminated in the past, and were not used in the final results. For example, when the lead contents of soils were plotted against the organic matter contents, six soils stood out from the rest (Lexmond et al. 1986). They were soils which had received applications of night soil in the past, and had thus received lead pollution.

Improved A values are given in Lexmond et al. (1986), for mineral and organic soil materials. These have been converted into "soil quality reference values", and formulae have been produced which enable calculation of the reference values for specific soils with different clay and organic matter contents (Tables 3 and 4) (Moen & Hosman 1987; see also de Bruijn & de Walle 1988), although Dr Lexmond was not happy about the way in which that had been done. These values were submitted in the Dutch planning ministry's yearly report to their house of commons. In using the tables, reference values for heavy metals, arsenic and fluorine can be calculated for all soil types with the formula presented for each substance. In these formulae, the reference value is a function of the clay fraction and/or organic matter content. The clay fraction is defined as the percentage of mineral elements smaller than 2 m in the total dry weight of the soil. As an example, the reference values have been presented for a standard soil with 25% clay and 10% organic matter. A major problem with reference values such as these is that they have no standard errors, and there is no allowance for soil heterogeneity. This could lead to difficulties.

Lexmond et al. (1986) gave upper limits for the normal range of a number of elements, using mean plus twice the standard deviation rather than mean plus one standard deviation as used by Vegter. Values for copper and nickel in cultivated mineral soils were similar to those found in nature reserves. Of course, this work refers only to total contents of heavy metals, their effects will depend on speciation.

The Dutch definition of soil includes groundwater, but except for phosphate and ammonium compounds, the reference values for groundwater in the saturated zone are independent of the soil type. It is expected that the prevailing detection limits for a large number of 'black list' substances are not exceeded when groundwater concentrations equal the norms in the 1984 Decree on

Table 3. Reference values for inorganic compounds (see text for use of the table) (From Moen & Hosman 1987)

Soil Name	Soil Formula	Standard soil reference value for H=10; L=25 in mg kg^{-1} on a dry matter basis	Groundwater	
Chromium	(Cr)= 50+2L	100	1	µg l^{-1}
Nickel	(Ni)= 10+L	35	15	µg l^{-1}
Copper	(Cu)= 15+0,6(L+H)	36	15	µg l^{-1}
Zinc	(Zn)=50+1,5(2L+H)	140	150	µg l^{-1}
Cadmium	(Cd)=0,4+0,007(L+3H)	0.8	1.5	µg l^{-1}
Mercury	(Hg)=0,2+0,0017(2L+H)	0.3	0.05	µg l^{-1}
Lead	(Pb)=50+L+H	85	15	µg l^{-1}
Arsenic	(As)=15+0,4(L+H)	29	10	µg l^{-1}
Fluorine	(F)=175+13L	500	-	
Nitrate*		-	5.6	mgN^{-1}
Sulphate**		-	150	mg l^{-1}
Bromides		-	300	µg l^{-1}
Chlorides**		-	100	mg l^{-1}
Fluorides**		-	0.5	mg l^{-1}
Ammonium compounds**		-	2/10	mgN l^{-1}***
Phosphate (total phosphate)*		-	0.4/3.0	mgP l^{-1}***

() Concentrations in mg kg^{-1} on a dry matter basis
H = weight percentage of organic matter basis in the soil
L = weight percentage of the clay fraction in the soil
* lower values can be required for protection of nutrient poor regions
** higher values appear naturally in regions with a strong marine influence (salty groundwater)
*** the lower values apply to groundwater in sandy regions; the higher values apply to groundwater in regions with clay and peat soils

Table 4. Reference values for organic compounds (see text for use of the table) (From Moen & Hosman 1987)

Name	Reference value at 10% organic matter (H=10) on a dry matter basis (for individual substances)*
a) Halogenated hydrocarbons and choline-esterase inhibitors	
hexachlorocyclohexane; endrin	
tetrachloroethane; tetrachloromethane; trichloroethane; trichloroethene; trichloromethane PCB IUPAC numbers 28 and 52	less than 1 μg kg^{-1}
chloropropene; tetrachloroethene; hexachloroethane; hexachlorbutadiene; heptachlorepoxide; dichlorobenzene; trichlorobenzene; tetrachlorobenzene; hexachlorobenzene; monochloronitrobenzene; dichloronitrobenzene; aldrin; dieldrin; chlordane; endosulfan; trifuluralin; azinphos-methyl; azinphos-ethyl; disulfoton; fenitrothion; parathion (and -methyl); triazophes PCB IUPAC numbers 101, 118, 138, 153 and 180	less than 10 μg kg^{-1} weight per substance
DDD; DDE; pentachlorophenol	less than 100 μg kg^{-1} dry weight per substance
b) Polycyclic aromatic hydrocarbons	
naphthalene; chrysene	less than 10 μg kg^{-1}
fenantiene; antracene; fluorantene; benzo(a)pyrene	less than 100 μg kg^{-1}
benx(a)antracene	less than 1 mg kg^{-1}
benzo(k)fluorantene; indeno (1, 2, 3cd) pyrene; benzo(ghi)perylene	less than 10 mg kg^{-1}
c) Mineral oil	
total	less than 50 mg kg^{-1}
octane; heptane	less than 1 mg kg^{-1}

* or detection limit if this is higher than the value indicated

Water Supply, the surface water quality objectives for preparing drinking water, or the values based on effect and risk considerations (WHO drinking water guidelines, EPA water quality criteria). In connection with this, values for these substances have not been included in the table. When the prevailing detection limit for organic compounds appearing on the 'black list' is exceeded, it can be seen as having a signalling function for groundwater (saturated zone). Of course, this is also true with respect to organic 'black list' compounds which have not been presented for the solid phase for the reasons mentioned above.

In general, the Dutch view is that when concentrations are less than or equal to the values presented in the tables, the soil can be considered multifunctional according to current insights, which means that the substance involved is not expected to cause effects which can be considered detrimental. The still-to-be-published technical manual should be used in evaluations of soil quality. Concentrations in excess of the reference values do not necessarily have to mean that the soil is no longer multifunctional. Locally higher contents can appear naturally, and interesting plant communities occur on soils with naturally-high heavy metal contents, for example serpentine soils which have very high nickel contents and a specialized flora. If there is reason to evaluate the soil's multifunctionality further, more information is needed about these local circumstances and about the environmental factors there which can influence possible human, animal or plant exposure routes.

Where reference values are exceeded as a consequence of human soil use, it is also important to evaluate the extent to which the situation must be considered irreparable. Temporarily higher concentrations resulting from allowed soil uses, for example after application of permitted pesticides, must be taken into account in this evaluation.

Moen et al. (1986) also discussed the system of setting standards for environmental quality described in the Indicative Multi-year Programmes on Environmental Protection (IMP) presented by the Dutch government. The target value for a substance is the concentration, in a part of the environment, at the 'no-adverse effect level'. If the actual value cannot be reduced to the target value in less than 10 years, the quality standards will be revised at least once every 10 years, this is called 'progressive standard setting'.

They considered that working with such provisional standards deserves serious consideration by those concerned with retaining or restoring soil quality. Dutch experience has shown that using no standards at all is more confusing than using provisional standards of known limitations. Furthermore, the setting of provisional standards and putting them into practice results in much useful knowledge and accelerates the process of achieving 'definite' standards.

Restorative soil protection requires an assessment of whether the soil quality has been disturbed to such an extent that remedial action is required. Preventive soil protection requires an insight into the risk associated with certain specific activities and the rate at which a soil quality is deteriorating. Consequently, preventive soil protection can be considered to be even more complex than restorative protection. In the Dutch approach for preventive soil protection a distinction is made between local (point) and diffuse (non-point) sources of soil contamination. Current measures for preventing local contamination concern the use of building materials and the storage of potential contaminants, including refuse tips. Measures for preventing diffuse contamination concern the application of manure and soil structure improvers (Bavinck et al. 1988). In the case of local potential sources, no significant emission to the soil is allowed. For this reason, the significance levels of the emissions have to be defined and therefore source-oriented standards will have to be developed. If these standards are exceeded, the Isolate, Control, and Monitor concept applies. For diffuse sources, the basic philosophy is that the quantity of potential soil contaminating compounds that is applied to the soil should, over a certain period, be in equilibrium with the amount that is leaving the soil. A combination of source- and effect-oriented standards is required.

Limitations of the Dutch approach

Moen et al. (1986) discussed A, B and C values of the Dutch clean-up guideline and noted that they should be considered only in the context of cleaning-up conditions. They noted two limitations of the index:

i. The values given in the criteria index were based upon the available knowledge of the substances involved (toxicity, vapour pressure, solubility, mobility, accumulation, corrosiveness etc.) at that time. It was clear that a lot of research remained to be carried out into the toxicological effects of substances to which the environment and human beings are exposed;

ii. As the index was set up for quick reference, and other criteria have to be taken into account for individual situations, no differentiation with regard to soil type was considered necessary.

Also, the values do not take fully into account the exchange between the soil solid phase and groundwater. The system was never meant to be a scientifically watertight or conclusive method for determining the seriousness of a given situation, but rather as an aid to examination for administrators and others in planning and implementing investigations and remedial actions. Despite its limitations the system has been found to work in practice. Nevertheless, evaluation and reconsideration of the system is necessary, especially because cleaning-up is tied closely with the evolving policy towards a good quality of the soil in general.

Application to other properties

It might be possible to use the approach of Lexmond et al. (1986) to define reference values for properties, other than pollutants, which influence the soil's functioning in natural cycles, e.g. bulk density. However, there will be difficulties with some properties. Thus, although there are some indications that systems with low organic matter levels have sub-optimal production levels, Newbould (1982) concluded that it was not possible to predict an ideal or target level of organic matter. Organic matter content is only one of many factors affecting plant growth. Cultivation of the sod remaining after pasture or leys tends to lower the soil organic matter content. Reduced tillage results in a different distribution of organic matter to conventional cultivation, especially where ploughing is used, but has little effect on total organic matter content and on crop production.

In the context of recommending liming to adjust soil pH, Alley and Zelazny (1987) emphasized the need to make the recommendations in the context of solving particular problems rather than for merely adjusting all soils to some predetermined 'good' pH value. Because of spatial and temporal variability, a soil sampling procedure representative of a given field is required (Sabbe & Marx 1987).

Table 5. Normal background (bkgd) and maximum permissible (perm) heavy metal concentrations (mg kg^{-1} dry wt) in EC agricultural soils (from Sauerbeck 1987). (Source: Webber et al 1984; CEC 1986)

Element	Germany		France	United Kingdom			CEC Directive perm
			perm		perm		
	bkgd	perm		bkgd	Non-calcareous	Calcareous	
Cd	0.2	3	2	1	3.5	3.5	1-3
Cr	30	100	150	100	600	600	-
Cu	30	100	100	5	140*	280*	50-140
Hg	0.1	2	1	< 0.1	1	1	1-1.5
Ni	30	50	50	1	35*	70*	30-75
Pb	30	100	100	50	550	550	50-300
Zn	50	300	300	2.5	280*	560*	150-300
As				5	10	10	
B				1	3.25	3.25	
F				200	500	500	
Mo				2	4	4	
Se			10	0.5	3	3	

* These values are EDTA - extractable amounts, the remainder are totals.

In the majority of cases, however, the reference parameter, and the reference values, chosen to define soil quality can only be defined with reference to a specific use of the soil. For example, good quality soil for optimal growth of wheat necessitates particular pH and nutrient levels; these levels define good soil quality for that particular use. Because soils are complex systems, soil quality cannot be defined adequately by a single parameter. Several parameters would be needed for each soil system, and no single value could be set for each parameter because of natural variation, both seasonal and spatial.

<u>Relation to maximum permissible concentration</u>

Used in the above way, the quantitative evaluation or definition of soil quality is very similar to the concept of maximum permissible concentrations. This latter concept is also applied to heavy metal contents of soils; thus a directive of EC Council of Ministers of 12 June 1986 set maximum permissible levels for heavy metals in soils treated with sewage sludge. Several countries of the EC, including the UK, have their own maximum permissible levels (Table 5). The difference between the two concepts, soil quality reference values and maximum permissible concentrations can perhaps be related to Vegter's series of values for a given soil parameter (Fig. 2); thus, the soil quality reference value is set as close as possible to S while the maximum permissible concentration would be similar to U. It is noteworthy that the Dutch reference values (Table 3) are either lower than, or in the lower part of the range of, the CEC Directive permitted values given in Table 5, whereas the UK permitted values tend to be rather generous.

<u>The UK view</u>

The UK view (CDEP 478/53) is that in the UK there are both theoretical and practical objections to the Dutch methods for setting soil quality standards, even if it were possible to agree on why they are needed and how they should be used. The theoretical objections are: (i) the values are based on 'average background' concentrations; the local background concentrations found in different parts of the UK vary markedly and no single 'average background' value can be chosen; (ii) uncertainties over the adequacy and representativeness of the samples from which the 'average background' values are derived; (iii) uncertainty in relating the sites chosen to define the average background values to those found in other areas (e.g. sites included in clean-up programmes or derelict land reclamation schemes). The main practical objections are: (i) if judged against 'average background' concentrations, however they have been obtained, many sites already in use in industrial or urban areas will appear 'contaminated' when in fact the contamination presents no risk to their present use; (ii) the background values do not take either present or future land uses into account, although actual significance of soil contamination depends markedly on the use. Surveys by SSLRC and AFRC (IACR, Rothamsted) would enable 'background' values to be established, possibly using some form of regional stratification.

Independently and for different reasons, MAFF and DoE have devised their own separate approaches to soil quality/land use questions. The MAFF initiatives relate to controlling the application of sewage sludge to agricultural land. On behalf of DoE, the Interdepartmental Committee on Redevelopment of Contaminated Land (ICRCL) has proposed the concept of 'trigger concentrations', which vary with land use and are intended to be used for the assessment of sites proposed for reclamation or redevelopment. The actual values proposed for the same contaminants differ between the MAFF and ICRCL guidelines. This is because their purpose and means of application differ. For example, MAFF propose a value of 300 mg kg^{-1} for lead in agricultural soils in order to provide a sufficient margin of safety for compliance with the Lead in Food Regulations: agricultural crops grown for sale to the public must not contain more than 1 ppm lead. If the concentration of lead in the soil is greater than the MAFF guideline value, there is in practice a distinct risk that the permitted maximum value in the crop will be exceeded. By comparison, the ICRCL threshold Trigger Concentration for lead in domestic garden soils is 500 mg kg^{-1} because the purpose is not to eliminate the contamination of crops or vegetables but the need to protect the most vulnerable group among the population exposed: these are young children, especially those suffering from pica; the number at risk is, however, extremely small. For a different land use where the chance of exposure is less, the trigger concentration for lead could be set far higher: for recreational uses, for example, it is 2000 mg kg^{-1} while for industrial uses it is not considered necessary to set a trigger concentration for lead at all (CDEP 478/53).

The ICRCL view, that soil quality and criteria are best considered in the context of land reclamation and redevelopment, and that the actual values to be adopted must depend on which particular use is in mind, finds no parallel at present in the Dutch approach. It may also be difficult to reconcile it with 'Bodenschutz' philosophy. This fundamental difference of view on a basic principle needs to be recognised and allowed for in the development of UK policy on soil quality standards (CDEP 478/53).

Soil quality standards: the role of ISO

In 1985, ISO/TC 190-Soil quality was established as a new Technical Committee of the International Organization for Standardization (ISO). The scope of TC 190 is "Standardization in the field of soil quality, including classification, definition of terms, sampling of soils and measurement and reporting of soil characteristics." TC 190 is concerned only with defining the most appropriate methods to use. A definition of soil quality is outside its remit.

The need for such a committee is seen, by ISO, to arise from the fact that on national and international levels policies are under development which intend to protect soil and groundwater against further deterioration. Five sub-committees were formed, each dealing with a group of priority subjects:

- SC1 on terminology, classification, codification and evaluation of critera (functions of the soil to be considered)

- SC2 dealing with all problems related to sampling of soils, such as sampling strategies, sampling techniques, and conservation of samples

- SC3 concerned with methods of chemical analysis of soil and determination of soil characteristics such as pH and CEC

- SC4 deals with soil quality as it affects biological systems in the soil

- SC5 deals with physical investigations of the soil, especially directed at the detection and location of possible contamination sources and to supply methods for the determination of parameters needed to describe the transport of contaminants.

- SC6 deals with radiological methods.

At the outset, TC 190 concentrated on standardization in relation to the agricultural function, the function of ground water conservation, and the ecological function of soil. Each subcommittee can set up working groups, SC3 alone proposed 17, one for each subject.

The first three years of the work of TC 190 were concerned largely with organization and procedural matters. Now that working arrangements have been settled progress is expected, at least in chemical and biological areas. The main problem is the slow way in which ISO works. Everything has to be approved by the central committee, which meets annually. There appears to be a substantial German input, concerned with heavy metals. The Dutch are concerned mainly with groundwater. The UK's main input is in microbiological aspects. There is to be a meeting in Berlin in April 1989, after which some material may be available for informal circulation.

1.7.3 Application in land capability and land suitability

Although soil quality is not mentioned explicitly, concepts of land suitability for particular crops or land capability for agricultural use contain implicit ideas about aspects of soil quality.

Concepts of land suitability for particular crops or farming systems are based on climate and relief as well as on soil. Suitability is assessed for sustained production in a rational cropping system (McRae & Burnham 1981; FAO 1976). For land to be judged to be suitable for a particular crop there must be reasonable confidence that the crop can be grown regularly and make a predictable contribution to the farm economy. For a particular crop, land is placed in one of four suitability classes: well suited, moderately suited, marginally suited, unsuited. Suitability assesements include details of required levels of such soil properties as organic carbon, nitrogen, phosphorus, potassium, and magnesium contents (FAO 1980), which essentially give the soil quality standards for that crop or use. Uses may range from growth of a specific crop, to application of a particular form of management e.g. direct drilling, to a particular use e.g. golf courses, footpaths, winter playing fields.

Estimates of agricultural land capability are also made from information on soil, climate, and topography. The system of Bibby and Mackney (1969) divides lands into seven classes, subclasses, and units depending on the factor(s) which most limit its capability to support agriculture. The classification emphasises the flexibility and adaptability of land to changing market priorities and assumes a moderately-high level of management. The system relies on physical properties because of their relative permanence compared to chemical properties. Soils placed in any one capability unit respond in a similar way to management and improvement or ameliorative practices. Class 1 land has very minor or no physical limiation to use, Class 7 land has extremely severe limitations that cannot be rectified. Classes 2 to 6 have increasingly severe limitations to use. Hence, these classes include the concept of quality for agricultural use in terms of physical properties.

Similarly, in the Land Capability Classification for Britain, Bibby et al. (1982) defined the values of selected soil properties considered necessary for the land to qualify as Class 1 land; for example, the soil should be at least 60 cm deep, should contain less than 5% stones, be non-droughty, should be well drained and not at risk from erosion. MAFF also has an Agricultural Land Classification (MAFF 1966, 1976). The Soil Survey of England and Wales (now the Soil Survey and Land Research Centre) classified land according to its suitability for various crops. Implicit in such classifications is the setting of quality standards for arable agriculture.

1.7.4 Summary and conclusions

The concept of 'soil quality' is a useful one but the quantitative definition of soil quality is complex. Reference parameters must be agreed and reference values defined for each parameter. In the Dutch approach, this procedure is followed for soil contaminants which are potentially toxic to humans and animals; the reference parameter is the soil content of the given contaminant, the reference value is based on the level at which the contaminant begins to enter the food chain, or water supplies at potentially toxic concentrations. The reference level will vary with other soil properties, particularly clay and organic matter contents. Soil heterogeneity needs to be taken into account, but so far this has not been done, which constitutes a weakness in this approach.

According to UNECE (1987), without such reference values, it would be necessary to have recourse to a rather general definiton of the desired state of a soil as being one which:

- has a varied and active flora and fauna, a typical structure for its situation, and an unimpaired capacity for decomposition
- allows the vegetation, natural or cultivated, to develop normally
- guarantees vegetable products of good quality, and which do not adversely affect the health of man or animals

However, the UK view is that there are both theoretical and practical objections to the Dutch approach. The theoretical objections are concerned with the problem of setting 'average background values' of pollutants with which samples could be compared. The practical objections involve the fact that many sites already in use in industrial or urban areas will exceed 'average background values' however the latter are obtained, even though the levels present no risk to their present use. The UK view is that the actual significance of soil contamination depends markedly on the use. Other reference parameters, and reference values for these parameters, can only be defined with reference to a particular use, or function of soil. However, because soils are complex systems, soil quality cannot be defined adequately by a single parameter. Several parameters would be needed for each soil system, and no single value could be set for each parameter because of natural variation, both seasonal and spatial.

From that point of view, it is only feasible, in most cases, to have assessments of soil quality which involve considerations of current or intended use. An example is provided by the various classifications of the suitabiilty of land for particular crops or of the capability of land to support agricultural use. These involve the comparison of actual soil and land properties with the required values for a range of uses.

The definition of soil quality in terms of reference values is very similar to the concept of maximum permissible concentrations, which is also applied to contents of heavy metals in soils. The difference is that a reference value would be lower than a maximum permissible concentration.

1.8 SOIL DEGRADATION

1.8.1 Definition

The aim of soil protection could be seen as the prevention of soil degradation. The FAO (1979) defined soil degradation as "a process which lowers the current and/or the potential capability of soil to produce (quantitatively and/or qualitatively) goods or services". The term 'soil degradation' implies a regression from a higher to a lower state; a deterioration in productive capability. The process is not necessarily continuous, and may occur between periods of ecological stability (FAO 1983). An alternative definition of soil degradation for a broadly-based soil protection policy might be any change in soil properties which produces a reduction in the range of functions which a given soil can perform. This is the concept of multifunctionality.

Changes in heathland soils provide an example of the way in which the use of the term 'degradation' can vary depending on the viewpoint. Most heath soils are podzols or podzolised soils which developed from brown soils following clearance of the original vegetation and practices such as burning and grazing. This would be considered to be a form of degradation (Dimbleby 1962) using the FAO definition. However, heathlands are also valued as ecosystems with characteristic assemblages of plants, insects, birds and animals. In the Netherlands the natural colonization of heathlands by grasses, possibly because the latter gain nutrients from atmospheric pollution, is a matter of public concern. Although the grass colonization is probably the first stage in a natural regeneration, the Dutch public wishes to keep the heather moors and regards this change as degradation.

In some cases, the natural changes in soils reduce the production potential, albeit generally over very long periods of time. The risk of degradation increases when circumstances combine to bring about changes in use. The risk is greater for the more sensitive soils (Section 1.10), which are those with the lowest buffer capacities (Section 1.9).

1.8.2 Forms of degradation

Many authors have defined and grouped the various types of degradation which affect soils; three examples are given as Tables 6, 7 and 8. Although the various approaches to classifying degradation have differing emphases, usually reflecting the major problems of degradation in the author's home country, there is an underlying similarity and agreement.

For example, the FAO divided types of soil degradation into two groups: (i) erosion by wind and water, and (ii) loss of fertility due to chemical, physical, or biological changes. Examples of chemical changes are leaching and acidification, the accumulation of toxic substances and salinization. Leaching and acidification are likely to be a problem in high rainfall areas and/or sandier soils (section 1.6.3). Physical degradation may arise from compaction resulting from a decline in organic matter content and degradation of structure (sections 1.6.6 and 1.6.7).

Biological degradation refers to the reduction and degradation of the population of soil organisms, with consequent changes in processes such as organic matter transformation and in soil structure (section 1.6.7). Soil fertility and condition are related to the number of micro-organisms which is, in general, proportional to the soil organic matter content (FAO 1983).

The classification produced by Yassoglou (1987 and Table 6) links forms of degradation to the main processes involved in each type of degradation; this is one of the clearest, most comprehensive but still succinct categorizations.

Because of the complex nature of soil systems and interactions between the various components, these types of degradation may be linked.

1.8.3 Assessment of soil degradation

Degradation can be assessed in four ways:

i. the current state of degradation of soils
ii. the rate of degradation of soils
iii. the risk of degradation of soils
iv. predicted rates of degradation

Table 6. Forms of degradation and degrading processes (After Yassoglou 1987)

The main causes contributing to serious deterioration of soil quality:

a) loss of soil volume
b) degradation of soil structure
c) loss of organic matter and biological activity
d) chemical degradation
e) soil fertility degradation

The main processes producing the above types of degradation:

(a) loss of soil volume

(1) erosion; (2) compaction; (3) induration; (4) flooding

(b) degradation of structure

(1) erosion; (2) mechanical breakdown; (3) alkalinization; (4) flooding; (5) loss of organic matter; (6) raindrop impact; (7) deposition

(c) loss of organic matter

(1) erosion; (2) exhaustive soil management; (3) excessive drainage

(d) Chemical degradation

(1) leaching; (2) acidification; (3) salinization; (4) alkalinization; (5) carbonation; (6) chemical pollution; (7) unbalanced fertilization; (8) erosion; (9) deposition

(e) soil fertility deterioration

(1) erosion; (2) leaching; (3) fixation; (4) volatilization; (5) exhaustive soil management

---

Table 7. Forms of soil degradation (from Sparrow *et al.* 1984)

A. Loss of Soil Materials

1. Erosion by water
2. Erosion by wind
3. Loss of soil organic matter

B. Chemical Deterioration

1. Soil Salinization
2. Soil Acidification
3. Soil Contamination
(includes herbicides and heavy metals)

C. Physical Deterioration of Agricultural Land

1. Soil Compaction
2. Soil Mixing and Disturbance

Table 8. Types of soil degradation and units of measurement (FAO 1979)

- **Soil erosion by water:** soil loss in t ha^{-1} $year^{-1}$ or in mm $year^{-1}$*
- **Soil erosion by wind:** soil loss in t ha^{-1} $year^{-1}$ or in mm $year^{-1}$*
- **Salinisation:** increase of electrical conductivity of a saturated paste at 25°C, in mmhos cm^{-1} $year^{-1}$
- **Sodication:** increase of ESP = $\frac{Na}{\text{Cation exchange capacity}} \times 100$ percent $year^{-1}$+

* Assuming a value of 1.5 for the dry bulk density of soil, 1 t ha^{-1} $year^{-1}$ = 0.06 mm $year^{-1}$ and 1 mm $year^{-1}$ = 15.0 t ha^{-1} $year^{-1}$.

\+ ESP Exchangeable sodium percentage.

Both salinisation and sodication refer to the soil layer 0 - 60 cm depth.

Chemical degradation:

i. **Acidification:** decrease of base saturation in percent/year

$$\text{base saturation} = \frac{\text{total exchangeable bases}}{\text{cation exchange capacity}} \times 100$$

ii. **Toxicity:** increase in toxic elements, in ppm $year^{-1}$.

As both chemical degradation processes are often active mainly in the topsoil. the soil layer 0 - 30 cm depth is referred to, in order to dilute the effect by taking another 30 cm of possibly little affected soil into account.

Physical degradation: increase in bulk density, (g cm^{-3} $year^{-1}$), or decrease in permeability, (cm^{-1} $hour^{-1}$ $year^{-1}$).

For physical degradation, the 0 - 60 cm soil layer is referred to.

Biological degradation: decrease in humus, in percent decrease $year^{-1}$.

As biological degradation is also very much a topsoil phenomenon, the 0-30 c depth is referred to.

Although it is not possible to compare these quantities directly, it is however possible to make broad classifications of the seriousness of each process in such a way that the classes are approximately equal. Such classifications are of necessity largely based on personal judgement.

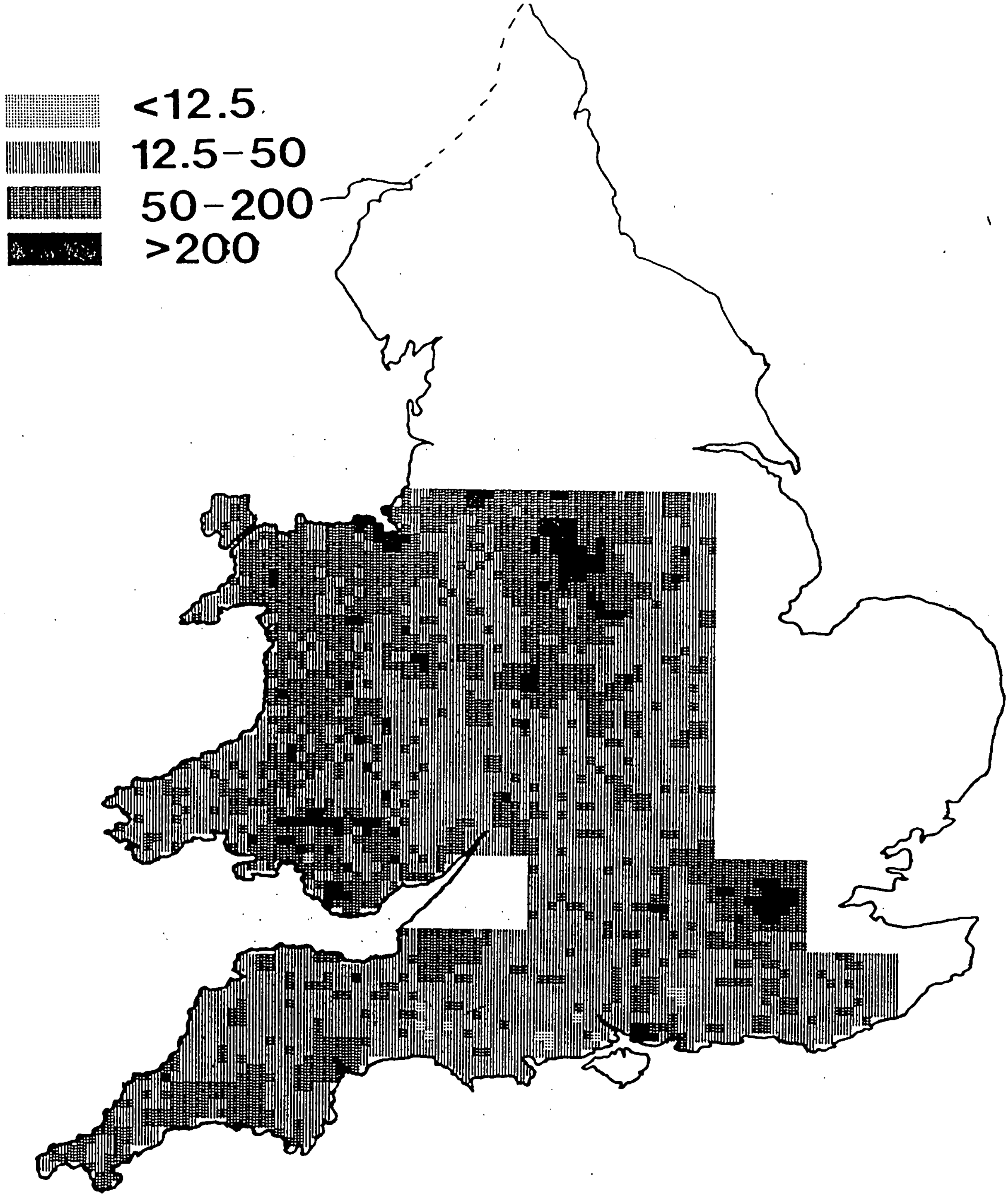


Figure 3. Smoothed map of lead concentrations in topsoils from England and Wales (mg Pb/kg soil) (After McGrath 1987a)

i. The current state of degradation of soils

Surveys of the extent of current soil erosion could be said to be an example of the assessment of the current level of one type of physical degradation. Other examples are surveys of heavy metal contents (e.g. Fig. 3) and of compaction. The data bases of the Soil Survey and Land Research Centre and MLURI would enable an assessment to be made of several types of degradation in Britain on a regional scale. Assessment of the current levels of degradation requires a benchmark against which to compare degraded soil. Federoff (1987) has suggested comparing cultivated soils in northern Europe with natural woodland or forest soils. Ball and Stevens (1981) argued for the conservation of 'type' examples of soils in Britain as benchmarks.

Ideally, one would like to use a non-degraded soil. However, there is the problem of how to decide if a soil is non-degraded. Indeed, pristine, non-degraded soils may not exist. For organic and inorganic contaminants the Dutch have overcome this problem by decreeing that, for the purpose of the exercise, certain soils can be regarded as 'non-degraded'. A similar approach could be followed in the UK, using soils in areas of low pollution which can serve as benchmark soils. For properties such as pH and base saturation, which can change naturally, there is more of a problem (e.g. see section 1.13).

ii. The rate of degradation of soils

The assessment of the rate of degradation requires the measurement of a rate of change. Most work of this type has focussed on soil erosion but the FAO (1979) has developed a broadly-based provisional methodology of 'soil degradation assessment'. The rate of degradation of a given soil, in terms of a particular type of degradation, can be assessed by comparison with the rate of change of some benchmark soil. The FAO methodology provides suggested units for the measurement and assessment of degradation (Table 8); these units express the rates of a given type of degradation as rates of change in a selected index parameter. This is usually a soil property but in the case of erosion can be the rate of soil loss. A series of classes is then defined for each type of degradation, e.g. Table 9, and methods of assessing each type of degradation are presented. It should be stressed that the classes listed in

Table 9. Soil degradation classes (FAO 1979)

	Water erosion (E) and Wind erosion (W) Soil loss: $t\ ha^{-1}\ yr^{-1}$	or $mm\ yr^{-1}$	Salinization (Sz) Increase in conductivity at 0-60cm ($mmhos\ cm^{-1}\ yr^{-1}$)	Sodication (Sa) Increase at 0-60 cm ($ESP\ yr^{-1}$)	Chemical degradation (C) Decrease in base saturation ($\%\ yr^{-1}$) if base saturation is <50%	>50%
none to slight	10	0.6	2	1	1.25	2.5
moderate	10-50	0.6-3.3	2-3	1-2	1.25-2.5	2.5-5
high	50-200	3.3-13.3	3-5	2-3	2.5-5	5-10
very high	200	13.3	5	3	5	10

	Physical degradation (P): increase in bulk density ($\%\ yr^{-1}$) A	B	C	D	decrease in permeability ($\%\ yr^{-1}$) E	F	G	Biological degradation (B): decrease in humus at 0-30 cm ($\%\ yr^{-1}$)
none to slight	5	2.5	1.5	1	2.5	1.25	1	1
moderate	5-10	2.5-5	1.5-2.5	1-2	2.5-10	1.25-5	1-2	1-2.5
high	10-15	5-7.5	2.5-5	2-3	10-50	5-20	2-10	2.5-5
very high	15	7.5	5	3	50	20	10	5

For initial levels ($g\ cm^{-3}$): A = 1, B = 1.1-1.25, C = 1.25-1.4, D = 1.4-1.6

For initial levels ($cm\ h^{-1}$): E = 20, F = 5-10, G = 5

Table 9 are provided as an example of the approach used by the FAO. The classes would need to be redefined for UK conditions if this approach were adopted. In their book on land degradation, Blaikie and Brookfield (1987 p61) said that "It is easy to criticize the [FAO] Soil Degradation Methodology but hard to suggest alternatives. Perhaps it's major strength is not in the numbers and categories that come out at the end, but in the way in which it focuses attention on the range of degradation processes and at least ensures that each is considered and estimated."

Important aspects of the approach used in the FAO methodology are (a) the identification of a reference parameter which is used as the criterion to assess a given type of degradation, and (b) the attempt to evaluate each type of degradation in terms of rates of change in the reference parameter. These approaches could be adapted for use in the UK. The types of degradation identified for preliminary assessment in the current study (Vol II and section 1.13) correspond to forms of degradation considered by the FAO, and the index parameters suggested by the FAO may be usable here. Thus, compaction could be regarded as physical degradation and the degradation assessed as the rate of increase in bulk density, or decrease in permeability. Similarly, acidification is a form of chemical degradation in the FAO scheme and is assessed by the rate of decrease of base saturation.

If we draw parallels with de Haan's (1987) schematic representation of the relationship between compound content in soil and its effect (Fig. 4), the assessment of the rate of degradation is a measure of the rate at which a given parameter, rather than compound, changes between 1 and 2 on de Haan's plot.

Assessment of the rate of degradation should ideally be linked to a quantitative definition of 'soil quality' for the particular index parameters. Predictions could then be made of the time at which the value of a given reference parameter would fall outside the definition of good quality soil.

Much emphasis has been placed on the use of soil chemical and physical properties for the assessment of degradation. Little is known about the interactions between chemical, physical, biological, and hydrological

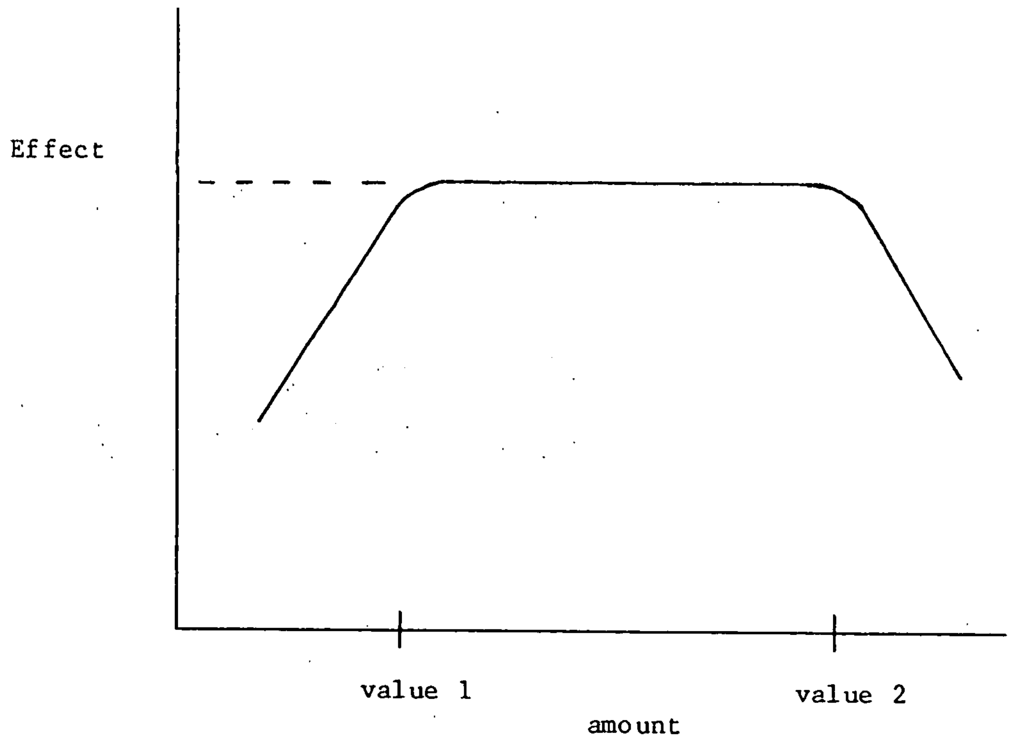


Figure 4. Schematic relationship between the amount of a compound in soil and its effect, for an essential (———) and a non-essential (- - - -) element. From deHaan (1987).

variables and processes and the functioning of biological communities. When a degradative stress is applied to a soil, some effect on the soil fauna or micro-organisms may be expected. Tests for the effects of pesticides have been devised (Somerville et al. 1985), they could be modified, and others introduced, to test the effects of other stresses. Dealing with pesticides, some effects on the environment may be too complex, subtle, or delayed to be detected by ordinary laboratory or field testing. Furthermore, such tests cannot possibly cover the great variety of conditions in which the pesticide may be used in practice. Nevertheless, experience has shown that, in many instances, predictions can be made of probable environmental effects of a compound from consideration of certain basic information (Somerville et al. 1985).

For aerobic soils, respiration rate is a useful indicator of the overall level of activity of soil organisms as respiration provides the necessary energy. It can therefore be used to assess the state of degradation of populations of soil organisms. Somerville et al. (1985) recommended measuring respiration as carbon dioxide evolution. However, the ratio of volume of carbon dioxide evolved to volume of oxygen taken up (respiratory quotient) differs for different types of substrate, and it is preferable to measure oxygen uptake. The rate of decomposition of plant material (litter bag test) is also useful. The release of ammonium ions from organic nitrogen compounds is a fundamental and important process which has been proposed as an indicator of microbial activity in different soils (Alef and Kleiner 1987) and could be used to assess the effects of degrading influences.

The effects of chemicals with biocidal properties may be reversible or irreversible within the monitoring period. Whatever test is used, the magnitude of the response to the man-made chemical stress should be compared with that of naturally-occurring stress situations. Similarly, the determination of the time required for the restitution of normal microbial populations or functions after the end of natural stress conditions is required as an ecological 'yardstick' (Somerville et al. 1985).

Insam and Domsch (1988) reasoned that the basic carbon and energy source for the production of heterotrophic micro-organisms is net primary production (NNP). As long as NPP exceeds the respiration loss of carbon (R) by heterotrophs, in a given ecosystem, then organic matter will accumulate. As soon as R equals NPP, a steady state will be reached. In steady state conditions the proportion of the microbial biomass carbon (Cmicr) in the total soil organic carbon (Corg) will be characteristic of the ecosystem, at least for agricultural ecosystems. Deviations from this value would indicate that a soil is either losing or accumulating carbon. If the characteristic value for an ecosystem is known, the observed value should provide information on how near the soil is to its equilibrium state.

Values of the ratio Cmicr/Corg were determined for an agricultural and a forest chronosequence of open-pit mine reclamation soils. In the A horizon, after reclamation, microbial biomass increased very rapidly to levels characteristic of undisturbed soils. The ratio Cmicr/Corg decreased with time, more rapidly on the forest sites than on the agricultural ones. However, it was evident that 50 years after reclamation both chronosequences had not yet reached a steady state. The ratio was considered to be superior to other parameters for assessing the recovery of soils after disturbances such as reclamation following mining.

iii. The risk of degradation of soils

The prediction of the risk of degradation necessitates an understanding of the factors which control a given type of degradation, or which control the response of the soil to a given stress. This is then used to formulate a model to assess the risk.

The method of assessing risk proposed in the FAO provisional methodology uses a parametric model based on the factors which interact to control degradation, the general formula used is:

$$D = f(C,S,T,V,L,M)$$

D = Soil degradation
C = Climatic agressivity factor
S = Soil factor
T = Topographic factor
V = Natural vegetation factor
L = Land use factor
M = Management factor

In the risk assessment, the general formula is written as,

$$D = f(C,S,T,K)$$

where K is a constant representing the standard conditions of V, L and M. These latter are often referred to as the 'human factor' in the methodology.

Thus, each type of degradation is seen as resulting from the interaction of climate, soil, topography and a 'human factor'. The element of climate and the soil property which control degradation will, however, vary between types of degradation. Thus, leaching of bases (chemical degradation) is controlled by excess moisture expressed as the sum of the monthly differences between precipitation and potential evapo-transpiration, minus the soil moisture reserve (Table 10). The soil property of relevance to leaching is considered to be texture and clay type, while slope angle is the relevant element of topography (Table 10).

Natural vegetation is seen as serving as a store which protects soils from leaching. Clearance and burning, and addition of fertilizers may, however, enhance leaching. The authors of the methodology state that it is not yet possible to provide ratings for the 'human factors'.

The same classes are used to rate the risk of degradation as are used to assess the current rate of degradation (Table 9).

The FAO approach aims at a model which is flexible and can be applied to any form of degradation. An alternative approach is to develop separate models for particular types of degradation. Thus, for example, a number of models have been used to assess risk of soil erosion or erosion hazard (Morgan 1986). These include schemes based on rainfall erosivity, factorial scoring systems, rainfall aggressiveness and parametric models. Morgan (1985) has produced a map of 'areas susceptible to agricultural soil erosion' in England and Wales (Fig 5) by combining mean annual rainfall erosivity with information on the susceptibility of soils to water and wind erosion from 1:1 000 000 map of land use capability published by the Soil Survey in 1979.

Table 10. Method for calculating the risk of a given type of soil degradation (FAO 1979)

Climatic factor $C = \sum_{1}^{12} P-PET$, for the humid season

when $P > PET$ (P, Precipitation; PET, Potential evapo-transpiration)

or

$$C = \left[\sum_{1}^{12} P-PET\right] - R$$ where R is the soil moisture reserve

The rating factor for the calculation of the risk rating, for base cation leaching, is C/100.

Soil factors = Texture ($(S)_{texture}$) and clay type ($(S)_{clay}$)

Texture	Coarse	Medium	Fine
Rating factor	2	1	0.5
Clay type	Kandite	Illite	Smectite
Rating factor	1	0.5	0.25

Topographic factor T = slope

Slope is considered an important influence on leaching.

Slope %	0 - 8	8 - 30	>30
Rating factor	1	0.5	0.3

The risk of base cation leaching is calculated from the four rating factors as follows:

$$\frac{C}{100} \times (S)_{texture} \times (S)_{clay} \times T$$

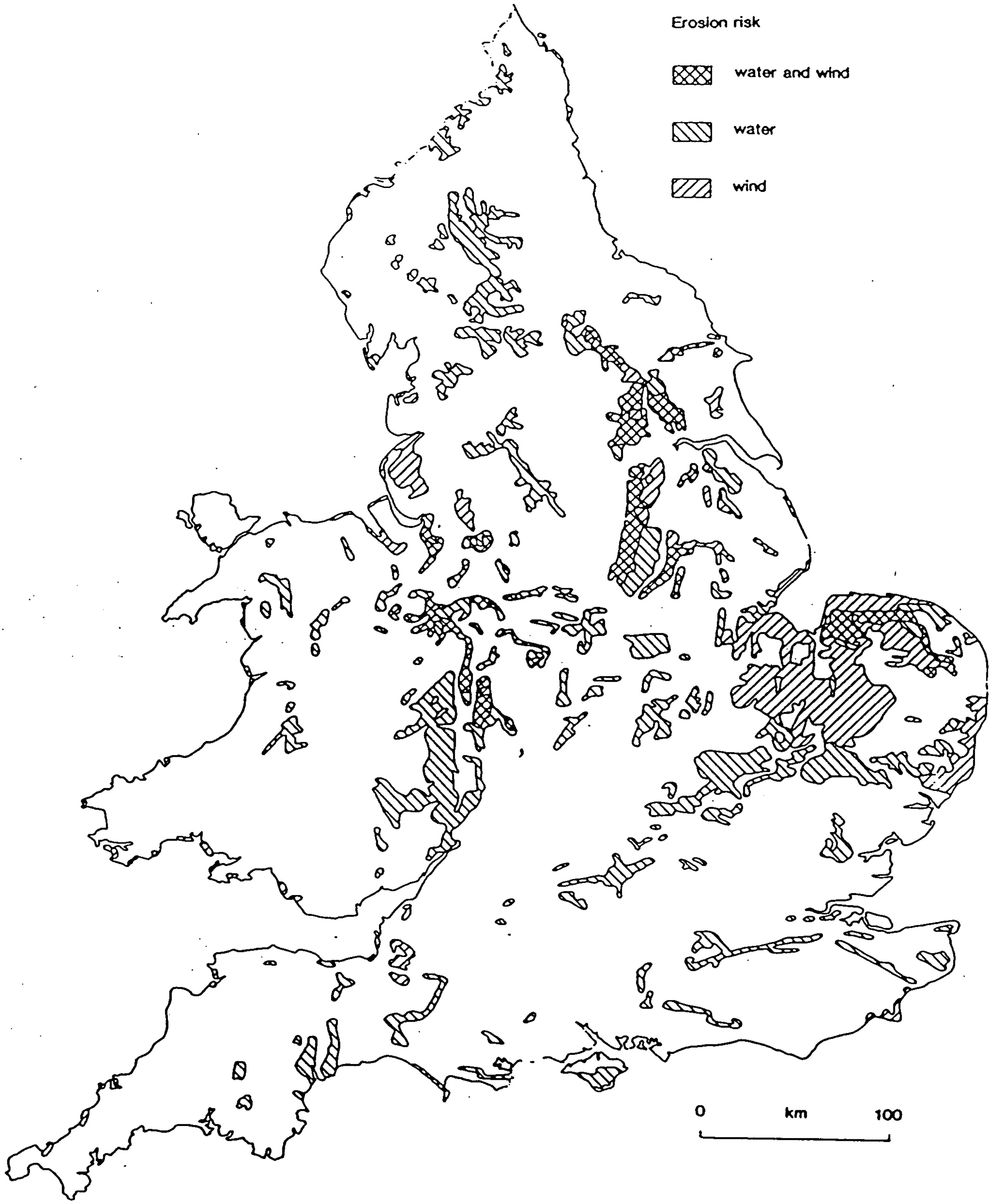


Figure 5. Areas of soil erosion risk in England and Wales (after Morgan 1985)

iv. Predicted rates of degradation

Prediction of the rate of degradation of soils as a result of a given stress necessitates the development of mathematical models. These models may have a similar conceptual basis to those used to determine the risk of degradation. Classifications of risk are, however, frequently qualitative. Prediction of rates requires quantitative relationships between cause and effect and rates of response. Models of this type have been developed to predict the rate of acidification of soils, as measured by the reduction in base saturation, by given inputs of acid deposition: these models are considered in more detail in section 1.13, and for other forms of degradation in Volume II. The Universal Soil Loss Equation is a model which has been used widely in the USA for predicting rates of erosion. Other erosion models are discussed in Volume II (Section 2.5). Prediction of rate of degradation due to heavy metals is complicated by the interaction of heavy metals with other soil properties and the fact that little is known about aspects such as compound speciation and toxicology.

1.8.4 Ecosystem degradation

In section 1.4 it was stressed that soils are formed by the interaction of a number of factors, and that soils are parts of ecosystems. Disruption of other parts of an ecosystem (ecosystem degradation) can lead to soil degradation and vice versa.

Degradation need not mean the complete breakdown of a productive ecosystem, a considerable loss of species would constitute degradation as would the replacement of a mature forest by a grassland.

Although ecosystems do evolve, and in some cases degrade, naturally, most ecosystem degradation is caused by man's activities. Broadly speaking, it seems that as the degree of habitat modification increases and as natural communities are altered or replaced by communities composed largely of exotic species, a knowledge of the structural and functional relationships of the orginal ecosystems becomes less relevant to the management of the modified systems. However, in systems that are utilized essentially as managed natural systems, a knowledge of the structural and functional relationships probably provides the soundest basis for effective long-term management consistent with both conservation and maintenance of productivity. Such systems include many terrestrial woodland forest ecosystems. Managed natural systems have received relatively little attention, yet when they are utilized by man they tend to become destabilized rapidly, with associated severe, and sometimes essentially irreversible, changes (Slatyer 1977). In the UK most ecosystems are managed to some extent. Indeed, some ecosystems would not exist without management. For example, without sheep grazing the communities of rare plants in Upper Teesdale could not compete with the grasses.

Important modifiers of ecosystems are:

i. Chemical modifiers - atmospheric deposition, fertilizers and sewage, toxic substances.

ii. Physical modifiers - atmospheric physical properties (such as turbidity), fire, excavation and construction, temperature changes, water flow.

iii. Biological modifiers - cropping populations, manipulation of species density and distribution, manipulation of genetics.

The different modifiers vary in the extent of their effects (Holdgate 1978).

Chemical modifiers

A Dutch team is working on soil degradation as a consequence of atmospheric deposition. In 1979-80 they began work on nutrient cycling in an oak-birch woodland on calcareous subsoil, studying throughfall, stemflow, soil solution, etc. in order to model quantitative hydrologic fluxes. After a few months, they found that the system is heavily affected by ammonium (much of the atmospheric ammonia entering the soil in the Netherlands originates from manure and slurry) and sulphate in dry deposition. In the surface soil there is strong nitrification at pH 3 to 4, and a heavy nitrate load. At low pH there are aluminiuim, nitrate, and sulphate ions in the soil solution (van Breeman et al. 1984, 1988). In all forests in central, southern, and north-eastern Holland inputs are high, 40 to 100 kg nitrogen ha^{-1} $year^{-1}$, with similar amounts of sulphate. Deposition is lower in heathlands, and there is less nitrification. Some microbiological work has been done in this woodland using ^{15}N. Nitrogen enrichment changes the ground flora, the mineral soil becomes acid and rich in aluminium ions. Evidently, something is happening in these woodlands, but it is difficult to link cause and effect.

Douglas fir is reluctant to root into the mineral soil in such polluted areas, and there is a negative effect of high aluminium ion concentration on some conifers. Monitoring studies on poor soils with Scots pine showed a similar, but less marked, effect. Attempts are being made to explain the observed effects by modelling. There is a possibility of making predictions and of regenerating soils by adding basic substrates. Monitoring work continues under Douglas fir. A university group from Amsterdam is studying experimental plots where they manipulate the system to change the stress, in some cases catching the throughfall before it reaches the soil and substituting simulated 'natural' (unpolluted) rainfall.

Physical modifiers

Alteration of water flow by man is one of the major impacts leading to ecological changes, and often to degradation. Thus, drainage of wetlands leads to modifications of the carbon cycle through the oxidation of organic soils, with loss of organic matter and direct changes in the distribution of species and composition of ecosystems. In the UK, the most dramatic examples are in the fenlands. Similarly, irrigation leads to major changes in the pattern of primary producers, and affects rates and directions of processes of leaching or salinisation.

Biological modifers

Some current soil problems result from past land practices. In France, the clearing of forests from leached brown soils, podzols, podzolic soils, and brown rendzinas followed by 10 to 12 years of cultivation, resulted in decreases in total organic matter content and carbon/nitrogen ratio (Dutil 1982). With cultivation, free organic matter decreases and bound organic matter fractions become more important. A dominant humin fraction, which is very stable, remains (Muller 1972). Results of various long-term experiments show that the evolution of organic carbon is governed by environmental conditions such as climate and soil type, and the availability of mineral nitrogen.

Duchaufour (1948) put forward the view that in the Atlantic zone of France the climax soil on a wide range of parent materials was a brown forest soil. However, the brown soils on the poorer materials may degrade more or less rapidly, even under oak forest, and in such areas man's influence is only to accelerate the degradation process. Duchaufour proposed a genetic series to show the stages of deterioration of acid soils, resulting in a podzol. Similar series were proposed for North American soils. Dimbleby (1962) concluded that although a few of the British heathland soils which he examined had been podzols since the Atlantic period, the majority are secondary, having arisen as a result of man's assault on the landscape, particularly in Bronze Age times.

Since man first appeared in Britain he has disrupted naturally-occurring soil processes by clearing the forests, burning the vegetation, ploughing for cultivation, and grazing animals. These activities have led to extensive chemical, physical, and biological degradation of soils. In Britain, and elsewhere in northern Europe, forest clearance was very marked in the Bronze Age. In parts of Britain, the uplands and the lighter soils of the lowlands were as devoid of forest by Roman times as they are today, though the landscape differed in detail. In places the fertility of the land was altered usually for worse and sometimes, apparently, irreversibly. Much of the wet moorland of the north-west European seaboard and the extensive heathland of the north European plain is a man-made artifact dating back mainly to prehistoric times. The situation was complicated by the fact that the original clearance was not the only impact, there were often successive waves of clearance and re-growth before extensive clearance became permanent (Dimbleby 1978).

On base-poor soils, particularly those which are freely-drained and/or in high rainfall areas, forest clearance created an imbalance by destroying the deep-rooted vegetation which maintained the topsoil fertility by bringing up bases from the deeper horizons. Hence, the leaching process was no longer compensated for and the upper horizons became more acidic. The soil became progressively more nutrient-deficient. Iron and aluminium moved down the soil profile. Soils lost their structure and secondary soil conditions such as development of thin iron pans, which impede drainge, developed (Dimbleby 1978). In the later stages, acidificatin results in degradation of clay minerals and release of aluminium.

Accumulation of mor humus and peat on such soils immobilizes large quantities of nitrogen and phosphorus, which become unavailable to many plant species. The management of such soils requires an understanding of the rates of flow of nitrogen through soil organic matter fractions, some of which may be intractable and act as nitrogen 'sinks'. The role of soil organisms needs to be understood so that management practices can encourage the types of organisms which permit the required type of nitrogen cycling.

Soil systems produced in this way appear to be different from those produced by natural, but slower, processes of retrogressive succession. Even where there are visual similarities, as with podzols, there seems to be marked differences in biology and organic matter turnover (Perrin et al. 1964; Tamm & Holman 1967).

Other examples of damage to soils and ecosystems are the disruption of vegetation by overgrazing and the disruption of vegetation and soils by trampling. Atmospheric pollution can result in the death of Sphagnum mosses and consequential erosion of the underlying peat, an example of the destruction of a whole ecosystem resulting from the degradation of sensitive components.

1.8.5 Summary and conclusions

Degradation is a widely-used concept in the description and assessment of the loss of productive potentials of soils. A number of authors have produced classifications of degradation; although these differ in detail they have broad underlying similarities - most recognise various forms of physical, chemical and biological degradations. The classification produced by Yassoglou (1987) has a simple structure, but is still comprehensive, and links each type of degradation to the main causative processes. The assessment of degradation can be done in four ways: current state of degradation, rate of degradation, risk of degradation, prediction of rates of degradation. A number of schemes have been proposed for assessing individual forms of degradation and the FAO (1983) has produced guidelines for comprehensive assessment of most types of degradation. The FAO guidelines are not ideal for use in the UK as they stand but they include valuable pointers: index parameters are identified for the assessment of each type of degradation, units are defined for each parameter, and values are assigned for the ranking of the levels of each type of degradation. The guidelines also use relatively simple parametric models for calculating the risk of degradation: models of this type would allow non-specialists to extract information from existing data bases and calculate risk; the main weakness in the models is the inability to assign values to the 'management' factor. Risk of degradation is a very similar concept to sensitivity of soils to a given threat: when the risk of degradation is related to a given threat, the two concepts can be regarded as identical. Good qualitative models exists which allow soils to be ranked in term of risk of various types of degradation.

Prediction of the rates of degradation necessitates mathematical models based on dose-response relationships, linking cause and effect. Suitable models have only been formulated for one or two types of degradation. One example is the prediction of rates of acidification by acidic deposition; the currently-available models have weaknesses but these are being addressed in current work.

The concept of degradation has limitations in the context of a broadly-based, multifunctional or multiuse soil protection policy because of the emphasis on productive potential. The concept could be redefined to cover a reduction in the range of uses to which a soil can be put, or functions it can perform, but redefinition of a well established widely-used concept is difficult and inadvisable. The concept would not cover some of the current threats being discussed under the general banner of soil protection. Thus, nitrate leaching to groundwater may not involve a reduction in productive potential of the soil and is not, therefore degradation. The concept is best used in its widely understood form and related to agricultural and forestry production. It should not be used as the foundation of a broadly-based soil protection policy.

1.9 BUFFERING CAPACITY AND RESILIENCE

1.9.1 Definition

In the context of soil protection, the buffering capacity of a soil is its ability to absorb or neutralize the impact of a given threat or stress. It is most frequently used in connection with acidity and acidification; the buffering capacity in this case is the ability of a soil to neutralize a given input of H^+ ions. The concept can, however, be applied to other stresses. The concept is closely linked to that of sensitivity. Soils with a large buffering capacity towards a given stress will have low sensitivity to that stress. The buffering capacity of a soil towards a given stress will be determined by those soil properties which are involved in neutralizing that stress. It can be used to rank soils in terms of their risk of degradation in response to a given stress loading. A given soil may have widely differing buffering capacities to a range of stresses or threats.

De Haan (1987) defined the buffering capacity of a soil with respect to soil contamination as the capacity of the soil to delay the negative effects of the contaminant's presence, because of inactivation by bonding onto soil constituents, or sometimes by conversion to insoluble compounds. The relationship between the amount of a contaminant in a soil and its effect may be represented as in Figure 4 (section 1.8.3). Taking as an example a heavy metal which is also a micronutrient, if there is not sufficient of it in a soil, an increase in the amount present will have an initially beneficial effect until the requirement for it is satisfied (value 1), when a small further increase will have no effect. Eventually, a point will be reached when the substance begins to have a deleterious effect (value 2). The region up to value 2 gives the buffer capacity of the soil for that substance. The extent of the soil buffering capacity varies widely for different compounds and different soils, and the curves may have different shapes.

Buffering capacity can be applied to the ability of soils to neutralize a stress which affects any of the soil's functions. Thus buffering capacity with respect to leaching of nitrate, phosphate or organic pollutants considers the ability of the soil to retain inputs of these pollutants, thus limiting release to surface and groundwaters.

Resilience is a measure of the ability of a soil system to recover naturally once a threat or stress is removed, or the loading of the given stress or threat is reduced. The concept of resilience has similarities with both buffering capacity and reversibility (section 1.11). Soils and ecosystems (see section 1.9.3) are generally resilient within certain limits; if the given property being used as a measure of resilience moves outside those limits then the soil will not recover naturally. The effect may still, however, be reversible. In the context of soil compaction, a resilient soil will recover naturally, i.e. bulk density will decrease, once the loading is reduced. If a soil has been acidified by acid deposition, resilience would express the ability of the soil to recover, i.e. for base saturation to increase, as the inputs of acidic pollutants were decreased.

1.9.2 Assessment

The concept of buffering capacity is reasonably well developed and there are qualitative models for some stresses. However, there are few examples of the quantitative assessment of buffering capacity. Fränzle (1987) discussed the ability of soil systems to buffer pollutants, and amplified the idea that the basic chemical and toxicological data have to be matched to additional data on the properties of the most important types of environment in which the substances occur. He used models to describe the input and state variables of the atmospheric system and its linkage with the adjacent terrestrial and aquatic systems, sorption processes in soil as controlled by moisture and microbial activity, and the interactions and cascading of matter and energy in air, water, vegetation, and soil. One of the most important sub-systems is that which illustrates the importance of adsorption and desorption. Together they determine the buffer capacity of the soil, and are largely determined by soil constituents having high specific surface and net charge, i.e. organic matter, clay minerals, and metal oxides and hydroxides.

An important task is to find the most important variables and establish a list of relative priorities. Fränzle selected representative test soil types and test chemicals, and carried out simple leaching experiments. The aim was to complement these by larger-scale lysimeter studies. In initial experiments with the herbicide 2,4-D, specific surface, organic matter, and sodium oxalate- and dithionite-soluble iron, manganese, aluminium, and silicon fractions (indicative of pedogenic clay minerals and oxides) and the sum of exchangeable cations, accounted for more than 90% of the observed variation in sorption rates. The relative buffer capacities of seven geopedological units (clusters of soil types) with respect to 2,4-D were assessed.

Fränzle (1987) also discussed soil sensitivity and buffer capacity in relation to acidification. Acidification of soil and water depends on the balance between the sum of internal H^+ ion production and its atmospheric input on the one hand, and on the other hand the consumption of H^+ ions in the soil.

H^+ ions may enter soil in the form of carbonic acid in rainfall. They are also produced naturally by several processes in an ecosystem. Carbonic acid results from the solution of carbon dioxide, produced by soil organisms and plant roots. H^+ ions are also produced when nitrogen and sulphur compounds are mineralized. The main part of H^+ ion production in soil results from the accumulation of soil organic matter and of excess cations in the biomass, during which there is a corresponding release of H^+ ions into the soil. Natural H^+ ion production in forest ecosystems depends on soil properties, productivity, tree species, climate, and management.

In this context, some of the more important soil properties are fabric, amount and type of organic matter, mineral composition, cation and anion exchange capacities, base-status, and soil depth. Soil acidity increases when H^+ ions exchange with base cations adsorbed to soil particles. Weathering reactions are the main sink of H^+ ions in soils. The intensity and efficiency of these exchange processes depends on base-saturation, soil pH, and the relative proportions of permanent and variable charges in the soil. These properties have to be matched to the pattern of infiltration and flow through the soil, which depends on soil structure, pore size distribution, and the quantity of water flowing through the soil.

In general, in order to assess the sensitivity of a soil we need to understand the important physical and chemical transformation mechanisms and their specific boundary conditions. Because of the complexity of soil systems, we need to know what are the important variables which indicate the state of, and trends within, those systems. Such variables will assume the nature of indicator variables (Fränzle 1987).

Conceptual models could readily be developed for predicting the resilience of soils under given stress. These models would include those soil properties which control the soils' response to the particular load, e.g. acidic inputs, or physical loading. In the case of compaction, the model would include the content and type of clay minerals and or organic matter. There are clearly strong similarities with the conceptual models used to assess the sensitivity of soils to a given stress. A qualitative ranking of the resilience of soils under a given type of stress could be developed relatively rapidly based on the conceptual models. Considerably more research is needed, however, before quantitative models can be developed to allow the determination of rates of recovery; the only existing mathematically-based models address rates of recovery from acidification by acidic atmospheric inputs.

1.9.3 The buffering capacity of ecosystems (ecosystem stability) and ecosystem resilience and restoration

The concept of buffering capacity as the ability of a system to absorb or neutralize the impact of a given threat or stress can be extended to ecosystems. Stability is the ability of a system to return to an 'equilibrium' state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is (Holling 1973). A system with low stability and high resilience will survive, but with large fluctuations.

The tendency of ecosystems to remain in a quasi-steady state if undisturbed and to return to that state, through the modification of internal system processes, if disturbed, is termed 'homeostasis'. Ecosystem types vary greatly in the degree of homeostasis exhibited. In ecosystems which have a high degree of homeostasis, disruption of the normal pattern of structure and function is difficult, and internal disturbances that are induced are corrected rapidly. That is, the response of the system depends more on the characteristics of the system than on the nature of the disturbance. Conversely, in ecosystems which have a low degree of homeostasis, changes in the physical or biotic environment produce a stronger and more lasting effect on ecosystem structure and function, and so are of greater importance in determining the response of the system (Collier et al. 1973).

Within certain limits ecosystems show a high degree of stability. However, a change in an important controlling factor can disrupt the functioning of a system. This is well illustrated in a study by Hutchinson (1970), which provides an example of changes in linked lake and terrestrial ecosystems. Lake ecosystems are affected by water draining from surrounding terrestrial ecosystems, and lake sediments provide records from which changes in surrounding terrestrial ecosystems may be deduced. Hutchinson reconstructed the series of events which occurred in a small crater lake in Italy over the period 2000 BC to 1970. From the last glacial period in the Alps until Roman times the lake had established a trophic equilibrium with a low level of productivity, which persisted in spite of dramatic changes in the surrounding country. The changes in soil conditions and drainage water resulting from terrestrial ecosystem succession from Artemesia steppe, through grassland, to fir and mixed oak forest were absorbed by the lake ecosystem. However the construction of the Via Cassia by the Romans in about 171 BC produced changes in the drainage water that the lake ecosystem was unable to accommodate, and there was a change to a more eutrophic systems. Modern parallels are often reported (e.g. see Holling 1973).

Ecosystem stability has long been a subject for debate by ecologists (e.g. papers in van Dobben & Lowe-McConnell 1975). Mathematical models developed by May (1975) suggest that as a system becomes more complex it becomes more dynamically fragile. May argued that a stable environment is a necessary condition for a delicately-balanced ecosystem to develop and maintain itself. A corollary of this is that the large perturbations imposed by man are likely to be more traumatic for complex natural systems than for simple ones. Hence, there is reason to expect simple natural monocultures to be stable. One example of this is bracken which has, in recent years, shown itself to be a robust and aggressively invasive natural monoculture over increasing areas in Britain.

However, May (1975) found it difficult to visualize any simple method for quantifying the stability and resilience of a natural ecosystem. In real systems with any degree of complexity, it seems likely that the capacity to withstand perturbations will depend on the kind of perturbation. An ecosystem might be resilient to a violent storm, but be vulnerable to an apparently minor disturbance such as the construction of a road or powerline.

Margalef (1975) pointed out that cropped land may seem to be unstable because it returns to a different state when it is not exploited. However, it can be thought of as stable when it is coupled with an exploiter (man) and made part of a larger system that includes man.

In the management of ecosystems, a viewpoint that regards ecosystems as stable suggests that nature's excess production can be harvested with as little fluctuation as possible. However, this approach might so change the deterministic conditions which define the characteristics of the ecosystem that its resilience is lost or reduced, leaving it susceptible to a chance event. On the other hand, a management approach based on the viewpoint of ecosystem resilience would emphasize the need to keep options open and to emphasize heterogeneity. It would require the recognition of our ignorance and the need to devise systems that can absorb and accommodate future events in whatever unexpected form they might take (Holling 1973).

The concept of resilience has also been applied in studies of ecosystems. In this context, resilience is a measure of the ability of systems to absorb changes of state variables, and parameters, and still persist. Persistence of the system is the result of high system resilience, probability of extinction of the system is the result of low system resilience (Holling 1973). A resilient system can have low stability and show large fluctuations, but still survive. Some so-called 'elastic' ecosystems will return rapidly to their pre-disturbance situation if the disturbance does not persist for too long (cf. Holling 1973; Patten 1974). Resilience of an ecosystem must depend also on general environmental factors. Systems which have low productivities because of factors such as climate or nutrient supply will have low capacities for recovery (Whittaker 1975).

1.9.4 Summary and conclusions

In spite of the fact that the term 'buffering capacity' is most frequently used in connection with soil acidity, the term is equally applicable to any soil property. We can use the term to describe the ability of soils to neutralize a stress which affects any of the soil's functions, for example to absorb heavy metals, nitrate, phosphate, or organic pollutants and so limit their release to surface and groundwaters.

Well-buffered soils retain their properties between upper and lower limits which are characteristic of a given soil. If properties are pushed outside those limits by a stress, the original condition may still be recoverable if the soil is resilient. Resilience is a measure of the ability of a soil system to recover naturally once a threat or stress is removed or the loading of the given stress is reduced.

Although the concept of buffering capacity is reasonably well developed, and there are qualitative models for some stresses, there are few examples of the quantitative assessment of buffering capacity. One quantitative model is discussed in relation to effects of pollutants and acidification. Conceptual models could be developed for predicting the resilience of soils under a given stress, and there are strong similarities with the conceptual models used to assess the sensitivity of soils to a given stress. However, apart from the recovery of soils from acidification, considerably more research is needed before quantitative models can be developed to allow the determination of rates of recovery.

The concepts of buffering capacity and resilience can also be applied to ecosystems. Stability is the ability of a system to return to its initial quasi-steady state after a temporary disturbance. Ecosystem types vary greatly in this respect. Ecosystem stability is linked to ecosystem resilience. A system with low stability and high resilience will survive, but with large fluctuations. Systems which have low productivities because of factors such as climate or nutrient supply will have low capacities for recovery.

The complexity of ecosystems and the limits to current understanding of the interacting mechanisms and processes by which they function makes it difficult to visualize any simple method for quantifying the stability and resilience of a natural ecosystem. It seems likely that the capacity to withstand perturbations will depend on the kind of pertubation.

1.10 SENSITIVITY AND SUSCEPTIBILITY TO STRESS

1.10.1 Definition

In the context of soil protection, soil sensitivity can be seen as the rate of response of a soil to a given stress, or threat; or, in terms of the rate of degradation, assessed by some index parameter, in response to a given stress. Some authors use the term 'fragility' to cover essentially the same concept.

If we consider the de Haan model relating soil content of an element or compound, and effect (Fig. 4, section 1.8.3), then the sensitivity of a soil would be inversely proportional to magnitude of the difference between values 1 and 2 (in the case of an essential element) or to value 2 (in the case of a non-essential element), with respect to a given reference parameter.

Yassoglou (1987) defined soil sensitivity as "the rate of variation of dependent properties caused by given influxes;" he expanded this with, "If we assume that a soil system has reached a slow rate of change under a constant set of state factors, we could also assume that the system is in a steady state for a given time period. A sudden change in the influxes will upset the state of the soil and initiate processes that will lead to changes of soil properties and consequently they will alter the performance of the whole soil system." He suggested that the sensitivity of a soil system could be expressed in a general way as follows:

$$\frac{ds}{dt} = KI^{(m)}$$

where the rate constant K is the initial state of the soils, and I represents the influx(es). Yassoglou (1987) pointed out that the sensitivity of soil systems is not a constant and will change as physical, chemical, mineralogical and biological characteristics of the soil system change.

Expressed as above, the concept is very similar to 'buffering capacity' as outlined in the previous section, in fact 'sensitivity' is inversely related to buffering capacity. The concept is best used with respect to a given threat, or form of degradation. Thus, for a given soil, there should be separate estimates of sensitivity with respect to, for example, acidification,

Table 11. Sensitivity coefficients used by Federoff (1987) to calculate the sensitivity of the soils of north west Europe to intensive agriculture

	Not at all sensitive (0)	Low sensitivity (1)	Fairly low sensitivity (2)	Average sensitivity (3)	Fairly high sensitivity (4)	High sensitivity (5)
Texture	-	Balanced	Slight imbalance towards clay	Moderate imbalance towards clay	Sandy silt silty sands medium silts	Silt
Mineralogical characteristics of the clays	Abundant swelling clays		Swelling clays present		No swelling clays	
Pedological fabric	Developed calcareous cambic clayey fabrics		Dystro-cambic palaeo-argilaceous fabrics			No fabrics Gley fabrics Hydromorphic clay fabrics
Organic matter	-	Over 2%		Between 1 and 2%	Less than 1%	-
Biological activity	-	Indicates high level of earthworm activity		Indicates presence of earthworms		Earthworms apparently absent
Aggregation and macro-porosity	Very marked crumbly, fluffy, polyhedric and highly macroporous structures			Not very marked to average development of subangular, polyhedric structure. Macroporosity average to low		Massive structure No macro-porosity
Structural stability	$Log_{10}I_s$ 0.8 and $Log_{10}K$ 1.8			$Log_{10}I_s$ between 0.8 and 1.2 $Log_{10}K$ between 1.8 and 1.3		$Log_{10}I_s$ 1.2 and $Log_{10}K$ 1.3
Permeability (hydraulic conductivity K) (cm x s)	Values of less than 2×10^{-2}			Value of between 2×10^{-2} and 1×10^{-4}		Values of over 1×10^{-4}
	No waterlogging	Sub-soil waterlogged	Exceptional episodes of waterlogging up to the surface of the soil	Occasional waterlogging up to the surface	Waterlogging frequently reaches surface	Soil waterlogged up to the surface throughout the winter

compaction, nitrate leaching; the sensitivity of a given soil to each of a number of threats may very considerably. Sensitivity is related to risk of degradation, since a soil that is sensitive to a particular impact will have a high risk of undergoing degradation.

The susceptibiity of a soil system to a stress may be defined as the likelihood of a given form of degradation occurring. Thus, a soil may be susceptible to erosion, and erosion results from a soil's sensitivity to rainfall. That sensitivity is determined largely by soil texture, slope, and surface cover.

Some authors use the term 'vulnerability' instead of sensitivity. In considering some currently-perceived threats, sensitivity may be a more useful concept than susceptibility.

1.10.2 Assessment

The assessment of sensitivity of soils to a particular stress is based upon a cause - effect model. The model may be a conceptual one which identifies those soil factors, or properties, which control the response of soils to the given stress, or threat. For example, the sensitivity of soils to acidification by atmospheric deposition is mainly a function of base saturation, cation exchange capacity, content of carbonate and weatherable silicate minerals (cf. section 1.13).

With regard to erosion, the sensitivity classes with respect to rainfall can be derived from known, broad relationships between soil type and the controlling parameters, parametric models incorporating the controlling variables, or mathematical models.

Federoff (1987) has discussed the 'Sensitivity of Principal Soil types to the Intensive Agriculture of North-Western Europe'. He identified a series of first order and second order factors which will determine the soil's sensitivity to intensive agriculture. A 'coefficient of sensitivity' is then attributed to each of the factors controlling sensitivity; the coefficients range from 0 - 5 for each factor (Table 11). An integrated assessment of the sensitivity of a given soil can then be obtained by summing the individual coefficient scores. This approach could be used to produce a map showing the distribution of soils in a range of sensitivity classes by calculating the

Table 12. Relative ratings of soil sensitivity to degradation in Southern Europe. (I = slight, II = medium, III = high, IV = very High) (Yassoglou 1987)

Soils	Types of soil degradation				
	Loss of volume	Loss of organic matter	Physical degradation	Chemical degradation	Fertility degradation
i. Flood Plains					
Eutric Fluvisols (Je)	I	II	II	IV	I
Calcaric Fluvisols (Jc)	I	II	II	III	I
Dystric Fluvisols (Jd)	I	II	II	III	III
Vertisols (V)	I	I	III	II	I
Histosols (O)	II	II	III	III	III
ii. Quarternary Terraces					
Orthic Luvisols (Lo)	II	III	III	III	III
Chromic Luvisols (Lc)	II	III	III	III	III
Calcic Luvisols (Lk)	III	III	III	IV	IV
Vertic Luvisols (Lv)II	II	II	II	I	II
Ferric Luvisols (Lf)	II	III	II	III	IC
Rhod-chrom Luvisols (Lch)	II	II	II	II	II
Plinthic Luvisols (Lx)	IV	II	IV	IV	IV
Eutric Planosols (We)	III	II	III	II	II
Dystric Planosols (Wd)	III	II	III	IV	IV
iii. Rolling Tertiary Hills					
Calcaric Regosols (Re)	I	III	I	I	II
Eutric Cambisols (Be)	I	II	I	I	II
Calc-calcic Cambisols (Bck)	III	II	II	III	III
Calc-vertic Cambisols (Bcr)	I	II	I	I	II
Vertisols (V)	I	I	II	I	I
Chromic Luvisols (Lc)	III	III	III	III	III
Rendzinas (E)	II	III	III	II	IV
iv. Mountain Watershed					
Lithosols (I)	I	III	I	I	I
Regosols (R)	I	II	I	II	II
Dystric Cambisols (Rd)	III	II	III	IV	IV
Eutric Cambisols (Be)	III	II	III	III	III
Orthic Luvisols (Lo)	III	III	III	III	III
Chromic Luvisols (Lc)	III	III	III	III	III
Acrisols (A)	III	III	III	IV	IV
Rankers	IV	III	IV	III	IV

sums of the coefficient scores for mapping units on a soil map and establishing class limits.

Yassoglou (1987) discussed the sensitivity of the soils of southern Europe to degrading influences/processes (cf. Table 12). He presented relative ratings of sensitivity of the main soil groups of southern Europe to the major types of degradation; the underlying model used in determining the ratings is not set out in detail.

The concept can be applied in the context of most of the currently-perceived threats to soil systems. In the case of erosion, sensitivity is an assessment of the likelihood of erosion; applied strictly, one would assesss the sensitivity of a soil to a given form of management. In the case of acidification, and compaction, sensitivity assesses the change in a soil, or soil property, in response to a given stress. In the case of nitrate and phosphate leaching, however, the concept is applied to the soil as a pathway which controls the transfer of a stress to a linked system. Thus, sensitivity to nitrate leaching considers the transfer of nitrate from the soil to groundwaters. A similar approach can be used for leaching of organic pollutants or phosphate; in these cases sensitivity assesses the ability of soils to retain the given pollutant.

Quantitative dose-response models are not yet available on which quantitative estimates of sensitivity can be based for all the current threats to soils . However, conceptual models are available which identify those soil properties/factors which control the response of soils to particular threats; these conceptual models can be used to rank soils in terms of their sensitivity.

1.10.3 Ecosystem sensitivity

When the sensitivity concept is applied to natural or semi-natural ecosystems it may be preferable to assess the sensitivity of the system rather than the soil per se. Thus, for example, many areas of the British uplands can be said to be highly susceptible to erosion (i.e. to have a high erosion risk) on the basis of the high rainfall, steep slopes and erodible soils. Erosion may, however, be limited at present due to the existence of a complete plant cover. If this vegetation were disrupted, severe erosion may follow. A sensitivity of soils to erosion based on slope, rainfall and soil texture could be combined with one which ranked the vegetation in terms of sensitivity to a given loading, e.g. walkers, grazing, acid deposition. It should be relatively easy to develop qualitative models which would allow the most sensitive systems to be identified. They could then be monitored and, if necessary, protected. However, mathematical models are not available.

The estimation of the susceptibility of the various ecosystems to the variety of influences and pressures which exist is complicated and difficult. Only in cases of drastic environmental change, such as exposing a new soil parent material or total disturbance of a soil profile, do we know that all ecosystems are maximally susceptible to stress. For most influences, the susceptibility is not known exactly. However, for Dutch ecosystems, tentative estimates of susceptibility on 5-point scales have been made for three influences: eutrophication, desiccation, and treading. Generally,the susceptibility will depend on the nutritional status (with the oligotrophic systems being the most susceptible), the soil moisture conditions, and the status of 'natural' environmental dynamics (van der Maarel 1978).

Applications of susceptibility analysis usually have an ad hoc character, when some specific development plan is checked for its environmental side-effects. An important step forward will occur when a more detailed estimation of 'environmental quality' is required to be confronted with impacts from various activities. Van der Maarel (1978) gave three examples from the Netherlands. The first example concerned the possible ecological impact of a highway development scheme, the second concerned the ecological impact of an urban development scheme, and the third concerned the susceptibility of natural ecosystems to a lowering of the phreatic water table in a water resource management scheme.

Three kinds of system are particularly susceptible to degradation (Holdgate 1978)

i. Systems whose physical integrity depends critically upon the maintenance of the biota. An example of this is deep peat mire systems, in which the maintenance of the organic soil depends on waterlogging, which in turn (especially in soligenous mires) depends on the maintenance of the unbroken plant cover if the soil is not to be eroded.

ii. Systems whose biotic function depends on physical integrity, e.g. wetland systems dependent upon the maintenance of waterlogging of the organic soils.

iii. Systems with biological features related to abnormal ecological functioning, e.g. peatland systems, with a low decomposer component, liable to major changes in this section of the ecosystem if the soils are made aerobic.

1.10.4 Summary and conclusions

In the context of soil protection, the term 'sensitivity' applies to some soil parameter(s), and can be thought of as the rate of change of the value(s) of the parameter(s) in response to a given stress. The sensitivity of soils to some types of stress can be modelled mathematically, but quantitative dose-response models are not yet available for all the current threats to soils. However, conceptual models could be used to rank soils in terms of their sensitivity to various threats.

The sensitivity of a soil system to a stress is not a constant, it will change as physical, chemical, mineralogical, and biological characteristics of the soil system change. Sensitivity is inversely related to buffer capacity, as a soil with a high buffer capacity can absorb a certain amount of stress without changing its characteristics beyond the normal boundaries. Hence, the soil will not be sensitive to that stress.

Ecosystems are also susceptible to various stresses, and it should be relatively easy to develop qualitative models which would allow the most sensitive systems to be identified. Mathematical models are not available. The estimation of the susceptibility of ecosystems to the variety of influences and stresses which exist is complicated and difficult. For Dutch ecosystems, tentative estimates of susceptibility on 5-point scales have been made for eutrophication, desiccation, and trampling.

1.11 REVERSIBILITY

1.11.1 Definition

An effect is reversible if the property or properties which have changed can be returned to their original values. Soils and ecosystems are generally resilient within certain limits (Section 1.9); if the property of interest moves outside those limits then the soil will not recover naturally. The effect may still, however, be reversed by management measures. Some effects are irreversible, thus the accumulation of heavy metals in soils is generally irreversible.

For example, soil compaction may be reversed naturally, i.e. bulk density will decrease, once the loading is reduced; the extent of the recovery of the soil from compaction would also be a measure of the reversibility of that form of degradation on the given soil. Soil compaction can also be reversed by suitable cultivation techniques but the applicability of the techniques will vary between soils. Turning to acidification, if a soil has been acidified by acid deposition, reversibility would express the ability of the soil to recover, i.e. for base saturation to increase, as the inputs of acidic pollutants were decreased or as basic substances were added.

It may be useful to distinguish different types of reversibility. Effects which are reversed naturally once the load or stress is removed could be referred to as 'naturally reversible'; effects which can be reversed by the use of an ecological approach to management, e.g. the introduction or encouragement of various plant species, could be referred to as 'ecologically reversible'; effects which can be reversed by application of technology, e.g. a specific method of cultivation could be referred to as 'technologically reversible'. In general, the type of reversibility which is possible or practicable will be related to the deviation of a given parameter from its value (or normal range of variation) in the unstressed soil (Fig. 6).

1.11.2 Assessment

Conceptual models could readily be developed for predicting the reversibility of a given effect. These models would include those soil properties which control the soils' response to the particular load, e.g. acidic inputs, or

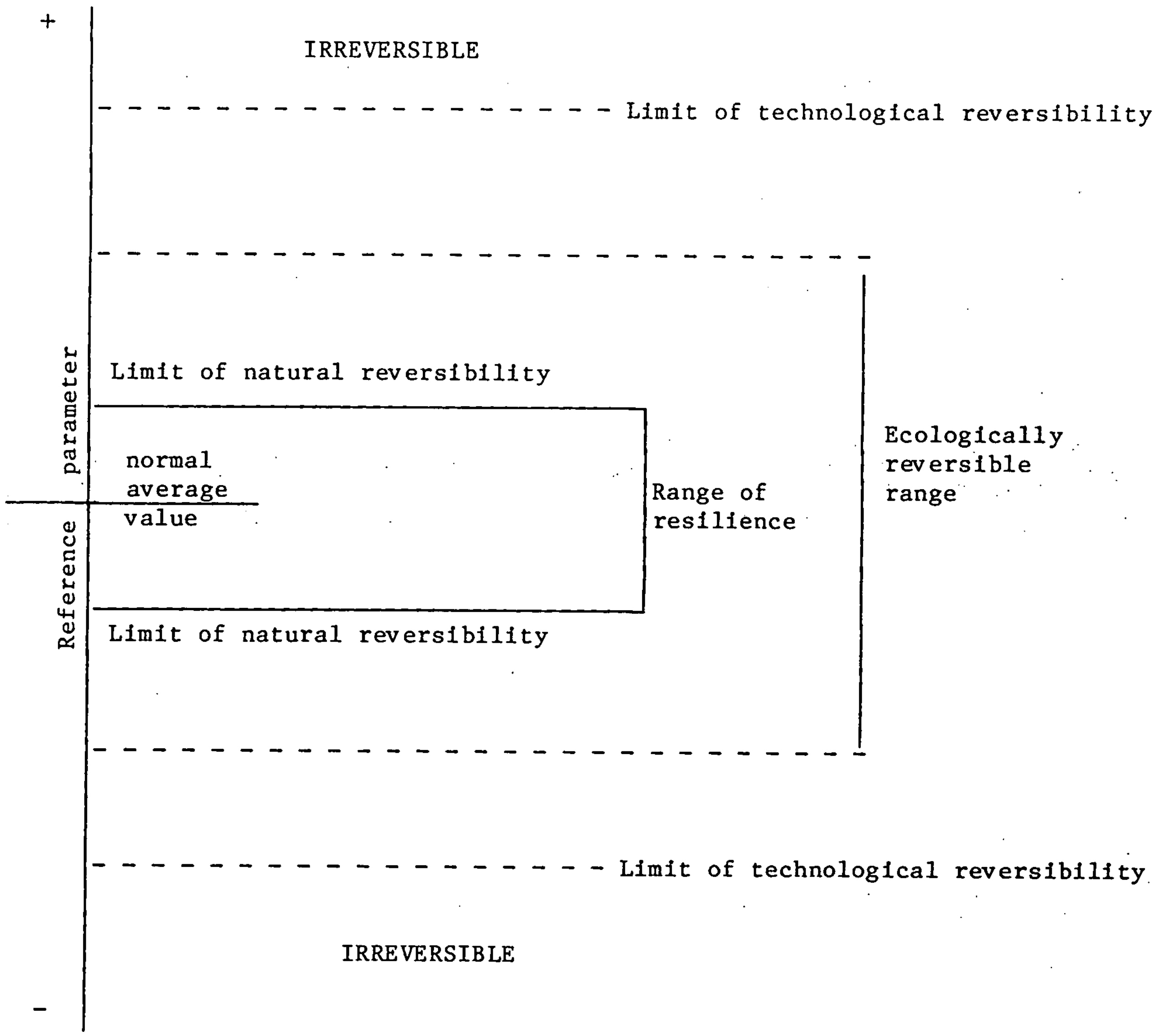


Figure 6. Relationship between type of reversibility and values of a reference parameter.

physical loading. In the case of compaction, the model would include the content and type of clay minerals and of organic matter. There are clearly strong similarities with the conceptual models used to assess sensitivity of soils to a given stress. A qualitative ranking of the reversibility of the effect could be developed relatively rapidly based on the conceptual models. Considerably more research is needed, however, before quantitative models can be developed to allow the determination of rates of recovery; the only existing mathematically-based models address rates of recovery from acidification by acidic atmospheric inputs.

1.11.3 Reversibility of changes in ecosystems: Ecosystem restoration

The extent to which changes in ecosystems are reversible depends on the nature and extent of the changes. Discussing the effects of forest clearance, Dimbleby (1978) noted that there are at least four possible consequences, that after clearance:

i. the forest ecosystem is restored, virtually unchanged, by natural succession
ii. succession leads to a weaker representation of the forest ecosystem
iii. the forest does not return because of continued use of the land
iv. the forest does not return because of environmental and soil deterioration.

Effects (i) and (ii) are reversible, and this occurs naturally. Effect (iv) is irreversible. Effect (iii) is reversible, but to reverse it requires that the cause (i.e. the land use) is removed.

Once it is decided that a degraded ecosystem should be rehabilitated, there might be several options in deciding the precise kind of rehabilitation. An option which is unlikely to be open is to restore the system to the precise condition that prevailed before human impact. It is unlikely because of changes in the physical environment resulting from the impact. There are, perhaps, two types of objective: (i) to restore or sustain certain 'outer limits' which determine the integrity of the system, for example in terms of soil profile or hydrological regime; (ii) to sustain a desired functional system, manipulated to provide a particular human benefit, i.e. an exploitation approach (Holdgate 1978).

Restoration possibilities depend upon the potentials of the area being considered, and these will be reflected in the pattern of potential 'natural' vegetation. In completely devastated or cultivated areas the determination of the potential natural vegetation may be very difficult, as it is based on a knowledge of both the present soil conditions and the phytosociological structure of remaining near-natural vegetation, usually a type of woodland. From the potential natural vegetation, a list of so-called 'replacement', or substitute, plant communities can be derived and used as a reference. A decision would have to be made on the kind of development that one would want in a given area, and the kind of ecosystem pattern that would result, given both the prospects and restraints of physical planning. Ecological success, i.e. the effectiveness with which the desired pattern will be obtained, will depend upon the still-existing variation in abiotic and biotic conditions and the environmental dynamics within the area (van der Maarel 1978).

In some cases, rehabilitation may not be practicable. For example if, as a result of excessive fertilizer use, a soil has become phosphorus-saturated, rehabilitation would involve the superimposition or replacement of topsoil.

1.11.4 Summary and conclusions

The reversibility of the effects of various impacts on soils and ecosystems is an important concept in soil protection. Irreversible changes should be avoided if they impair any of the soil/ecosystem functions. In some cases, soil or ecosystem properties may return naturally to their normal range of values once the impact is removed. Then the main question is the timescale required. In many cases the soil/ecosystem will not return naturally to its original condition, but would do so under mangement. In other cases, the soil/ecosystem will not return to its original condition but could, under mangement, be converted to some other desirable state. Some changes are ireversible.

If action is likely to be effective, what is done will depend on the social response to the effects produced by the impact. Holdgate (1978) noted that there are four main kinds of social response to environmental effects, including the degradation of ecosystems through human impact:

i. blindness, in which the change is ignored

ii. acceptance, that is, a failure to respond because it is considered that the effect needs to be tolerated because of other social factors

iii. calculated action, in which the response of the community is related to an evaluation of the impact and effects and some notion of the benefits and costs related to both

iv. over-reaction, in which there is a social reponse to the effects on the environment which is not related so closely to a critical evaluation, and where the demand to be seen to be responding is more important than the scale of either the effect or response.

A soil protection policy should take account of predicted effects of impacts on soils and ecosystems, whether or not the changes are reversible, and the likely cost of any recovery operation, as in (iii) above.

1.12 CRITICAL LOADS

1.12.1 Definition

The critical load concept has been developed in connection with assessments of the impact of acidic deposition. In that context, Nilsson (1986) provided a general definition of critical load as, "The highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecosystems." The 'load' here is the atmospheric input of acidifying ions. A definition related specifically to soils, and based upon Nilsson and Grennfelt (1988) could be, 'A quantitative estimate of the loading of one or more pollutants below which significant harmful effects on soils are not likely to occur according to current knowledge.'

Although the critical load approach is currently being used only in the context of the impact of acidic deposition it could be applied more broadly. The 'load' could be pollutant inputs, heavy metals, physical loading, fertilizer inputs. The definition of critical load will vary with the particular threat, e.g. in relation to compaction it might be, 'A quantitative estimate of the maximum physical loading of a soil which will not produce increases in bulk density, or decreases in permeability resulting in adverse effects on the functioning of the soil system.'

The concept of maximum permissible levels of heavy metals in sewage sludges, applied to agricultural land, is very similar to that of 'critical loads'. A more comprehensive consideration of critical loads for heavy metals would, however, include atmospheric inputs and would attempt to define the load which would not produce a harmful effect on the soil ecosystem, particularly the biological system.

The critical load approach, or concept, is directed towards linking cause and effect; or, in Moen and Brugman's (1987) terminology, linking an effect-oriented policy and a source-oriented policy. Thus, in the context of acidic deposition the critical load, once determined, could be used to fix acceptable levels of emissions of sulphur dioxide and nitrogen oxides.

1.12.2 Assessment

Determination of critical loads necessitate a quantitative mathematical cause-effect model. Nilsson (1986) used a proton budget approach to determine critical loads of sulphur and nitrogen for forest soils. The critical load is such that "the total input of hydrogen ions to the soil must not exceed the alkalinity produced by the weathering of primary minerals." 'Input' here includes proton inputs from the atmosphere plus hydrogen ions generated within the soil system. The approach requires data from comprehensive studies of element fluxes in soil-plant systems. Sverdrup and Warfvinge (1988) have suggested a modified approach based on a mass balance for acidity and alkalinity - this is considered in more detail in section 1.13.

Studies in the Netherlands have produced models to define the maximum inputs of nitrogen fertilizer, and the timing of these inputs, to limit leaching of nitrate to groundwaters. The models required here need to consider inputs, nitrate production by mineralization of organic matter, plant uptake, removal in plants, and controls on leaching processes. In effect, these models are defining a critical load of nitrogen fertilizer with respect to impacts on water quality.

1.12.3 Summary and conclusions

The 'critical load' concept was developed in the context of acidic deposition but the approach could be applied more broadly. The concept aims to define the maximum load of a given stress which will not produce adverse changes in soils - it could be applied to physical loading, pollutant inputs or fertilizer inputs; it has much in common with 'maximum permissible loads' calculated for heavy metal inputs in sewage sludge.

The critical load approach provides a means of linking controls on the load of given stresses to soil protection by cause-effect models. The approach requires mathematical models; the necessary models are only available for a few stresses.

1.13 ACIDIFICATION

1.13.1 Introduction and background

The concepts and principles outlined in sections 1.7 to 1.12 will now be examined with respect to one form of soil degradation.

Acidification is seen as one of the major, current threats to soil quality in northern Europe; or, expressed differently, it is seen as one of the main forms of soil degradation. Acidification of soils is, however, a natural process and acid soils have dominated large areas of Britain for hundreds, in some cases, thousands of years. In the context of soil degradation, the concern is with any increase in the rate of acidification as a result of man's activities. The particular focus of recent concern is the possible increase in the rate of acidification resulting from acid deposition; the rate of acidification can, however, also be increased as a result of land management, e.g. additions of fertilizers (Rowell & Wild 1985), replacement of deciduous woodland, or grassland, with exotic conifers (Hornung 1985), drainage of acid sulphate soils, removal of base cations in crops. The discussion of acidic deposition and its impacts concentrates mainly on regional changes in rainfall acidity and its effect on soils but there can be more dramatic local effects close to sources of emissions of acidifying pollutants (Killham & Wainwright 1984).

Over the past few years, a number of studies have been published from West Germany, Austria, Switzerland, Czechoslovakia and Sweden which show an unexpectedly large decline in the pH, and/or base saturation of forest soils over the last 10 to 50 years (Berdên et al. 1987). The results of such studies must be interpreted with caution because, as noted above, the observed increases in soil acidity could result from a number of causes. Thus, Berdên et al. (1987) suggested that, in a number of cases changes in land use or in forest stand age are the dominant cause. Hallbäcken and Tamm (1986) suggested that increases in the acidity of subsoil horizons are most likely to be due to the effects of acidic deposition while changes in surface horizon pH can result from forest growth and changes in land use, as well as from the impacts of acid deposition. Berdên et al. (1987) concluded, after reviewing a large volume of data, that in many of the reported instances "both biological acidification and acid deposition should be invoked as important causes of observed declines in soil pH."

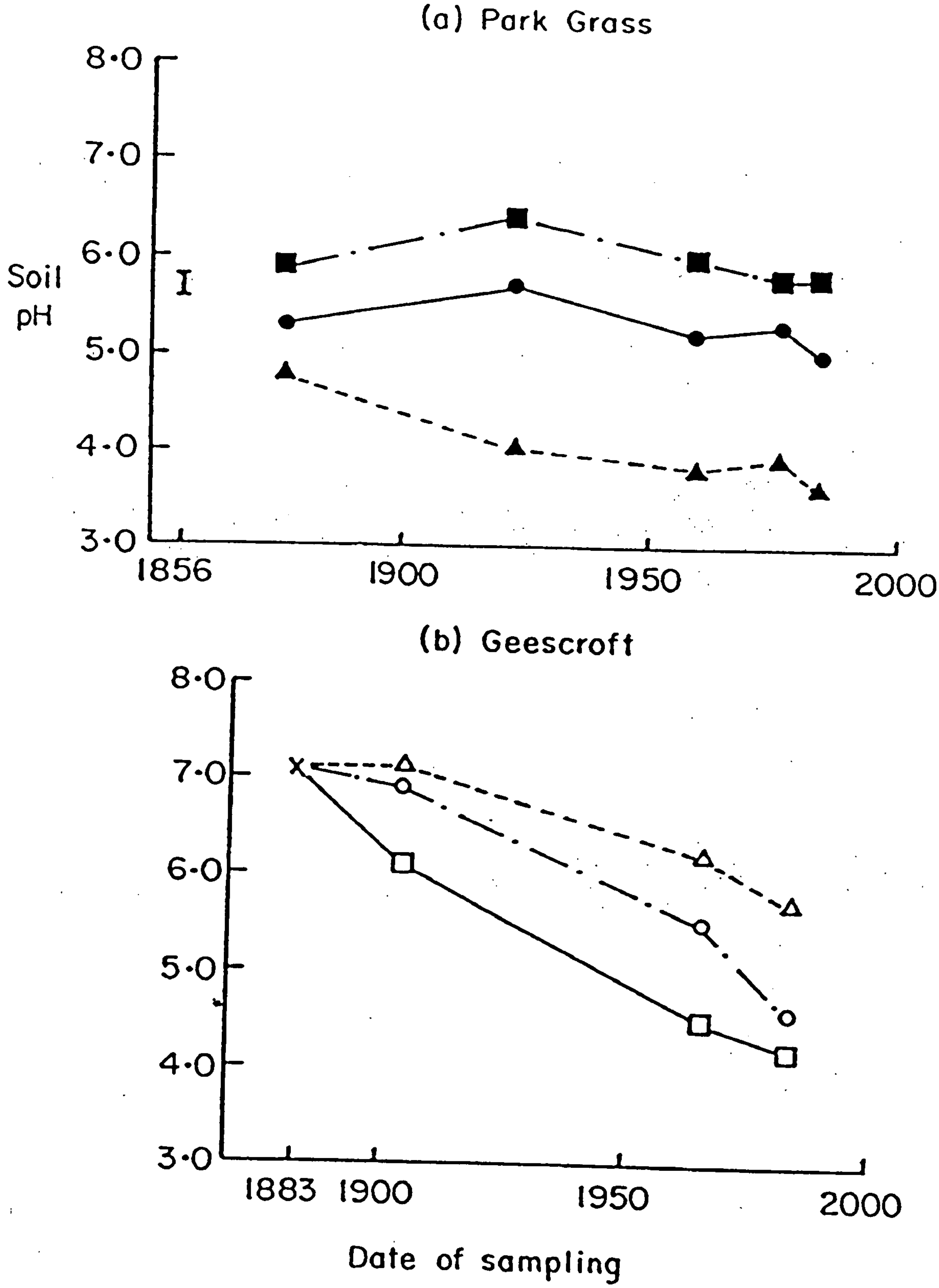


Figure 7. The pH of soil samples taken at various times from (a) the surface (0-23 cm) horizon of the Park Grass Experiment. ● Plot3; unmanured; ▲ Plot 9, ammonium - $N_2PKNaMg$; ■ Plot 14, nitrate - N_2 PKNaMg; (b) three horizons from the Geescsoft Wilderness: □ 0-23 cm, △, 23-46 cm, ○, 46-69 cm. (From Johnson *et al.* 1986).

A number of studies have examined the acidification of soils in the UK. Thus, Page (1968), Grieve (1978), Williams et al. (1979), Hornung and Ball (1972), Thompson and Loveland (1985) have shown a reduction in surface soil pH as a result of afforestation with exotic conifers. Johnston et al. (1986) have discussed changes in soil acidity at long term experimental sites at Park Grass and Geescroft, Rothamsted, over a 100 year period. At Park Grass, application of NH_4 fertilizer plus P, K, Na and Mg resulted in a decline in pH from c. 4.9 to 3.8 over 100 years. The main acidification here results from production of protons during conversion of the ammonium to nitrate. At the Geescroft Wilderness site there has been a reduction in surface soil pH from c. 7.0 to c. 4.3 since it was taken out of arable agriculture, and during the subsequent natural development of deciduous woodland (Fig. 7). While the acidification was primarily a result of the change in land use and vegetation, the authors calculate that atmospheric deposition currently accounts for at least 30% of the proton input to the soil. Killham and Wainwright (1984) have shown a marked increase in soil acidity downwind of a coking plant and Gorham et al. (1984) showed that the pH of blanket peat soils in the Pennines increased away from the industrial areas of south Lancashire, suggesting that pollution had produced enhanced acidification close to the main source areas. A similar relationship between the pH of blanket peat and atmospheric inputs of acidity and sulphate has also been shown in Scotland by Skiba et al. (In press). Billett et al. (1988), however, concluded that changes in ground vegetation and tree canopy were the key factors controlling the changes in pH of 14 soils, including podzols, brown soils, gleys and peats, over a 40 year period in north east Scotland but the authors also add that "some effects of acid depositon cannot be ruled out."

The impact of acidic deposition on soils and processes in the UK has recently been reviewed by the UK Terrestrial Effects Review Group (1988): the main conclusions of the review are given in the Annex.

1.13.2 Soil quality in relation to acidification

It is possible to identify the index parameters to be used to define soil quality in terms of acidity but it is not possible to assign single index values to those parameters. The index parameters would be base saturation and soil pH. The index values of those parameters can, however, be fixed only with reference to specific land uses, crops or plant species. Thus, soil pH, and base saturation, vary naturally between soil types and plant species have adapted to grow optimally within a given range of pH. Soil pH and base saturation for optimal production of wheat, potatoes, clover, for example can be defined; similarly, the soil pH and base saturation associated with a wide variety of natural species can be defined.

The pH and the base saturation, of naturally acid soils are commonly adjusted, i.e. increased, with additions of lime if the soils are used for intensive agriculture. Thus, Thompson and Loveland (1985) found that mean pH of Manod series brown podzolic soils in Wales were 5.4 (± 0.8) under agricultural use and 4.4 (± 0.4) under broadleaved woodland. The pH of a given soil under the natural or semi-natural vegetation could be taken as the definition of soil quality of that particular soil, e.g. the broadleaved woodland in the example quoted from Thompson and Loveland (1985). However, in much of Britain, the soils under natural or semi-natural vegetation have been influenced by acidic deposition and/or past management. It is also important to remember that the pH of such soils under natural or semi-natural vegetation changes naturally with time.

Comparison of agricultural soils with the same soil type under semi-natural vegetation frequently shows the agricultural soil to have a higher pH. Thus, soil quality, in terms of pH, could be said to have been improved following liming and conversion of acid moorland to pasture, for example; the soil is certainly improved from the point of view of ryegrass and clover production but it has deteriorated from the point of view of heather growth. The pH of the soil at the Geescroft Wilderness has declined dramatically since natural vegetation was allowed to invade. But this is only a reduction in soil quality with respect to the production of cereals. The concept of soil quality does not appear useful, with respect to soil acidity unless related to a given crop, vegetation community or use of soil.

1.13.3 Acidification as soil degradation

i. Assessment of the present level of degradation

The index parameters for assessment of acidification would be, as noted under soil quality, base saturation and pH. Assessment of current levels of degradation poses similar problems to fixing index values for assessing soil quality. The assessment of the current level of degradation by acidification can only be done with reference to a given baseline or benchmark. Comparison of base saturation and pH of managed soils with those of soils under natural or semi-natural vegetation can be used in some situations. For example, pH and base saturation data from beneath conifer plantations and adjacent deciduous woodland, or grassland, on the same soil parent material can be used to assess acidification resulting from the planting of conifers (see above). Thus, Hornung and Ball (1972) report a reduction in pH of up to 0.7 units in the surface horizon of a brown podzolic soil 25 years after afforestation with Sitka spruce. On a regional scale, Thompson and Loveland (1985) found that the mean pH of the surface horizon of Manod Series brown podzolic soils in Wales was 4.8 under rough grazing, and 4.0 under coniferous woodland.

Comparison of the current pH and base saturation of soils with historical data from the same sites provides an alternative approach. Thus, Hallbäcken and Tamm (1986) resampled podzols under forests in Sweden some 55 years after the initial sampling and found reductions of the pH in the Ao horizon of between 0.33 and 0.87 units, and of the C horizon of between 0.51, and 0.71 units.

Where there are high local inputs of pollutants from specific sources, the impact of the pollution can be assessed by comparison of soils from within the pollutant zone with nearby, similar unpolluted soils. Thus, Killham and Wainwright (1984) report that surface soil pH was more than one unit lower downwind of a coking plant near Rotherham than in similar, nearby less polluted soils. Similarly, Martin and Coughtrey (1987) showed enhanced soil acidification at a site downwind of a smelter near Bristol. The study, by Skiba et al (1989) of the variation in the pH of upland peats in Scotland with atmospheric inputs of H^+ and SO_4 is an example of a similar approach but on a regional scale.

ii. Rates of acidification

The assessment of rates of acidification should be based on variation in base saturation and/or pH with time. The FAO guidelines suggest that acidification rates are given in % decrease in base saturation per year (FAO 1979). Assessment of rates can be made by repeated sampling of a given site over time. The Scandinavian studies on acidification of forest soils during the last 50 years, or less, and the studies at Park Grass and Geescroft, Rothamsted, are examples of this type of study. In the case of Hallbäcken and Tamm's (1986) Swedish study, the rate of acidification of the surface soil was, therefore, c. 0.5 pH units/55 years. The data from Geescroft (Johnston et al. 1986) show a reduction in pH of the 0-23 cm layer of c. 1.0 unit over the first 20 years following cessation of cultivation, 1.75 units over the next 60 years and 0.2 units over the last 20 years; the rate of acidification has, therefore, declined from c. 0.5/10 years to c. 0.2/10 years. At Park Grass (Johnston et al. 1986), fertilization with ammoniun-N (plus P, K, Na and Mg) resulted in a decline in pH in the 0-23 cm layer of something over 1 unit in 100 years.

Transfer of soils between sites can be used to assess the rate of acidification due to pollution. Thus, Killham and Wainwright (1984) transferred soils from an unpolluted site and placed them downwind of a coking plant, and below the main plume of pollutants; the pH of the surface soil dropped from 4.9 to 3.9 over a 30 month period.

As noted in the introduction to this chapter, in any assessment of the rate of degradation (acidification) due to one particular cause, eg acidic rain, the effects of other causes, e.g. natural acidification and/or land use effects, must be subtracted. It is also important in such studies, or monitoring exercises, that methods are standardised and carefully documented, and that sites are permanently marked or logged. A national network of monitoring sites which will be used to assess any long term soil degradation, or changes in soil quality, over time (e.g. National Swedish Environmental Protection Board 1985) is being established in Sweden, Norway, West Germany and France. In all these countries, the monitoring sites are under natural and semi-natural vegetation. Such a series of sites in Britain would provide valuable benchmarks.

iii. Risk of acidification

The concept of 'risk of acidification' is very similar to that of sensitivity to acidification. A number of models to predict sensitivity of soils are discussed later in this chapter. In both cases the 'risk', or 'sensitivity' should be evaluated with respect to a given threat.

The risk of acidification of soils will depend on soil type, land and soil management, atmospheric inputs, changes in vegetation and a number of internal soil factors. The main soil factors controlling the risk of acidification by acidic deposition are the content of carbonate and readily weatherable silicate minerals, base saturation, cation exchange capacity anion adsorption capacity, and texture, mainly clay content. Cation exchange capacity is highly correlated with texture and organic matter content. The most sensitive soils to acidification are those with a moderate base saturation but a low cation exchange capacity; these soils will usually be derived from coarse grained acid igneous rocks, sandstones or grits, and will be coarse texture. Soils containing carbonates and high contents of pyroxenes, olivines, and amphiboles are not normally sensitive.

The FAO guidelines on the assessment of soil degradation (FAO 1979) use the excess of precipitation over potential evapotranspiration, (i.e. moisture available for leaching = leaching potential), texture and base saturation in a parametric model to predict risk. The FAO model essentially ranks soils in terms of their risk of natural acidification, although the parametric model can include a 'management' factor which could be used to incorporate the influence of fertilizers and or base cation removal in crops. The model could be readily applied in the UK. Climatic data are available for the whole of Britain thus enabling the calculation of leaching potential, and data on soils held by the SSLRC, and others, include information on texture and base saturation. The FAO (1979) guidelines suggest a scoring system for the individual factors, the individual scores being summed to determine a potential rate of reduction in base saturation (cf. section 1.8.3). A more comprehensive model would include the other soil factors noted above, i.e. content of carbonates and anion, particularly sulphate, adsorption capacity.

The risk of acidification as a result of oxidation of sulphides in the soil material, i.e. the risk of creating acid sulphate soils, is controlled by the mineralogy of the soil forming material and land management. Susceptible parent materials are marine and lacustrine clays containing sulphides; oxidation of these minerals, with the production of sulphuric acid, results from drainage of the sulphide containing horizons. The occurrence of the high risk soils has been investigated and maps of this occurrence are available for parts of the UK, e.g. Burton and Hodgson (1987).

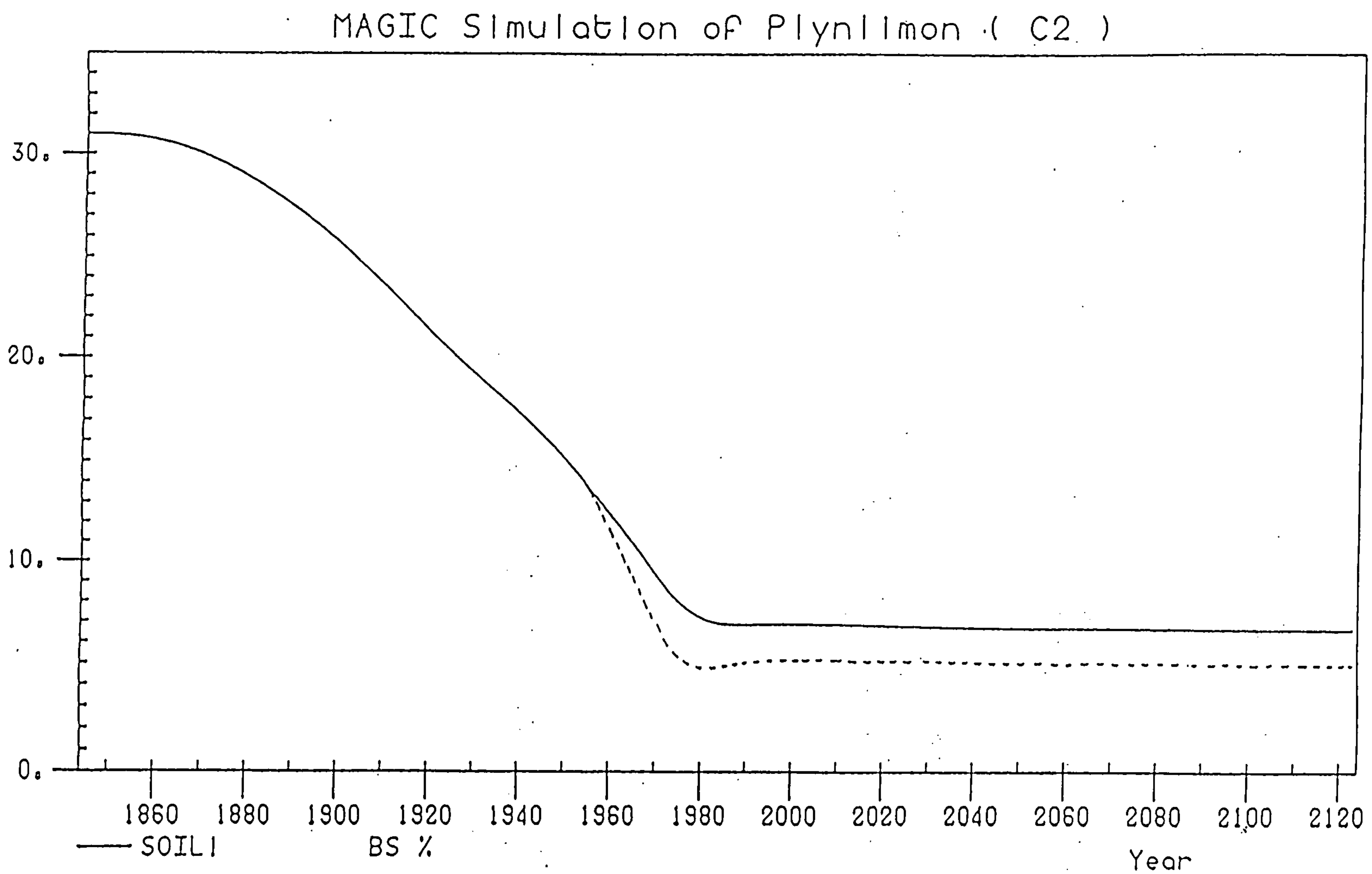


Figure 8. Changes in base saturaturation of stagnopodzol B horizons at Plynlimon, mid-Wales predicted using the Magic model. Moorland constant rate of deposition of pollutants ——— Forest constant rate of deposition of pollutants - - - - - - -

iv. Predicting rates of acidification

A number of mathematical models are now available which enable broad predictions to be made of rates of acidification of soils by acidic deposition. The MAGIC (Cosby et al. 1985) and ILWAS (Chen et al. 1983) models were primarily developed to describe and predict acidification of surface and groundwater. The MAGIC model contains a soil sub-model which can be run separately to determine future trends in base saturation under given loads of atmospheric deposition. The model requires data on soil depth, porosity, bulk density, cation exchange capacity, base saturation, exchange of sulphate with water in the soil,hydrogen ion concentration, weathering rates, selectivity coefficients for Al, Ca, Na, Mg and K, and partial pressure of CO_2. The processes on which the model is based are:

- anion retention by catchment soils (e.g. sulphate adsorption)
- adsorption and exchange of base cations aluminium by soils
- alkalinity generation by dissociation of carbonic acid (at high CO_2 - partial pressures in the soil) with subsequent exchange of hydrogen ions for base cations
- weathering minerals in the soil to provide a source of base cations
- control of Al^{3+} concentrations by an assumed equilibrium with a solid phase of Al(OH).

The soil sub-model was developed largely by Reuss and is discussed in Reuss (1980) and Reuss and Johnson (1986). The current version of the model considers only one soil horizon but a new version, now being developed, will incorporate two horizons. The model has been used to examine temporal changes, both historic and predicted for the future, in base saturation in south west Scotland and central Wales (e.g. Fig. 8) (Cosby et al. 1986, Whitehead et al. 1988). The model suggests a sharp decline in base saturation of ferric stagnopodzols in mid-Wales, from 30% to c. 10%, between 1880 and 1980 (Fig 8), followed by a very gradual decline to c. 7% between 1980 and 2120 (assuming continuing pollutant inputs at 1980 levels). The soil data required as input to the model are not routinely available from data such as those provided by soil surveys. To date, the model has been applied to sites which are being used for intensive experimental studies; even at these sites, data are rarely available on weathering rates or CO_2 partial pressures although these parameters are major controls on rates of change of base saturation.

The ILWAS model can accommodate any number of soil horizons but the soil processes modelled are similar to those contained in MAGIC. Few UK sites have the mass of input data required to run this model but it is currently being applied to soils in north Wales.

A group at the International Institute for Applied Systems Analysis (IIASA) has developed a model specifically designed to predict changes in soil pH. The theoretical basis of the model has been discussed by Ulrich (1981, 1983); when the total acid input exceeds the silicate weathering rate it is buffered by ion exchange and/or aluminium dissolution. The ion exchange part of the model is adapted from Reuss (1983) and has, therefore, similarities with the ion exchange section of the MAGIC model; the data inputs to the model are also similar to those listed above for the MAGIC model. The main weaknesses of the model are that (i) it assumes the soil is homogenous, ie comprises one horizon, and (ii) biological processes are ignored. Also in common with the current version of MAGIC, aluminium dissolution is assumed to be controlled by gibbsite equilibria.

The Trickle-Down model (Schnoor 1984) also has similarities with the soil submodels of both MAGIC and ILWAS but, like the IIASA model, was designed specifically to assess impacts on soils.

Bloom and Grigal (1985) have produced a simpler model but one which shares some basic principles with the other models discussed above. The model is designed specifically to predict trends in soil pH and base saturation under given inputs of acid deposition. The model developed by Bloom and Grigal (1985) requires the following soil data as input:

- pH
- sum of bases in the soil
- cation exchange capacity
- partial pressure of CO_2 in the soil atmosphere.

The model also requires data on precipitation inputs and chemistry and evapotranspiration. A major weakness in this particular model is the assumption that sulphate is not adsorbed in the soil. An advantage, however, is the model's basic simplicity, the authors designed it for use by planning or regulatory agencies and based it on readily available data. However, data on partial pressure of CO_2 is rarely available; the requirement for this data is also a problem with all the models discussed above.

Tipping and Hurley (1988) have developed an ion exchange model, CHAOS (Complexation by Humic Acid in Organic Soils), for organic-rich soils and peats which can be used to assess the impact of acidic deposition on these types of soil. The soil inputs to the model are:

- total humic substances
- total aluminium
- total base cations
- total strong acid anions
- water content

The CHAOS model is soon to be incorporated in the MAGIC model. CHAOS is being used to provide an alternative to the Reuss soil submodel for use with organic soils. This development will be valuable for work on many British upland soils.

The models discussed above were developed to assess the impacts of acid deposition. The soil component of the MAGIC, ILWAS and Trickle-Down model could, however, be adapted to assess the impact of changes in land use or management, e.g. afforestation or use of nitrogen fertilizers, on base saturation. Thus, simulations using the MAGIC model predict a c. 2% reduction in base saturation of ferric stagnopodzols as a result of afforestation of a moorland site in mid-Wales. The use of the models in this way is, however, limited by the poor handling of biological processes, particularly N cycling, and by inadequate data on changes in occult inputs following afforestation and on rates of sequestration of base cations in the tree crop.

1.13.4 Buffering capacity and resilience

The major soil factors which control the ability of soils to buffer raised 'inputs' of acidity, over and above natural 'inputs', are base saturation, cation exchange capacity, content of carbonate and readily weatherable silicates and sulphate adsorption capacity. Ulrich (1981) has grouped soils into 5 classes on the basis of the main mechanism responsible for buffering

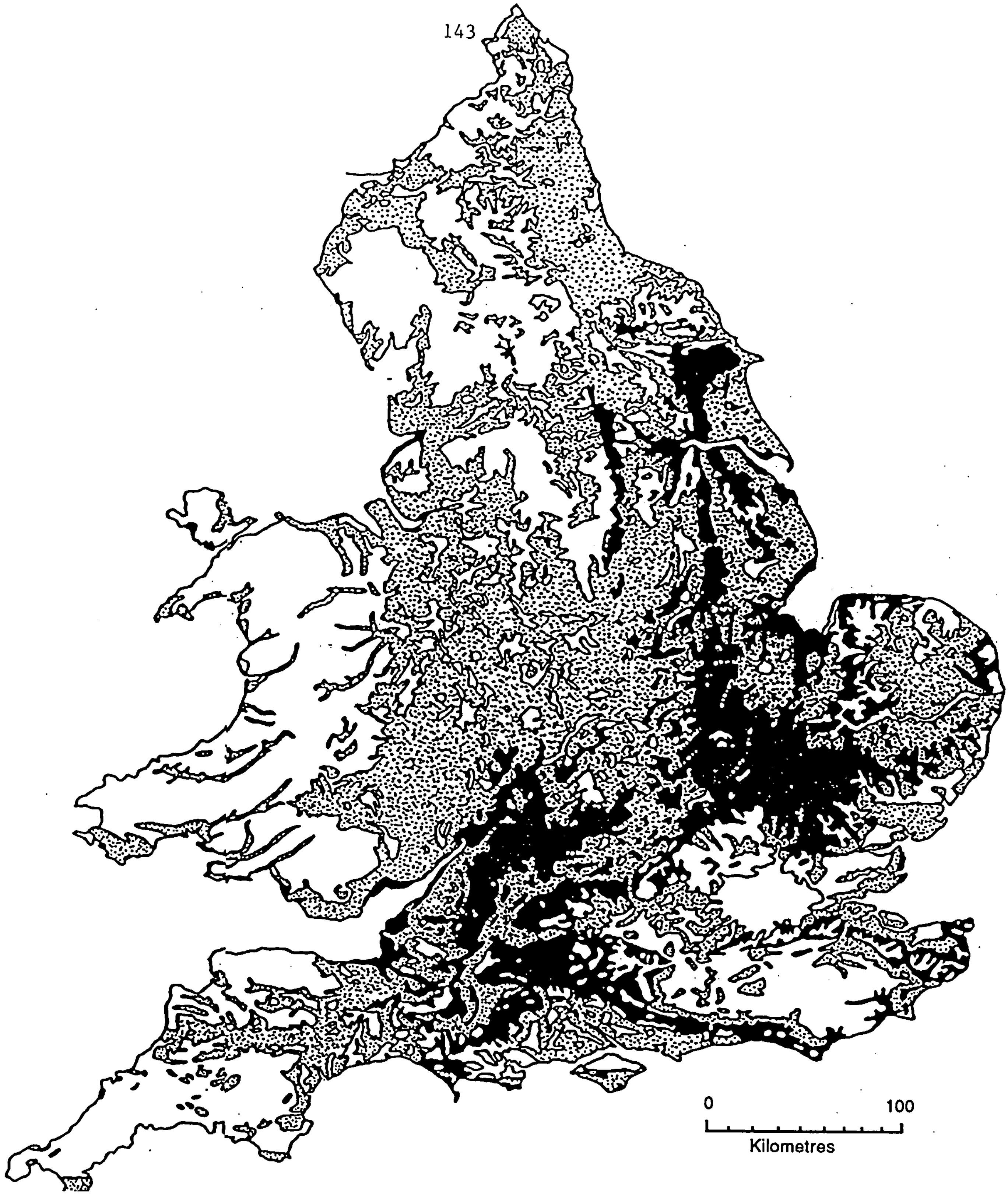


Figure 9. Distribution of soils in England and Wales which have large (black), moderate (stippled) and little or no (white) neutralising capacities.

acidity - (i) carbonate solution, (ii) silicate weathering, (iii) ion exchange, (iv) Al buffering and (v) Fe buffering. In general, soils in the ion exchange group are more sensitive to rapid acidification than those in the other groups. Very acid soils, buffered by aluminium mobilization, show relatively slow changes in pH and base saturation in response to increased acid inputs.

Catt (1985) has produced a qualitative classification of the soils of England and Wales into three neutralizing capacity classes (Table 13) on the basis of the base saturation of the subsoil, and has produced a map showing the distribution of soils with large, moderate, and little or no neutralizing capacity in England and Wales (Fig. 9). The boundaries on the map are based on the 1:250 000 soil map of England and Wales. Catt (1985) calculated that soils with little or no buffering capacity, i.e. with base deficient subsoils, occupy 37.7% of England and Wales, mainly in the uplands of the west and north.

Meiwas et al. (1986) have discussed parameters which can be used to evaluate the elasticity (resilience) of a soil system. They suggest that two types of chemical parameters require consideration: (i) those which are temporarily less variable (capacity parameters, e.g. contents of exchangeable cations or salts such as $CaCO_3$), and (ii) those which are more variable in time (such as soil pH or ion ratios in the soil solution). The authors suggest the latter parameters can only be used as elasticity parameters in conjunction with capacity parameters. In the context of acidification, the elasticity parameters of relevance will be those which can lead to the buffering or loss of protons without causing any significant change in the chemical status of soils (Meiwas et al. 1986).

The parameters proposed by Meiwas et al. (1986) are:

- soil pH
- base neutralizing capacity
- exchangeable cations
- cation exchange capacity
- soil solution chemistry (extract from soil paste)
- humus chemistry - C, N, P, Ca, Al
- fine root chemistry (specifically Ca/Al ratio).

Table 13. Soil buffering classes (Catt 1985); terminology based on the soil classification of Avery (1980)

Soils with little or no neutralizing capacity.	Holocene podzols; deeply weathered palaeo-argillic soils, thin rankers on non-calcareous Paleozoic rocks; brown earths on silicious gravels; gley soils on non-calcareous or pyritic clays and shales; raw bog, basin and blanket peat soils.
Soils with moderate neutralizing capacity.	Non-calcareous pelosols; brown earths on base-rich materials; gleys soils on non-calcareous clay; fen peats.
Soils with large neutralizing capacities.	Little weathered soils on Holocene marine clays and calcareous sands; rendzinas; calcareous pelosols; brown calcareous earths; calcareous gleys formed during the Holocene or calcareous sediments.

Table 14. Classification of pH, the content of exchangeable cations, and their equivalent contribution (X^s) to the exchange capacity (CEC_e) as measures of the elasticity of soils, with respect to acid toxicity and the supply of K and Mg to tree species tolerant to acidity (for $CEC_e > 5$ µeq g^{-1} soil) (From Meiwas et al. 1986)

Toxicity due to acid	pH_{H_2O}	$X^s_{Ca} + X^s_{Mg}$	$X^s_H + X^s_{Fe}$	X^s_{Al}	$X^s_K \; X^{s\,2}_{Mg}$	Elasticity
Unlikely	>5.0	> 5.0	< 0.02	< 0.3	> 0.4	very high
Possible	4.2-5.0	0.15-0.5	< 0.02	0.3-0.6	0.02-0.04	high
Probable	3.8-4.2	0.05-0.15	< 0.02	0.6-0.8	0.01-0.02	low
Highly probable	<3.8	< 0.05	0.02-0.05	> 0.8	< 0.01	very low

Table 15. Base saturation of the O_H horizon of the humus layer as a parameter of elasticity for acidification (From Meiwas et al. 1986)

$\frac{Ca}{Ca+Al+Fe}$ (eq)	Likelihood of acid toxicity
0.1	Very little likelihood of acid toxicity for fine roots and mycorrhizal fungi
0.05-0.1	Medium likelihood probably leading to increased rate of turnover of fine roots
0.05	High likelihood of acid toxicity during the growth and activity of fine roots.

The authors then provide indicator values for each parameter to be used in assessing the elasticity of the soil system towards acidification, e.g. Tables 14 and 15.

The approach is designed for use with forest soil systems and aims to identify situations where the soil is unable to buffer any increase in acidity and where forest growth will be affected. It is empirically based but the indicator values correlate well with the decline in productivity of spruce stands in West Germany in acid impacted areas.

1.13.5 Sensitivity of soils to acid deposition

The assessment of the sensitivity of soils is very similar to the evaluation of the risk of acidification. Several schemes have been proposed for classifying the sensitivity of soils to acidic deposition, e.g. Wiklander 1974, McFee 1980, Wang and Coote 1981, Nolan et al. 1984 (Tables 16 and 17). These classifications are based on a combination of carbonate content, cation exchange capacity, base saturation, clay content, pH and frequency of flooding. Most of the classifications are qualitative and produce a simple ranking of soils in terms of their sensitivity to acid deposition. Wiklander (1974) and Wang and Coote (1981) ranked soils in terms of their sensitivity without any reference to the load of acid deposition. In contrast, McFee's classification (1980) is based on a specific annual input of H^+ ions. McFee (1980) has applied his classification to the production of a map showing the sensitivity of the soils in the United States to acid deposition. The constituent soil series of mapping units on 1:1 million soil maps are allocated to one of McFee's (1980) three sensitivity clases (Table 17). The map units are then allocated to one of the following 5 classes:

- NS the area contains mostly non-sensitive soils
- S1 sensitive soils dominate the area
- SS1 slightly sensitive soils dominate the area
- S2 sensitive soils are significant but cover less than 50% of the area
- SS2 slightly sensitive soils are significant but cover less than 50% of the area.

Table 16. Soil sensitivity ratings (after Wang & Coote 1981)

	Texture	Clay %	CEC (meq. l^{-1})	pH
		All calcareous soils		
Non-sensitive	Clayey	>35	25-40	>5.0
	Loamy	10-35	10-25	>5.5
Moderately sensitive	Clayey	>35	25-40	4.5-5.0
	Loamy	10-35	10-25	5.9-5.5
	Sandy	<10	2-10	<5.5
Sensitive	Clayey	>35	25-40	<4.5
	Loamy	10-35	10-25	4.5-5.0
	Sandy	<10	2-10	>5.0

Table 17. Sensitivity of soils to acid precipitation (After McFee 1980)

1. **Non sensitive areas (NS)**
   a. all soils with free carbonate in the top 25 cm.
   b. all soils subject to frequent flooding.
   c. all soils with an average CEC > 15.4 meq per 100 g in the top 25 cm.

2. **Slightly sensitive areas (SS)**
   areas not included in 1a or 1b, that have an average CEC, in the top 25 cm, of 15.4 - 6.2 meq per 100 g.

3. **Sensitive areas**
   areas not included in 1a or 1b that have an average CEC, in the top 23 cm, of < 6.2 meq per 100 g.

Nolan et.al. (1984) used a similar approach to that of McFee (1980) to allocate the mapping units on the 1:250 000 soil maps of Scotland to a series of susceptibility classes. There is no current assessment of the sensitivity of the soils of England and Wales to acid deposition but Catt (1985) has produced a map showing the distribution of soils in England and Wales within a range of neutralising classes (Fig. 9).

None of the above classifications incorporates a consideration of the sulphate adsorption capacity of soils. In some situations the bulk of the sulphate input from the atmosphere is adsorbed within the soil and is not available to 'drive' leaching and acidification of soils (Reuss & Johnson 1986); this adsorption is, in effect, a neutralising mechanism. Cresser and Edwards (1987) have stressed the importance of this mechanism in parts of Scotland and Jenkins et al. (1988) show the retention of atmospheric inputs of sulphate in a catchment based study in the Cairngorms. Nitrate inputs to nitrogen deficient ecosystems can also be retained by plant uptake, thus limiting leaching and acidification. On a regional basis, however, carbonate content and base saturation will be the major factors determining soil sensitivity while in individual soil-plant systems sulphate adsorption and nitrate retention may be determining factors.

1.13.6 Reversibility

The natural and ecological reversibility of acidification of soils is controlled mainly by the rate of production of base cations by weathering of soil minerals. This is related to the content of rapidly weatherable minerals within the near surface horizons of the soil and amount of such mineral surfaces available for weathering. There are no current classifications, qualitative or quantitative, of soils into classes of reversibility. However, conceptual models could be developed relatively easily on which a qualitative ranking of soils could be based.

The classification of soils, on the basis of mineralogy, used in assessing critical loads (Table 18) could form the basis of such a ranking. Thus, acidification of soils containing biotite, amphibole, pyroxene, epidote and olivine in the rooting zone will take place naturally if atmospheric inputs of acidity decline; or, if the inputs of organic fertilizer and/or base cation

Table 18. Mineralogical and petrological classification of soil material (From Nilsson and Grennfelt 1988)

Class	Minerals controlling weathering	Usual parent rock
1	Quartz k-feldspar	Granite Quartzite
2	Muscovite Plagioclase Biotite (< 5%)	Granite Gneiss
3	Biotite Amphibole (< 5%)	Granodiorite Greywakee Schist Gabbro
4	Pyroxene Epidote Olivine (< 5%)	Gabbro Basalt
5	Carbonates	Limestone Marlstone

Table 19. Critical load for forest soils (0 - 50 cm) (From Nilsson and Grennfelt 1988)

Class	Total acidity kmol (H^+) km^2 yr	Equivalent amount of sulphur kg ha^{-1} yr^{-1}
1	< 20	< 3
2	20- 50	3- 8
3	50-100	8-16
4	100-200	16-32
5	> 200	> 32

removal in crops are reduced. Reversibility of acidification could also be achieved ecologically on these soils, plus those containing muscovite and plagioclase by the planting of suitable species, e.g. birch (cf. Miles 1981).

Acidification of soils can almost always be reversed technologically by the application of neutralizing materials, e.g. lime (CaOH), limestone, chalk.

1.13.7 Critical loads

As noted earlier, the critical load concept has been developed in relation to acidification of soils, surface waters and groundwaters. The definition of 'critical load' will vary depending on whether soils or waters are being considered. However, Sverdrup and Warfvinge (1988) give the following broad definition, "the load to an ecosystem (of acidic deposition) which will not cause acidification of any part of the ecosystem, to such an extent that adverse effects to the ecosystem biology is caused". A recent workshop on critical loads endorsed an alternative definition, "A quantitative estimate of the loading of one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not likely to occur according to present knowledge" (Nilsson and Grennfelt 1988). In the present context, the "specified sensitive elements" would be soils.

A variety of approaches have been used to calculate critical loads. Nilsson (1986) suggested proton budgets while Sverdrup and Warfvinge (1988) have applied a mass balance for acidity, or for alkalinity. Sverdrup and Warfvinge (1988) suggest that a mass balance equation for acidity can be expressed as follows:

total acid deposition + cation bioremoval + N transformation acidity + increase in exchangeable bases = weathering + solution pool increase + outflux.

However, the critical load can only be evaluated at a steady state and under these conditions:

critical load = weathering-cation bioremoval - alkalinity output

The authors (Sverdrup & Warfvinge 1988) illustrated the calculation of weathering rate from (i) solute budget data and (ii) calculations from a

Table 20. Conditions influencing critical loads to forest soil (From Nilsson and Grennfelt 1988)

Factor	Decreasing critical load value	Increasing critical load value
Precipitation	high	low
Vegetation	coniferous	deciduous
Elevation/slope	high	low
Soil texture	course-sandy	fine
Soil drainage	free	confined
Soil/till depth	shallow	thick
Soil sulfate adsorption capacity	low	high
Base cation deposition	low	high

steady state soil chemistry model. Data from a number of catchment studies, providing weathering rates, has been extrapolated, using data on soil mineralogy, texture and moisture to produce maps showing regional variations in critical loads in Sweden. It would be difficult to produce similar maps for the UK at present but critical loads could be calculated for a number of individual sites.

As can be seen from the above equations, weathering rate is an important factor influencing critical loads. Weathering rate is, in turn, determined mainly by soil mineralogy. The recent workshop on critical loads classified soils on the basis of mineralogy and the petrology of the rocks of associated rocks (Table 18). Critical loads for forest soils were then given for the various soil classes (Table 19); these range from < 20 kmol(H^+) input km^{-2} yr^{-1} for soils dominated by quartz and potassium feldspars to > 200 for soils with free carbonates. It is also suggested that a number of factors may increase, or decrease the critical load of a given class (mineralogical) of soils at a given site (Table 20), e.g. coniferous forest will decrease critical load, deciduous forest will increase it. In a given soil class, the lower limit of the suggested critical load (Table 19) applies when one of the factors which 'decreases' critical load obtains, the upper limit applies when a factor which 'increases' critical load obtains. Although critical loads, using Sverdrup and Warfvinge's (1988) approach can only be calculated for a few UK sites, this simpler scheme can be readily applied.

1.13.8 Summary and conclusions

The available data from the UK suggest that the clearest examples of recent, enhanced rates of acidification are linked to changes in land management or use or to the local impacts of point sources of pollution. To some extent, this reflects the absence of suitable, historic regional data sets which can be used as a baseline against which to assess present levels of soil acidity. The data from the Park Grass and Geescroft studies at Rothamsted demonstrate the value of long term data sets and monitoring. A series of long term sites throughout the UK would provide a means of assessing long term changes in rates of acidification. In such exercises, however, natural increases in acidity must be differentiated from those due to acidic deposition, for example.

The use of the concept of soil quality with respect to acidity does not appear useful unless related to a given crop, vegetation community or use of soil. The assessment of the current level of degradation, with respect to acidity, is best applied in connection with the impact of local, point sources of pollution where soils outside the pollutant plume can be used as 'unacidified' controls or in the assessment of the effects of land use, e.g. afforestation. Historic data sets can also be used to assess degradation but there are problems separating the various causes of the acidification.

Qualitative models exist which can be used to rank soils in terms of their buffering capacity. These qualitative models can be readily applied to the soils of the UK. Catt (1985) estimated that c. 37% of the soils of England and Wales have little or no neutralizing capacity. Similar models are available for the assessment of the sensitivity of soil to acidification: such assessments should be related to specific 'threats', e.g. acidic deposition or land drainage. The SSLRC have identified areas of soils which are sensitive to acidification, or which are at risk of acidification as a result of oxidation of sulphides following drainage.

The reversibility of acidification is strongly linked to the capacity of soils to buffer acidity. Similar conceptual models can be used to predict natural reversibility; acidification can almost always be reversed technologically by application of liming materials.

Models exist to predict rates of acidification as a result of changes in atmospheric inputs. The required input data is only available from a few UK sites. In particular, data on sulphate sorption capacity, CO_2 partial pressure and weathering rates are rarely available. The models need improving to accommodate several soil horizons and to simulate biological processes.

The concept of 'critical loads' was developed in connection with assessment of the impact of acidic deposition. The most important soil parameter in assessing critical loads of acidic deposition is weathering rates. Critical loads based on the mineralogy of soil materials have been proposed by Scandinavian workers.

ANNEX: **Effects of acid deposition on soils**

1. Agricultural soils have a natural tendency to become acid and this is generally counteracted by applications of lime. Liming may also prevent acidification of drainage waters in upland pastures. Consequently, the role of liming practices must be carefully considered when formulating land use policies and management programmes.

2. It has only recently been recognized that unmanaged naturally acidic soils, such as the podzols of granitic catchments and upland peat, may be vulnerable to further acidification. The extent to which the acidity of upland peats has increased as a result of pollution is not clear but the potential exists for significant long term changes.

3. Certain geologically acid-sensitive soils in the UK are not fully saturated with sulphate, but others (podzols of north west Wales) have already become sulphate-saturated and further deposition of sulphate leads to increases in acidity and higher concentrations of aluminium in drainage waters. In some sites, the additional sulphate from acid deposition superimposed upon already substantial maritime-derived sulphate inputs may significantly alter the chemistry of terrestrial and fresh water ecosystems.

4. In general, the solubility of heavy metals in soils increases, with increase in acidity. In the context of acid deposition, the implications of their solubility for soil organisms, plant growth and freshwater quality in the UK have received little attention.

5. Large inputs of nitrogen from the atmosphere (in the form of NO_2, NO, NO_3^- and NH_4^+) may have a substantial impact on sensitive soils. Ammonia released to the atmosphere from animal urine and faeces may contribute significantly to soil acidification.

6. The planting of trees may increase the acidity of soils and drainage waters in the absence of pollutants because of:

   i. trapping of neutral salts from the atmosphere, especially in maritime climates;

ii. uptake of large amounts of nutrients;

iii. production of acidic litter horizons.

Such changes may be offset partly by changes in water flux through the soil.

7. Trees also appear to trap pollutants from the atmosphere more efficiently than shorter vegetation. Unless absorbed by foliage, these pollutants reach the forest soil as throughfall and stemflow. Coniferous species tend to increase the acidity of the rainfall whereas hardwood species (in leaf) tend to partially neutralize rainfall acidity.

8. Soil organisms (both micro-organisms and soil fauna) are important in the maintenance of soil fertility especially by converting nutrients into forms suitable for plant uptake and by controlling soi organic-matter content. In general terms, the more acid the soil the less diverse and less active are the soil organisms.

9. Long term changes in soil pH may reduce the rate of litter decomposition and subsequent release of nutrients.

10. Increased soil acidification may also damage the mycorrhizal relationship between certain fungi and the fine roots of forest trees, either directly or by the mobilization of toxic heavy metals.

11. In managed agricultural soils, farm practices are designed to provide nutrients as fertilizer and to counteract acidity by liming. The activity of soil organisms is thus of less importance than in natural, unmanaged lowland and upland forest soils which are consequently considered to be most at risk.

1.14 THE SCIENTIFIC AIMS AND PRINCIPLES OF A SOIL PROTECTION POLICY

1.14.1 The context of a policy

The scientific aims and principles of a soil protection policy are closely linked to the underlying rationale and philosophy of that policy. The use of the term 'soil protection' implies a certain approach and philosophy.

The term is currently used in mainland Europe to indicate a broad protection of soils which is not linked to any particular end use. In this sense it differs from earlier soil conservation policies and legislation which aimed to ensure the maintenance of the production potential of soils, mainly for agricultural and forestry use.

The stimulus for the broader approach, divorced from a particular end use seems to derive from a combination of practical and ethical considerations (cf. section 1.5). Thus:

i. mankind depends upon the existence of suitable soils for the production of food, raw materials and, in some areas, fuel;

ii. the area of fertile soils is limited and is being reduced as a result of increased urbanization and development of transport systems;

iii. the productive capacity of some soils is also being damaged by erosion, accumulation of heavy metals, and pesticides, and structural changes - some of which are the result of current agricultural practices;

iv. other uses to which man puts soils, e.g. as filters and buffers, sources of water, foundations, have assumed increasing importance - in some areas the ability of soils to perform these functions is under threat because of the build-up of nitrates, phosphates and organic pollutants;

v. the structure and appearance of the rural landscape reflects variations in the underlying soils - changes in these soils can lead to changes in vegetation, and hence the appearance of the landscapes, and in other linked components of the environment, e.g. surface and groundwaters;

vi. the soils of rural, semi-natural or natural ecosystems are under threat from regional pollution; the most dramatic examples are those linked to forest dieback in central Europe and to acidification of surface waters;

vii. soils contain a large faunal and floral population which are variably sensitive to pollutant impacts, cultivation, fertilizer inputs, for example - this flora and fauna forms a potentially valuable gene reservoir - representative soils require protection in the same way as plants, animals, birds and insects;

viii. the understanding of the processes and functioning of natural, undisturbed soils forms an essential basis to the assessment and prediction of the impact of man's activities on soils.

Present generations have responsibilities as 'stewards' of the natural environment, including soils, on behalf of future generations. The exploitation of these resources should not limit the ability of future generations to meet their own needs.

1.14.2 The importance of the definition of soil

Fundamental to any soil protection policy is the view taken, or the definition used of soil in that policy. In section 1.4 it was shown that soils are complex dynamic systems which comprise inter linked organic (living and dead) and inorganic materials, solid components, solutions and gases; they contain populations of fauna and flora; the organic, chemical and physical properties of soil vary both between soil types and within soil types at a variety of scales; soils are in a state of flux and development as a result of interlinked biological, chemical and physical processes which operate at a variety of timescales. Because of its complexity the soil system is able to perform a wide variety of functions (Table 1), these functions will vary between soil types but are characteristic of the soil. Because of the complex, interlinked nature of the soil system, alteration of one component of the system will lead to changes in the other components. Soils also form parts of ecosystems, which comprise (i) a biological community composed of populations of plants, animals (including man), and micro-organisms, and (ii) its environment of physical and chemical factors. If another part of the ecosystem is modified e.g. vegetation, this will lead to changes in soil.

1.14.3 The overall aims of the policy

Soil protection implies, therefore, protection of a complex dynamic, heterogeneous system: it aims to maintain the complexity, the dynamic nature and the variability within and between soils; it aims to ensure that soils can continue to function as systems. Protection of soils does not aim to prevent natural changes, the natural development and evolution of soils. Neither could it aim to protect soils against all man induced changes in soils. Any utilization of soils by man results in some change in the soil system. The aim of soil protection is, rather, to protect soil systems from adverse and undesirable changes resulting from man's activities and influences. It also aims to protect all soils from these changes not just those currently being directly utilized, e.g. in agriculture, by man.

However, a policy based solely on the 'prevention of adverse changes in soils' would be too restrictive. Areas of soils exist which have already suffered 'adverse changes' and man's activities will inevitably produce some 'adverse changes' in the future, e.g. as a result of construction or of extraction of minerals. The policy should, therefore, also be concerned with restoration of damaged soils, and with the reversal of 'adverse changes' in soils. The policy would, therefore, need to aim to prevent or reverse adverse man-induced changes in soil systems.

The prevention of adverse changes can be seen as the mirror image of the maintenance of 'good soil quality' (section 1.7) - the central aim of the Dutch soil protection policy. Protection of soils against 'adverse changes' also has similarities to prevention of 'soil degradation' (section 1.8), another widely-used concept in the discussion of soil protection and soil conservation. The overall aims of a soil protection policy could, therefore, be expressed as: (i) the prevention, and where necessary the reversal, of adverse, man-induced changes to soils; (ii) the maintenance, and where necessary the restoration, of good soil quality; (iii) the prevention, or where necessary the reversal, of soil degradation. Scientifically, there is little difference between the three approaches, all three could form the basis of a similar policy. In fact, the Dutch approach to setting soil quality reference values arose from the need to set standards for cleaning contaminated soils.

Problems could arise, however, if a soil protection policy was based on 'the prevention of soil degradation' because of connections implicit in the use of the term 'soil degradation'. It has come to be linked with the maintenance of the productive potential of soils for agriculture and forestry. This is not implicit in the term but has become its accepted useage. As soil protection has broader aims and is not use-oriented the use of 'prevention of soil degradation' as the main aim of the policy could lead to a misinterpretation of the aim; it could be seen as linked to productive potential. In addition, current concerns with leaching of nitrate, organic pollutants and phosphate from soils to groundwaters are not considered in discussions on degradation, e.g. Yassoglou 1987.

1.14.4 Definition of the aim

However the main aim of a soil protection policy is expressed, the terms used need definition. Thus, 'adverse changes', or alternatively 'soil quality' requires definition within the context of the policy. The terms can be defined qualitatively but the ultimate aim should be to derive quantitative definitions.

Moen et al. (1986) have given the following qualitative definition: 'good quality soil' is soil which:

- poses no harm to any use by human beings or animals
- can function without restriction in natural cycles
- does not contaminate other parts of the environment

An alternative definition is provided by UNECE (1987); it is soil which:

- has a varied and active flora and fauna, a typical structure for its situation, and an unimpaired capacity for decomposition

- allows the vegetation, natural or cultivated, to develop normally

- guarantees vegetable products of good quality, and which do not not adversely affect the health of man or animals

Using a similar approach, adverse changes to soils could be defined as changes which:

- result in soils, or crops grown on them, forming a potential danger to human beings or animals

- prevents the soil carrying out its characteristic functions

- prevent the normal growth of vegetation

- result in contamination of linked components of the environment

- restrict the natural cycling of elements

As noted above, a soil protection policy would, ideally, include quantitative definitions of 'soil quality', or of 'adverse changes' (or, conversely, acceptable levels of change). The problems involved in the quantitative definition of soil quality have been discussed earlier (section 1.7); these problems arise from the natural heterogeneity and complexity of soils. There is no single parameter which can be used to define 'soil quality' or 'adverse changes'. A series of reference parameters are needed which will assess the biological, chemical and physical properties, process and functions of soils. However, even given an agreed series of parameters, there is no single set of reference values for these parameters which will define 'quality' or 'adverse'; this is because of the natural variability between and within soils and the variation in the impact of given stresses on soil processes and functioning. The reference values can really be set only with respect to a given end-use, to the ability of soils to perform various functions or to the operation of certain soil processes. Soil protection policies are, however, broadly based and aim to ensure that soils can continue to perform all their characteristic functions and would be available for a wide variety of uses. A quantitative definition of soil quality which is relevant to several functions or uses will be possible for only a few parameters, e.g. toxic heavy metals.

An alternative approach to the qualitative definition of 'adverse change' would be:

i. changes in soils which cannot be reversed naturally or by ecological approaches (section 1.11)

ii. changes in soils greater than those which occur naturally as a result of natural variations in other environmental factors, e.g. climate.

These could also form the basis of a quantitative definition but would require evaluation by a series of reference parameters. As noted above, there would be no one reference value for each reference parameter but in (i) the datum could be values for the reference parameters in undisturbed, natural soils. It would also be necessary to determine the magnitude of change in the parameters, for particular soils, which can be reversed naturally, or ecologically; or, in (ii) above, the range of variation in the index parameters which occur as a result of natural environmental variations. Domsch (1984) has discussed the approach represented by (ii) with respect to the impact of pesticides and heavy metals on soil flora and fauna. It is not possible, currently to define the limits of change of most reference parameters which are naturally reversible, or are within the range resulting from environmental variation. However, it is possible in some cases to identify qualitatively changes which are not reversible naturally, e.g. the accumulation of heavy metals, or to identify land/soil uses which produce a range of changes which are not reversible naturally, e.g. construction, extraction of minerals, disposal of certain wastes. A soil protection policy would seek to avoid or restrict activities which produce irreversible changes, and to restore the soil, by technological means, if the particular use ever ceased.

1.14.5 The elements of a soil protection policy

Bearing in mind that the achievement of these aims will be governed by the extent to which the magntude of each threat (a) can be assessed, and (b) is perceived to warrant the investment of the necessary resources, the implementation of a soil protection policy requires:

i. a characterization and assessment of the soils of the UK and their current status

ii. monitoring of changes in soils over time

iii. assessment of the impact of man's activities on soils, particularly the impact of changes in land use and management

iv. definition of acceptable loads of man-induced stresses and means of controlling those stresses

v. development of alternative management methods and techniques to reduce the impact of man's activities on soils

vi. definition of target values of soil parameters to be used in rehabilitation of damaged soils.

<u>Characterization and assessment of the soils of the UK</u>

Implementation of any soil protection policy will require basic information on the soils of the UK, their characteristics and distribution; that is, a characterization and definition of what is being protected. Such a data base forms the essential baseline for evaluation of the present status of the soils of the UK, detection and evaluation of future changes in soils, and for the evaluation of the impact of mans' activities, present and future, on soils. The information included in the data base and its resolution will vary with the particular application, e.g. a national assessment and evaluation as opposed to a local, more detailed appraisal. The national data base will enable impacts to be assessed nationally and information from detailed local studies or at a limited number of sample sites to be extrapolated to provide a national overview. The data should include information on biological, physical, mineralogical and chemical properties and characteristics of the main soil types of the UK. The data should characterize the soils but also provide the basis for future impact assessments and evaluation at the national scale; the baseline data should not be limited to information required to assess currently-perceived threats to soils, but should permit an assessment of the impact of any stress. It should include information on parameters which permit an assessment of the functioning of the system; this will necessitate data pertaining to biological chemical and physical processes operative in soils. The data could be said to provide a statement of current 'soil quality' (section 1.7) or the 'current level of degradation' (section 1.8) in the UK.

Data for local evaluation e.g. as part of structure plans or local EIS and assessments should be essentially similar to that available for national overviews, it would only vary in resolution. Ideally the detailed local information should be a subset of the national data base.

The databases held by the SSLRC and MLURI clearly form the basis of the required information on the soils of the UK. The resolution of these data bases and the information contained in them may, however, necessitate further input. Thus, both data bases have only limited information on soil biology, e.g. populations of soil fauna and flora, characterization of soil organic matter, measures of biological activity. Data on heavy metals are included in the data base for Scotland but not in that for England and Wales; a separate data base on heavy metals is, however, available for England and Wales. Soil maps are available for the whole of the UK at 1:250 000 scale, for the whole of Scotland at 1:50 000 (or 1:62 500) but for only 25% of England and Wales at scales = > 1:62 500. The information in these data bases was also collected over a period of c. 50 years; it could not be said to provide an instantaneous evaluation of the 'health' of the soils in the UK.

Available soil data bases need evaluation in the context of a UK soil protection policy; this evaluation should include data held by universities and research institutions, in addition to those held by the SSLRC and MLURI. Additional data on selected parameters, to fill current deficiencies and sampling to provide a current statement of the health of the soils of the UK, could be obtained from a limited number of sites linked to the existing data bases and also to the establishment of a national monitoring network.

<u>Monitoring changes in soils over time</u>

Soil protection requires the identification, quantification and evaluation of changes in soils over time. This necessitates monitoring of changes in a series of reference parameters which together allow the evaluation of the 'health' and functioning of the soil system. This monitoring might be equated with assessment of the 'rate of degradation' (section 1.8) or the identification of adverse changes. The approach to this monitoring will vary with the precise aim; in particular whether a national overview is required, a district based assessment or the evaluation of the impact of a specific pollution source.

The national, or regional, assessment of soil change could be based upon a network of long term monitoring sites, such is now being established in Sweden, Norway, West Germany and France, or on repeat surveys. If a network of sites were established, careful consideration would be required of the number of sites, their location, the parameters to be measured to evaluate change, the frequency of sampling, methods of sampling and of analyses. The test parameters should include biological, chemical and physical measurements which allow the functioning and 'health' of the soil system to be assessed. The parameters used in the Swedish Monitoring Programme, and the frequency of sampling are listed in Table 20i,ii. Interpretation of any changes in the test parameters will necessitate information on the management of the sample plots, changes in vegetation of the plots, climate, atmospheric chemistry and deposition: natural changes in the soils must be separated from change resulting from mans' activities. Although a limited number of parameters may be measured regularly, a comprehensive characterization of the soils should be done when the plots are established; this should provide biological, chemical, physical and mineralogical data. Any series of test parameters agreed at the present time will, inevitably, be based upon current knowledge and judgements. The broader baseline data should provide a basis for evaluation of additional measurements added in the future and in the light of new research or new threats to soils.

The national monitoring networks being established in other countries are concentrating on the soils of natural, or semi-natural ecosystems.

These sites will provide information on natural changes and on changes resulting from regional 'threats' such as atmospheric deposition of pollutants. They will not, however, provide data on the impact of localized threats such as soil erosion, compaction or fertilizers. There would seem, therefore, to be a need for 'use-oriented' or 'threat-oriented' monitoring sites to assess the impact of, for example, agricultural and forestry practices on soils, in addition to the semi-natural sites. These use-, or threat-oriented sites could also be seen as part of impact assessment which is discussed below. The number of reference parameters used to monitor and assess changes at use- or threat-oriented sites, or to assess local pollution impacts, may be limited to those already linked to the particular threat. A parallel can be drawn with the parameters identified in the FAO guidelines for the assessment of rates of degradation; specific parameters, and the associated units of measurement, are identified for each type of degradation (cf. section 1.8). Thus, the reference parameter for acidification would be percentage base saturation; for compaction, bulk density and permeability; for erosion, rate of soil loss; for heavy metal pollution, total content of heavy metal; for loss of organic matter, percentage content of organic matter or organic carbon. The policy should also aim to provide reference values, for the various reference parameters, which would provide an 'evaluation' of the data. Two approaches are possible: (i) a ranking based on the rate of change of the given parameter, (ii) absolute values of given parameters. The first approach is illustrated in the FAO guidelines where the rate of degradation is ranked into four categories ranging from 'none to slight' to 'very high'. The second approach is similar to the quantitative definition of soil quality or to the definition of maximum permissible values, of pollutants. These approaches have really only been attempted for heavy metals and a few organic pollutions (cf. section 1.7). A useful approach has been suggested in the Netherlands, as part of their clean-up guidelines, which could be applied in monitoring of change, impact assessment and national inventories of soils; three reference values are provided for the reference parameter:

- A value = average background value
- B value = further investigation required
- C value = immediate action required

Considerable soil information is held for semi-natural sites by organizations such as the Nature Conservancy Council. Thus, for example, National Nature Reserves may form the basis of a network of sites in natural or semi-natural ecosystems. The network of sites to evaluate long-term environmental change currently being discussed by a committee established by NERC may, similarly, provide possible sites for monitoring of soils. Turning to more intensively managed soils, the research sites and experimental farms of the AFRC, MAFF-ADAS, and DAFS research institutes and the Scottish Agricultural Colleges provide a potential monitoring network. The long term research sites at

Rothamsted and Cockle Park, Northumberland could play a particularly important part in assessment of long term trends.

Impact assessment

In the context of a soil protection policy, impact assessment should assess the impact of man's activities on soils, their characteristics and functioning. It should include an assessment of the impact of activities which affect soils nationally, or regionally, e.g. atmospheric inputs of pollutants, and those which have a more localized impact, e.g. agricultural and forestry acitivities, building, transport developments; although localized these latter activities affect a considerable area of land in total. A comprehensive policy should also allow for the assessment of the impact of current activities/land use and of any changes. The latter should cover not only changes in land use but changes in land management, and changes in industrial emissions as a result of the introduction of new techniques or industrial processes. It is important that agricultural and forestry activities are included in the assessment and changes in agricultural and forestry practice. Changes in these practices may have a dramatic impact on soils while not representing a change in land use. It is similar to assessing 'risk of degradation' (section 1.8).

Impact assessment could be based upon (i) monitoring the response of soils to a given loading, a given land use, management practice or pollutant input, or (ii) the prediction of the impact of a given change in land use or management, the introduction of a new industrial process or the development of a given industry in a new area. The first approach has been discussed in the previous section on monitoring of changes. The second approach requires the development of models which predict the response of soils to a given stress; the model should incorporate those soil factors, or properties which control the soils response to the particular stress. The response of different types of soil to a given stress will vary greatly. Ideally, a dose-response (cause-effect) model is required which would enable the quantitative changes in relevant soil parameters to be calculated. However, empirically based models may be valuable in the short term. The development of the required models requires direct monitoring of the impact of a given stress on soils and/or experimental studies. The state of knowledge of the response of soils to the main currently-perceived threats, and the factors controlling those responses, is reviewed in Volume II of this report. The necessary mathematical models only exist for a few stresses e.g. acidification by acidic deposition and accumulation of heavy metals. However, conceptual models exist which allow soils to be ranked in terms of their sensitivity to most perceived threats or stresses (section 1.9), or their ability to buffer the effects of threats or stresses (section 1.10). In the short term, impact assessment, in the predictive sense, will have to be based on rankings in terms of sensitivity or buffering capacity; the application of this approach is illustrated in Volume III of this report. However, the eventual aim should be the development of the necessary dose-response models, and quantification of impacts.

As noted above, the response of soils to a given stress varies considerably between soil types. Thus, the impact of a given stress on soils generally can be limited if it is applied only to the least sensitive soils, or the soils with the highest buffering capacity, with respect to the particular stress. A ranking of soils in terms of sensitivity, or buffering capacity, to a given stress can be seen as a ranking in terms of suitability for the activity which gives rise to the stress or threat. Land suitability as conventionally used, is the suitability of the soil for the growth of a given crop, or land use; this is based on the soil conditions required for optimal growth of the given crop, or for carrying out a given use, e.g. sports fields, footpaths. The application of the land suitability approach is illustrated in Volume III of this report. The two uses of the term suitability have strong similarities but are not identical. For example, a given soil may be highly suitable for the growth of wheat but may also be highly susceptible to nitrate leaching. There would be great benefit from combining the two approaches in the assessment of man's activities on soils. Thus, the ranking of soils in terms of suitability for a particular use should be overlaid by a ranking in terms of sensitivity, or a susceptibility, to stresses arising from that use; the resultant ranking would give a suitability of the soil for a given use.

There is clearly no mechanism in the UK for directing a given type of agriculture, or other land use, to particular soils which have low sensitivity with respect to stresses arising from that type of agriculture. However, a comprehensive soil protection policy would, on scientific grounds, be linked to a land use policy which aimed to use land in such a way that the risk of soil damage was minimized. An important requirement of the Town and Country Planning Act is that in deciding whether or not to give planning permission, the planning authority "shall have regard to the development plan for the area and to any other material considerations". The value of the soil for any purpose, or its susceptibility to damge by the proposed development, in any location may be regarded by the planning authority as a "material consideration" if the value, quality, or susceptibility of that soil could be demonstrated adequately. Maps providing such information (e.g. see Vol. III of this report) would be of value to planning authorities if the required data were available.

Acceptable loads

If the exposure of a soil to a given stress loading cannot be avoided, then the aim of a soil protection policy should be to reduce the loading to a level which will not produce adverse changes in the functioning of the soil, or which the soil can buffer. Such loads are variously referred to as acceptable loads, maximum permissible loads (section 1.7) or critical loads (section 1.12). Calculation of the acceptable, or critical load requires a mathematical, dose-response or cause-effect model. The acceptable load will vary considerably between soils for a given stress. The required dose-response models are only available for one or two currently perceived threats to soils, e.g. acidification, heavy metal accumulation. Dutch workers have also developed models linking inputs of nitrogen fertilizers and time to leaching loss - these models can be used to define an acceptable load for nitrogen fertilizers which respect to leaching to groundwaters. The aim should be to produce the necessary models for other threats.

It is important that the target, or aim, of the acceptable load is defined. Thus, in defining acceptable loads for heavy metals the aim could be to ensure that the heavy metal being considered did not have adverse effects on plant growth, reach man via the food chain at toxic levels, have adverse impacts of soil microbiological populations and their functioning. The acceptable loads with respect to each of these target 'organisms' could vary.

Critical loads or acceptable loads provide a means of linking soil protection policy with legislation concerning, control of activities which may have adverse effects on soils. The critical load concept is being used to calculate recommended maximum levels of emissions of pollutants which lead to acidic deposition. Maximum permissible loads of heavy metals are used to fix levels of heavy metals in sewage sludges applied to agricultural land. This approach exemplifies the linking of effect-oriented and cause-oriented policies which is an important feature of the Dutch soil protection policy. Control of the emissions of atmospheric pollutants, e.g. sulphur and nitrogen oxides and heavy metals, form part of broader environmental policies and legislation. Similarly, controls on heavy metal levels in sewage sludge, and any future controls on fertilizer, are included in legislation relating to agriculture. This stresses the need for links between soil protection policy and policies, and legislation in other linked sectors, in particular those sectors involved in activities which produces stresses on, or threats to soil systems. Thus, for example, critical loads of acidifying pollutants for soils would, ideally be used to determine emission levels included in pollution control legislation enforced by Her Majesty's Inspectorate of Pollution or Local Authorities.

Development of alternative management strategies

The impact of a given stress on particular soils can be reduced by modifying land use practices or as a result of the development of new technologies or methods of management. As a simple example, the physical loading of soils can be reduced by the use of wide-profile tyres or tracked vehicles. The risk of soil erosion can be reduced by modification of the methods and timing of cultivation, and by maintaining a vegetation cover. Leaching of nitrates derived from fertilizers is reduced by winter planting of cereals and careful timing of fertilizer applications. Atmospheric concentrations of sulphur and nitrogen compounds, and hence acidic deposition to soils, can be reduced by the introduction of flue gas desulphurization plants in power stations and the development of new engine and/or exhaust technologies for cars. The concept of 'best practical means' is currently used in pollution control; this concept could be extended to agricultural, forestry and construction industry practices in the context of soil protection. However, the long term aim of the policy should be to improve the 'best practical means'.

The development of less damaging land management strategies has been referred to as 'optimization' in the Netherlands where great efforts have been put into the development of models to match nitrate fertilizer inputs to plant demand. Parallel work is in progress in the UK. The development of alternative management strategies and technologies requires an assessment of the impacts of particular land uses and an identification of the stresses arising from those uses. In the case of regional pollution, the sources of the pollutants must be identified. There is a clear link with the concept and application of critical loads; the aim of the alternative management and technology is to reduce stresses, or loads, to below the critical load.

Rehabilitation

A principle aim of a soil protection policy should be to limit those of mass activities which produce irriversible changes in soil properties which restrict the range of functions the soil can perform.

However, areas of soils already exist whose functioning is already impaired because of the impact of stresses at some time in the past, e.g. old heavy metal mine wastes, old waste disposal sites. Man's current activities are also inevitably damaging some soils such that their functioning is limited, e.g. due to compaction around construction sites. The restoration of such damaged soils should form one aim of any soil protection policy and the target should be to restore the soil such that it can perform as wide a range of functions as possible (Table 1) or is available for a range of uses. Evaluation of the success of any restoration should include reference parameters which cover biological, chemical and physical aspects of soils and their functioning. Wherever possible, reference, or target values should be assigned to each parameter. This approach already exists with respect to target heavy metal concentrations in reclaimed land but a broader range of reference parameters should, ideally, be used.

1.14.6 Summary and conclusions

The scientific aims and principles of a soil protection policy are closely linked to the underlying rationale and philosophy of that policy. The use of the term 'soil protection' implies a certain approach and philosophy which, unlike earlier soil conservation policies and legislation, is not linked to any particular end use. The stimulus for a broader approach comes from a combination of ethical and practical considerations.

The definition of 'soil' is central to the structure and aims of a soil protection policy. In this report emphasis is placed on the fact that soils are complex, dynamic systems which comprise interlinked organic and inorganic materials and contain populations of a fauna and microflora. Soils are in a state of flux and development as a result of interlinked biological, chemical, and physical processes which operate at a variety of timescales. These properties enable a soil to carry out a range of functions which vary between soil types but are characteristic of a given soil. Man exploits these functions in using soils for various purposes. The understanding of the processes and functioning of natural, undisturbed soils is essential for the assessment and prediction of the impact of man's activities on soils and associated ecosystems.

Soil protection implies the protection of the complexity and dynamic nature of soil systems and the variability within and between soil types without interfering with the natural development and evolution of soil unless as part of a specific aim for a particular purpose. The aim is to protect all soil systems from adverse and undesirable changes resulting from man's activities and influences. In order not to be too restrictive, a soil protection policy should also be concerned with restoration of damaged soils and with the reversal of 'adverse changes' in soils.

Of course, terms such as 'adverse changes' amd 'soil quality' require definition within the context of the policy, and ideally the definitions would be quantitative. However, the natural heterogeneity and complexity of soils present problems in the quantitative definition of soil quality (section 1.7). No single parameter can be used fo define 'soil quality' or 'adverse changes', and no single set of reference values would be satisfactory because of the natural variabilty between and within soils and the variation in the impact of given stresses on soil processes and functioning. Reference values can be set only with respect to a given end use, to the ability of soils to perform various functions, or to the operation of certain soil processes. A quantitative definition of soil quality which is relevant to several functions or uses will be possible for only a few parameters, e.g. heavy metals. 'Adverse change' could be defined as that which cannot be reversed naturally, or which is greater than changes which occur naturally. However, it is not possible, currently, to define the limits of change of most reference parameters which are naturally reversible, or are within the range of natural variation. In some cases, it is possible to identify, qualitatively, changes which are not reversible naturally, or to identify uses which produce changes that are not reversible naturally. A soil protection policy could seek to avoid or restrict such uses.

Bearing in mind that the achievement of these aims will be governed by the extent to which the magnitude of each threat (a) can be assessed, and (b) is perceived to warrant the investment of the necessary resources, the implementation of a soil protection policy would require:

i. A characterization and assessment of the soils of the UK and their current status. The existing databases, especially those held by the SSLRC and MLURI, clearly form the basis of the required information, but they need further input. In particular, both databases have only limited information on populations of soil fauna and flora, measures of biological activity, and characterization of soil organic matter.

ii. Monitoring of changes in soils over time. The national, or regional, assessment of soil change would require a network of long-term monitoring sites, such as those which are being established in other European countries. The number of sites, their location, and the parameters to be measured would require careful consideration.

iii. Assessment of the impact of man's activities on soils, particularly the impact of changes in land use and management on their characteristics and functioning. This requires the development of models which predict the responses of soils to a given stress. The necessary mathematical models exist for only a few stresses such as acidification and the accumulation of heavy metals. However, conceptual models exist which allow soils to be ranked in terms of their sensitivity to most perceived threats or stresses, or their ability to buffer the effects of threats or stresses. The models will require information which may be obtainable from the monitoring network or may need to be monitored separately on a regional or local scale. The impact of a given stress on soils generally can be limited if it is applied only to the least sensitive soils, or the soils with the greatest buffering capacity for that stress. A ranking of soils in terms of sensitivity to, or buffering capacity for, a given stress can be seen as a ranking in terms of suitability for the activity which gives rise to the stress or threat.

iv. Definition of acceptable loads of man-induced stresses and means of controlling those stresses. Calculation of the acceptable, or critical, load requires a mathematical, dose-response or cause-effect model. The acceptable load will vary considerably between soils for a given stress. The required dose-response models are available for only one or two currently-perceived threats to soils, notably acidification and heavy metal accumulation.

v. Development of alternative management methods and techniques to reduce the impact of man's activities on soils. There is considerable scope for reducing the impact of a given stress on a particular soil by modifying land use practices and/or developing new technologies. As a simple example, the physical loading of soils can be reduced by the use of wide-profile tyres or tracked vehicles. The risk of soil erosion can be reduced by modification of the methods and timing of cultivation, and by maintaining a vegetation cover. Such changes should be encouraged.

vi. Definition of target values of soil parameters to be used in rehabilitation of damaged soils. Evaluation of the success of any restoration should include reference parameters which cover biological, chemical, and physical aspects of soils and their functioning. Wherever possible, reference or target values should be assigned to each parameter.

An important requirement of the Town and Country Planning Act is that in deciding whether or not to give planning permission, the planning authority "shall have regard to the development plan for the area and to any other material considerations". The value of the soil for any purpose, or its susceptibility to damage by the proposed development, in any location may be regarded by the planning authority as a "material consideration" if the value, quality, or susceptibility of that soil could be demonstrated adequately. Maps providing such information (e.g. see Vol. III of this report) would be of value to planning authorities if the required data were available. In the UK, various instruments are available for protecting the environment. However, they are not linked or co-ordinated under a broad policy, and responsibilities are spread between departments. Furthermore, three-quarters of the UK, or at least of England and Wales, is excluded from planning control by virtue of being under agriculture or forestry. A soil protection policy would require links with general environmental policies and legislation, such as those concerning controls on emissions, pollution of waters, planning legislation, and with agricultural and forestry policies and legislation.

Table 21a. Measurements, and frequency of measurement, of soils used in the Swedish National Monitoring Programme soil chemistry and biology. (From, National Swedish Environmental Protection Board 1985)

Monitoring of Soil Chemistry and Soil Biology

No of sampling areas:

14, comprising a total of 20 sample plots

Measurements:

Thickness of mor (humus) and bleached-soil layers.
Weight loss after 1, 2 and 3 years of pine needles placed on the ground.

The same observations of trees, shrubs and plant communities within the sample plot as in the intensive plots used for vegetation monitoring - excluding observations in sub-plots.

In 3-5 different soil layers (12 samples from each layer collected from each plot):

pH value, concentrations of Na, K, Mg, Ca, Al, PO_4, Mn after extractions in salt solution. Total concentrations of C and N.

In mor and precipitation layers:

pH value, concentrations of Mg, Ca, Al in water extract

In the mor layer:

Total concentrations of S, V, Ni, Cu, Zn, Cd, Hg, Pb
Phosphatase activity

In the precipitation layer:

Concentrations of acid-soluble Cu, Zn, Cd, Pb

In 2 areas, the following analyses of soil water (6 samples each from 2 different depths):

pH value, conductivity
concentrations of Na, K, Mg, Ca, Al, NH_4, NO_3, SO_4, Cl

Frequency of measurements:

Concentrations in soil water:

Once every month during the frost season

Weight loss of pine needles:

Once every year

Thickness of mor and bleached-soil layers; concentrations in water extract from mor and precipitation layers; phosphatase activity in mor:

Every second year

Total concentrations of sulphur and heavy metals in mor:

Every fifth year

Other measurements:

Every tenth year

Table 21b. Observations, and frequency of observation, of vegetation in the Swedish National Monitoring Programme, vegetation. (From, National Swedish Envrironmental Protection Board 1985)

Vegetation Monitoring

No of monitoring areas:

18, comprising a total of 30 intensive plots (each containing 16-48 subplots), 9 lichen plots and 954 circular plots

Observations:

General observations of trees (made in each circular plot in most of the areas):

Location, species and trunk diameter of all major trees (diameter > 10 cm; dead trees, fallen logs and stumps also included)

Dominance class of major trees (living or dead)

Likely death caused for major dead trees

Degree of composition among major fallen logs and stumps

Stump type of major stumps

Height of a small number of sample trees (one each in the diameter classes 5-9 cm, 10-19 cm, 20-29 cm etc)

Basal area of each tree species

Occurrence and type of fire traces and traces of human activity

Estimates of forest damage (made in each circular plot in all of the areas):

Degree of crown thinning and type of damage (if any) in some of the sample trees (spruce and pine of the topmost dominance classes)

Occurrence of comb-spruce structure in spruce among these sample trees

Observations in the inner part of the circular plots (made in most of the areas - each plant community is documented individually if several communities are present within this part of the plot)

Cover (% of plot area) of the entire plant community, of tree, shrub, field and bottom layers, of open soil and deviating substrate (such as outcroppings), and of each individual plant species in each of the layers

Occurrence of sexual reproductive organs (flowers or corresponding organs) in each species in the shrub, field and bottom layers

Distribution pattern in the plot (sociability) of each species in the shrub, field and bottom layers

No. of small trees (trunk diameter < 10 cm) of each species in five different diameter classes

Observations in the intensive plots:

Location and species of all trees, shrubs, fallen logs and stumps
Height of standing trees
Trunk diameter of major trees (height > 5 m)
No. of trunks among trees with several trunks
Likely death cause for major dead trees
Degree of decomposition among fallen logs and stumps
Stump type of stumps
Distribution of various plant communities and major stands of single species

Observations in each sub-plot within the intensive plots:

Cover of field and bottom layers, of low trees and shrubs, of open soil and deviating substrate, and of each individual species in the field and bottom layers

Occurrence of sexual reproductive organs in each species in the field and bottom layers

Humidity of bottom layer

continued ...

Table 21b (continued)

No. of trees in the plot with crown thinning 20% (applies to spruce and pine of the topmost dominance classes)

Observations in the lichen plots:

Location, height, circumference, inclination and direction of inclination of selected sample trees (a total of 7 trees in four different diameter classes)

Location (in relation to the sample trees) and species of the four major trees (height 5 m) closest to each of the sample trees and of very nearby shrubs and smaller trees

Occurrence and position (along the circumference of the trunk at four different levels - 60, 90, 120 and 150 cm above ground - on each sample tree) of each of a total of about 20 lichen species or genera
Occurrence on other parts of the trunk of those species not found at the four levels
Occurrence of discoloured or dead specimens

Length of certain *Alectoria* and *Usnea* species (a total of about 5 species or genera) found between 120 and 150 cm above ground on each sample tree

Width and depth of bark cracks and breadth of bark flakes (120 cm above ground on each sample tree)

Frequency of observations:

Forest damage in circular plots and low vegetation in intensive plots:

Once every year

Vegetation in lichen plots and low vegetation in circular plots:

Every fifth year

Trees and shrubs in circular and intensive plots:

Every tenth year

1.15 REFERENCES

Addiscott, T. 1988. Farmers, fertilisers and the nitrate flood. New Scientist, **120** (1633), 50-54.

Agricultural Land, our disappearing heritage - a symposium. 1981. Proc. 18th annual Alberta Soil Science Workshop. Edmonton, Alberta: Alberta Soil & Feed Testing Laboratory.

Alef, K. & Kleiner, D. 1987. Applicability of arginine ammonification as indicator of microbial activity in different soils. Biol. & Fertil. Soils, **5**, 148-151.

Alley, M.M. & Zelazny, L.W. 1987. Soil acidity: soil pH and lime needs. In: SSSA Special Publication No 21, 65-72. Madison, Wisconsin: Soil Science Society of America.

Anderson, J.M., Ineson, P. & Huish, S.A. 1983. Nitrogen and cation mobilization by soil fauna feeding on leaf litter and soil organic matter from deciduous woodlands. Soil Biol. & Biochem., **15**, 463-467.

Anderson, R.V., Coleman, D.C. & Cole, C.V. 1981. Effects of saprotrophic grazing on net mineralization. In: Terrestrial nitrogen cycles (Ecol. Bull. 33), edited by F.E. Clark and T. Rosswall, 201-216. Stockholm: Swedish Natural Science Research Council.

Armstrong, M.J. & Bragg, N.C. 1984. Soil physical parameters and earthworm populations associated with opencast coal working and land restoration. Agriculture, Ecosystems and Environment, **11**, 131-143.

Atlavinyte, O. & Zimkuviene, A. 1985. The effect of earthworms on barley crop in the soil of various density. Pedobiologia, **28**, 305-310.

Avery, B.W. 1980. Soil classification for England and Wales (Higher categories). Rothamsted, UK: Soil Survey of England and Wales, 66 pp.

Ball, D.F. & Stevens, P.A. 1981. The role of "ancient" woodlands in conserving "undisturbed" soils in Britain. Biological Conservation, **19**, 163-176.

Ball, D.F. & Williams, W.M. 1968. Variability of soil chemical properties in two uncultivated Brown Earths. J. Soil Sci., **19**, 379-391.

Ball, D.F. & Williams, W.M. 1974. Soil development on coastal dunes at Holkham, Norfolk, England. Trans. 10th Int. Congr. Soil Sci., VI (II), 380-386.

Barlow, T. 1979. Three-quarters of the conservation job not being done. In: Soil conservation policies: An assessment, 128-132. Ankeny, Iowa: Soil Conservation Society of America.

Barnes, C.B. 1980. A new land use ethic. J. Soil & Water Conserv., **35**, 61-62.

Barrows, R. & Olson, C. 1981. Soil conservation policy: Local action and federal alternatives. J. Soil & Water Conserv., **36**, 312-316.

Barth, H. & l'Hermite, P. 1987. Scientific basis for soil protection in the European Community. London; New York: Elsevier, 630 pp.

Bavinck, H.F., Roels, J.M. & Vegter, J.J. 1988. The importance of measurement procedures in curative and preventive soil protection. Draft of a paper to be presented at the Second International TNO/BMFT Conference on Contaminated Soil, Hamburg, April 1988.

Beek, J. & van Riemsdijk, W.H. 1979. Interaction of orthophosphate ions with soil. In: Soil chemistry B, Physico-chemical models, edited by G.H. Bolt, 259-284. Amsterdam: Elsevier.

BELF. 1987. Nitratbelastung des Grundwassers. Beitrag der landwirtschaft zur Verminderung der Nitratbelastung des Grundwassers. Kurzfassungen von acht Teiluntersuchungen. Münster-Hiltrop, Federal Republic of Germany: Landwirtschaftsverlag GmbH (Schriftenreihe des Bundesministers für Ernährung, Landwirtschaft and Forsten, A No 350, 154 pp).

Bengtsson, G. & Rundgren, S. 1982. Population density and species number of enchytraeids in coniferous forest soils polluted by a brass mill. Pedobiologia, **24**, 211-218.

Bengtsson, G. & Rundgren, S. 1984. Ground-living invertebrates in metal polluted forest soils. Ambio, **13**, 29-33.

Bengtsson, G., Berdén, M. & Rundgren, S. 1988. Influence of soil animals and metals on decomposition processes: A microcosm experiment. J. environ. Qual. **17**, 113-119.

Bengtsson, G., Nordstrom, S. & Rundgren, S. 1983. Population density and tissue metal concentration of lumbricids in forest soils near a brass mill. Environ. Pollut., **30**, 87-108.

Berdén, M., Nilsson, S.I., Rosen, K. & Tyler, G. 1987. Soil acidification, extent, causes and consequences. An evaluation of literature information and current research. Solna, Sweden: National Swedish Environmental Protection Board.

Berg, N.A. 1979. Soil conservation: The physical resource setting. In: Soil conservation policies: An assessment, 8-17. Ankeny, Iowa: Soil Conservation Society of America.

Berghuys-van Dijk, J.T. 1985. ANIMO. Agricultural Nitrogen Model. (Nota 1671). Wageningen: Institute for Land and Water Management Research (ICW).

Best, R.H. 1981. Land use and living space. London: Methuen.

Bibby, J.S., Douglas, H.A., Thomasson, A.J. & Robertson, J.S. 1982. Land capability classification for agriculture. Aberdeen, Scotland: The Macaulay Institute for Soil Research.

Bibby, J.S. & Mackney, D. 1969. Land use capability classification. Rothamsted, UK: Soil Survey of England and Wales.

Bieri, M. & Besson, J.M. 1986. Der Einfluss unterschiedlich aufbereiteter Güllen auf die Regenwurmpopulation einer Kunstwiese. Bull. Bodenk. Gesell Schweig, No.10, 31-38.

Billett, M.F., Fitzpatrick, E.A. & Cresser, M.S. 1988. Long-term changes in the acidity of forest soils in north-east Scotland. Soil Use & Manage., **4**, 102-107.

Billings, W.D. 1983. Man's influence on ecosystem structure, operation, and ecophysiological processes. In: Physiological plant ecology IV Ecosystem processes: Mineral cycling, productivity and man's influence, edited by O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Ziegler, 527-548. Berlin; Heidelberg: Springer.

Blaikie, P. & Brookfield, H. 1987. Land degradation and society. London; New York: Methuen.

Bloom, P.R. & Grigal, D.F. 1985. Modelling soil response to acidic deposition in nonsulfate adsorbing soils. Journal of Environmental Quality, **14**, 489-495.

Blum, W.E.H. 1988. Problems of soil conservation (PE-R-SO(88)1). Strasbourg: Council of Europe, 56 pp.

Bradshaw, A.D. & Chadwick, M.J. 1980. The restoration of land. Oxford; London: Blackwell, 317 pp.

Brookes, P.C. & McGrath, S.P. 1984. Effects of metal toxicity on the size of the soil microbial biomass. J. Soil Sci., **35**, 341-346.

Bullock, P. & Murphy, C.P. 1983. Soil micromorphology. Vol 1 Techniques and applications; Vol 2 Soil genesis. Berkhamsted, UK: A.B. Academic.

Burton, R.G.O. & Hodgson, J.M. (Eds). 1987. Lowland Peat in England and Wales, Soil Survey Spec. Surv. No. 15.

Carlson, F.E. 1956. A better conservation program through radio. J. Soil & Water Conserv., **11**, 222-225.

Carlson, F.E. 1960. Adult education. Will it hasten soil and water conservation? J. Soil & Water Conserv. **15**, 123-125.

Catt, J.A. 1985. Natural soil acidity. Soil Use and Management, **1**, 8-10.

CDEP 478/53. Soil protection and soil quality. Internal document of the Department of the Environment, Central Directorate of Environmental Protection.

CEC 1986. Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Official Journal of the European Communities No L181/6-12, 4 July 1986.

Chanasyk, D.S. 1986. Soil degradation: An important national issue. Agric. For.. Bull., **9**, 18-23.

Chen, C.W. Gherine, S.A., Hudson, R.J.M. & Dean, J.D. 1983. The integrated Lake-Watershed acidification study. Vol. 1: Model principles and application procedures (EA-3221: Vol. 1 Research Project 1109-5). Palo Alto, Ca: Electric Power Research Institute.

Chisholm, A. & Dumsday, R. (Eds) 1987. Land degradation: Problems and policies. Cambridge, UK: Cambridge University Press, 404 pp.

Christy, L.C. 1971. Legislative principles of soil conservation (Soils Bulletin No 15). Rome: FAO.

Clayden, B. & Hollis, J.M.. 1984. Criteria for differentiating soil series. Rothamsted, UK: Soil Survey of England and Wales, 159 pp.

Cloke, P. 1988. Understanding rural policy & planning: The importance of concepts of the State. Planning Quarterly, **89**, 12-15.

COE 1987. Workshop on the situation and protection of ancient natural and semi-natural woodlands in Europe. Strasbourg: Council of Europe, 66 pp.

Cole, C.V., Elliott, E.T., Hunt, H.W. & Coleman, D.C. 1978. Trophic interactions in soils as they affect energy and nutrient dynamics. V. Phosphorus transformations. Microbial Ecol., **4**, 381-387.

Collier, B.D., Cox, G.W., Johnson, A.W. & Miller, P.C. 1973. Dynamic ecology. Englewood Cliffs, N.J.: Prentic-Hall, 563 pp.

Coppola, S. 1986. Summary of investigations in Italy into effects of sewage sludge on soil microorganisms. In: Factors influencing sludge utilisation practices in Europe, edited by R.D. Davis, H. Haeni & P.L'Hermite, 72-79. Barking, UK: Elsevier.

Cosby, B.J., Whitehead, P.G. & Neale, R. 1986. A preliminary model of long-term changes in stream acidity in southwestern Scotland. J. Hydrol., **84**, 381-401.

Cosby, B.J., Wright, R.F., Hornberger, G.M. & Galloway, J.N. 1985. Modelling the effects of acid deposition: assessment of a lumped parameter model of soil water and stream water chemistry. Water Resour. Res., **21**, 51-63.

Coughtrey, P.J., Jones, C.H., Martin, M.H. & Shales, S.W. 1979. Litter accumulation on woodlands contaminated by Pb, Zn, Cd and Cu. Oecologia, **39**, 51-60.

Cox, J.W. 1968. Town and country planning. In: Soils of New Zealand Part 1 (Soil Bureau Bulletin 26(1)), 119-123. Wellington, New Zealand: DSIR.

Cresser, M.S. & Edwards, A.C. 1987. Acidification of freshwaters. Cambridge, UK: Cambridge University Press. 136pp.

Culbard, E., Moorcroft, S., Watt, J., Thornton, I. & Thomas, J.F.A. 1983. A nationwide reconnaissance survey of metals in urban dusts and soils. Minerals and the Environment, **5**, 82-84.

de Bruijn, P.J. & de Walle, F.B. 1988. Soil standards for soil protection and remedial action in the Netherlands. Draft of a paper to be presented at the Second International TNO/BMFT Conference on Contaminated Soil, Hamburg, April 1988.

de Haan, F.A.M. 1987. Effects of agricultural practices on the physical chemical and biological properties of soils: Part III - Chemical degradation of soil as the result of use of mineral fertilizers and pesticides: aspects of soil quality evaluation. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 211-236. London; New York: Elsevier.

Dechant, T.T. 1979. Conserving cropland resources and enhancing soil fertility and productivity. In: Soil conservation policies: An assessment, 113-119. Ankeny, Iowa: Soil Conservation Society of America.

Delmhorst, B. 1987. The soil protection plan in the Federal Republic of Germany. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 423-427. London; New York: Elsevier.

Dettwiler, J. 1986. Gewässerschutz in der Landwirtschaft (Protection des eaux dans l'agriculture). UFA-Revue 12/86.

Dickson, B.A. & Crocker, R.L. 1953. A chronosequence of soils and vegetation near Mt. Shasta, California. II. The development of the forest floors and the carbon and nitrogen profiles of the soils. J. Soil Sci., **4**, 142-154.

Didden, W.A.M. 1987. Reactions of <u>Onychiurus fimatus</u> (Collembola) to loose and compact soil. Pedobiologia, **30**: 93-100.

Dimbleby, G.W. 1962. The development of British heathlands and their soils (Oxford Forestry Memoirs No 23). Oxford, UK: Clarendon Press, 120 pp.

Dimbleby, G.W. 1978. Prehistoric man's impact on environments in north west Europe. In: The breakdown and restoration of ecosystems, edited by M.W. Holdgate and M.J. Woodman, 129-144. New York; London: Plenum Press.

DoE 1988. Our common future; A perspective by the United Kingdom on the Report of the World Commission on Environment and Development. London: Department of the Environment.

Doelman, P. 1986. Resistance of soil microbial communities to heavy metals. In: Microbial communities in soil, edited by V. Jensen, A. Kjoller & L.H. Sorensen, 369-384. London; New York: Elsevier.

Domsch, K.H. 1984. Effects of pesticides and heavy metals on biological processes in soil. Pl. Soil, **76**, 367-378.

Duchaufour, P. 1948. Recherches écologiques sur la chênaie atlantique francaise. Ann. Éc. Eaux For. Nancy, **11**, 1-332.

Dumanski, J., Coote, D.R., Luciuk, G. & Lok, C. 1986. Soil conservation in Canada. J. Soil & Water Conserv., **41**, 204-210.

Dutil, P. 1982. Losses and accumulation of organic matter in French soils. In: Soil degradation (Proceedings of the land use seminar on soil degradation, Wageningen, October 1980), edited by D. Boels, D.B. Davies and A.E. Johnston, 163-179. Rotterdam: Balkema.

Edelman, T. & de Bruijn, M. 1986. Background values of 32 elements in Dutch topsoils, determined with non-destructive neutron activation analysis. In: Contaminated soil, edited by J.W. Assink and W.J. van den Brink, 89-99. Dordrecht: Martinus Nijhoff.

Edwards, C.A. 1984. Changes in agricultural practice and their impact on soil organisms. In: Agriculture and the environment, edited by D. Jenkins, 56-65. Cambridge, UK: Institute of Terrestrial Ecology.

Edwards, C.A. & Lofty, J.R. 1975. The invertebrate fauna of the Park Grass Plots. 1. Soil fauna. Rep. Rothamsted exp. Stn 1974, **2**, 133-154.

Edwards, C.A. & Lofty, J.R. 1977. The influence of invertebrates on root growth of crops with minimal or zero cultivation. In: Soil organisms as components of ecosystems (Ecol. Bull. 25), edited by U. Lohm and T. Persson, 348-356. Stockholm: Swedish Natural Science Research Council.

Edwards, C.A. & Lofty, J.R. 1978. The influence of arthropods and earthworms upon root growth of direct drilled cereals. J. appl. Ecol., **15**, 789-795.

Edwards, C.A. & Lofty, J.R. 1982. The effects of direct drilling and minimal cultivation on earthworm populations. J. appl. Ecol., **19**, 723-734.

FAO 1976. A framework for land evaluation (Soils Bull. No. 32). Rome: Food and Agriculture Organization of the United Nations.

FAO 1979. A provisional methodology for soil degradation assessment. Rome: Food and Agriculture Organization of the United Nations.

FAO 1980. Land evaluation guidelines for rainfed agriculture (World Soil Resources Rep. No. 52). Rome: Food and Agriculture Organization of the United Nations.

FAO 1981. World Soil Charter (C 81/27). Rome: Food and Agriculture Organization of the United Nations.

FAO 1983. Guidelines for the control of soil degradation. Rome: Food and Agriculture Organisation of the United Nations.

Fedoroff, N. 1987. The production potential of soils: Part I - Sensitivity of principal soil types to the intensive agriculture of north-western Europe. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 65-85. London; New York: Elsevier.

Follett, R.F., Stewart, J.W.B. & Cole, C.V. 1987. Soil fertility and organic matter as critical components of production systems. Madison, Wisconsin: Soil Science Society of America and American Society of Agronomy.

Forred, W.A. 1956. The Way, The Truth, and The Life. J. Soil & Water Conserv., **11**, 35-36 + 39.

Fournier, F. 1972. Aspects of soil conservation in the different climatic and pedologic regions of Europe. Council of Europe.

Fränzle, O. 1987. Sensitivity of European soils related to pollutants. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 123-145. London; New York: Elsevier.

Gibbs, H.S. 1968. Soil classification for land use. In: Soils of New Zealand Part 1 (Soil Bureau Bulletin 26(1)), 124-130. Wellington, New Zealand: DSIR.

Giller, K.E. & McGrath, S.P. 1988. Pollution by toxic metals on agricultural soils. Nature, **335**, 676.

Girling, J.A. 1983. Land as the subject of environmental law. In: Stress on land in Canada, edited by W. Simpson-Lewis, R. McKechnie and V. Neimanis, 304-323. Ottawa, Canada: Environment Canada.

Glacken, C.J. 1956. The origins of the conservation philosophy. J. Soil & Water Conserv., **11**, 63-66.

Glick, P.M. 1979. Soil conservation: Highlights of political and legal arrangements. In: Soil conservation policies: An assessment, 18-24. Ankeny, Iowa: Soil Conservation Society of America.

Godwin, H. 1975. The history of the British flora: A factual basis for phytogeography. Cambridge University Press, 541 pp.

Gomez, A. & Juste, C. 1987. Soil protection programmes and strategies in other community member states: setting up of an observation network for soil quality in France. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 437-443. London; New York: Elsevier.

Gorham, E., Bayley, S.E. & Schindler, D.W. 1984. Ecological effects of acid deposition upon peatlands: a negelected field of 'acid rain' research. Can. J. Fish. & aquat. Sci., **41**, 1256-1268.

Graziani, C.A. 1987. Report on the erosion of agricultural soils and on wetlands in the European Community (PE DOC A 2-20/87. Luxembourg: Office for Official Publications of the European Communities, 19 pp.

Grieve, I.C. 1978. Some effects of the plantation of conifers on a freely drained lowland soil, Forest of Dean. Forestry, **51**, 21-28.

Griffin, D.M. 1972. Ecology of soil fungi. London: Chapman & Hall, 193 pp.

Grubb, P.J., Green, H.E. & Merrifield, C.J. 1969. The ecology of chalk heath: its relevance to the calcicole-calcifuge and soil acidification problems. J. Ecol., **57**, 175-212.

Häberli, R. 1987. Soil protection in Switzerland. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 461-469. London; New York: Elsevier.

Hallbäcken, L. & Tamm, C.O. 1986. Changes in soil acidity from 1927 to 1982-1984 in a forest area of southwest Sweden. Scand. Journal of Forest Research, **1**, 219-232.

Hallsworth, E.G. 1987. Soil conservation down under. J. Soil & Water Conserv., **42**, 394-400.

Holdgate, M.W. 1978. The application of ecological knowledge to land use planning. In: The breakdown and restoration of ecosystems, edited by M.W. Holdgate and M.J. Woodman, 451-464. New York; London: Plenum Press.

Holling, C.S. 1973. Resilience and stability in ecological systems. Annu. Rev. Ecol. & Syst., **4**, 1-23.

Hornung, M. 1985. Acidification of soils by trees and forests. Soil Use and Management, **1**, 24-28.

Hornung, M. & Ball, D.F. 1972. Current studies involving soil chemical variability, Welsh Soils Disc. Group Rep. No 13, 71-90.

Howard, P.J.A. & Howard, D.M. 1984a. Effects of trees on soil properties, a resampling of J.D. Ovington's _Pinus nigra_ var _maritima_ plots at Bedgebury, Abbotswood, and West Tofts. Merlewood Research & Development Paper, No 97, 19 pp.

Howard, P.J.A. & Howard, D.M. 1984b. Effects of trees on soil properties, a resampling of J.D. Ovington's plots at Bedgebury. Merlewood Research & Development Paper, No 100, 47 pp.

Howard, P.J.A. & Howard, D.M. 1984c. Effects of trees on soil properties, a resampling of J.D. Ovington's plots at Abbotswood. Merlewood Research & Development Paper, No 101, 46 pp.

Howard, P.J.A. & Howard, D.M. 1984d. Effects of trees on soil properties, a resampling of J.D. Ovington's plots at West Tofts. Merlewood Research & Development Paper, No 102, 46 pp.

Howard, R.K. 1982. New Zealand's legislative background. Water and Soil Miscellaneous Publication No 46, 219-226.

Huber, B. 1984. How is the EEC likely to influence changes in agricultural impacts in Britain? In: Agriculture and the environment, edited by D. Jenkins, 20-24. Cambridge, UK: Institute of Terrestrial Ecology.

Hutchinson, G.E. 1970. Ianula: an account of the history and development of the Lago di Monterosi, Latium, Italy. Trans. Am. Phil. Soc, **60**, 1-178.

IMP-Environment 1986-1990. Netherlands Indicative Multi-Year Programme for the Environment 1986-1990. The Hague: Ministry of Housing, Physical Planning and Environment, Department of Information and Inernational Relations.

IMP-Environment 1987-1991. Netherlands Indicative Multi-Year Programme for the Environment 1987-1991. The Hague: Ministry of Housing, Physical Planning and Environment, Department of Information and International Relations.

Insam, H. & Domsch, K.H.. 1988. Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites. Microb. Ecol., **15**, 177-188.

Iversen, J. 1969. Retrogressive development of a forest ecosystem demonstrated by pollen diagrams from fossil mor. Oikos (Suppl. No 12), 35-49.

Jenkins, A., Ferrier, R.C., Walken, T.A.B. & Whitehead, P.G. (1988). A modelling study of long term acidification in an upland Scottish catchment. Water, Air & Soil Pollut., **40**, 275-291.

Jenny, H. 1980. The soil resource. New York: Springer-Verlag.

Johnson, L.C. 1987. Soil loss tolerance: Fact or myth? J. Soil & Water Conserv., **42**, 155-160.

Johnston, A.E. 1982. The effects of farming systems on the amount of soil organic matter and its effect on yield at Rothamsted and Woburn. In: Soil degradation (Proceedings of the land use seminar on soil degradation, Wageningen, October 1980), edited by D. Boels, D.B. Davies and A.E. Johnston, 187-202. Rotterdam: Balkema.

Johnston, A.E. in press. Benefits from long-term ecosystem research; some examples from Rothamsted. In: An international workshop: "Long-term ecological research: A global perspective", held at Berchtesgarten in September 1988. UNESCO: Man and the Biosphere.

Johnston, A.E., Goulding, K.W.T. & Poulton, P.R. 1986. Soil acidification during more than 100 years under permanent grassland and woodland at Rothamsted. Soil Use and Management, 2, 3-10.

Kaufman, J.L. 1980. Land planning in an ethical perspective. J. Soil & Water Conserv., 35, 255-258.

Killham, K. & Wainwright, M. 1984. Chemical and microbiological changes in soil following exposure to heavy atmospheric pollution. Environ. Pollut. A 33, 121-131.

Kraft, J.M. & Allmaras, R.R. 1985. Pea root pathogen populations in relation to soil structure, compaction, and water content. In: Ecology and management of soilborne plant pathogens, edited by C.A. Parker, A.D. Rovira, K.J. Moore & P.T.W. Wong, 203-205. Prosser, W.A.:USDA-ARS Irrigated Agriculture Research and Extension Centre.

Kromarek, P. 1984. European aspects of soil and ground protection policy. Translated by E. Lummis. Bonn: Institute for European Environmental Policy.

Lagerlof, J. 1987. Ecology of soil fauna in arable land. Dynamics and activity of microarthropods and enchytraeids in four cropping systems (Rapport 29). Uppsala: Swedish University of Agricultural Sciences.

Larson, W.E. 1981. Protecting the resource base. J. Soil & Water Conserv., 36, 13-16.

Lee, J. 1987. Land resources and their use in the European Communities. In: Scientific basis for soil protection in the European Community, edited by H. Barth and P. L'Hermite, 29-63. London; New York; Elsevier.

Leamy, M.L. 1974. Resources of highly productive land. N.Z. agric. Sci., 8, 187-191.

Lexmond, T.M., Edelman, T. & Van Driel, W. 1986. Voorlopige referentiewaarden en huidige achtergrondgehalten voor een aantal zware metalen en arseen in de bovengrond van natuurterreinen en landbouwgronden. In: Bijlagen behorende bij het advies Bodemkwaliteit (VTCB A86/02-II), contribution 4, 33 pp plus 16 pp of figures. Leidschendam, Netherlands: Technische Commissie Bodembescherming.

Lummis, E. 1984. Issues in soil and ground protection: A United Kingdom persepctive. London; Bonn; Paris: Institute for European Environmental Policy, 100 pp.

MAFF. 1966. Agricultural land classification (Agricultural Land Service Tech. Rep. No. 11). Ministry of Agriculture, Fisheries and Food.

MAFF. 1976. Agricultural land classification of England and Wales. The definition and identification of subgrades within Grade 3 (ADAS Tech. Rep. No. 11/1). Ministry of Agriculture, Fisheries and Food.

Macfadyen, A. 1963. The contribution of the microfauna to total soil metabolism. In: Soil organisms, edited by J. Doeksen and J. van der Drift, 3-17. Amsterdam: North-Holland Publishing Co.

McCormack, D.E., Young, K.K. & Kimberlin, L.W. 1982. Current criteria for determining soil loss tolerance. In: Determinants of soil loss tolerance (Spec. Publ. No. 45). Madison, Wisconsin: American Society of Agronomy.

McFee, W.W. 1980. Sensitivity of soil regions to long-term acid precipitation. In: Atmospheric sulphur deposition: environmental impact and health effects, edited by D.S. Shriner, C.R. Richmond, and S.W. Lindberg, 405-505. Ann Arbor, Michigan: Ann Abor Science.

McGill, W.B., Campbell, C.A., Dormaar, J.F., Paul, E.A. & Anderson, D.W. 1981. Soil organic matter losses. In: Agricultural land, our disappearing heritage - a symposium, 72-133. Edmonton, Alberta: Alberta Soil and Feed Testing Laboratory.

McGrath, D. 1982. Organic carbon levels in Irish soils. In: Soil degradation (Proceedings of the land use seminar on soil degradation, Wageningen, October 1980), edited by D. Boels, D.B. Davies and A.E. Johnston, 259-268. Rotterdam: Balkema.

McGrath, S.P. 1987a. Computerised quality control, statistics and regional mapping of the concentrations of trace and major elements in the soil of England and Wales. Soil Use & Manage., **3**, 31-38.

McGrath, S.P. 1987b. Long-term studies of metal transfers following application of sewage sludge. In: Pollutant transport and fate in ecosystems, edited by P.J. Coughtrey, M.H. Martin and M.H. Unsworth, 301-317. Oxford,; London: Blackwell.

McGrath, S.P., Brookes, P.C. & Giller, K.E. 1988a. Effects of potentially toxic metals in soil derived from past applications of sewage sludge on nitrogen fixation by Trifolium repens L. Soil Biol. & Biochem., **20**, 415-424.

McGrath, S.P., Hirsch, P.R. & Giller, K.E. 1988b. Effect of heavy metal contamination on the genetics of nitrogen-fixing populations of Rhizobium leguminosarum nodulating white clover. In: Environmental contamination, edited by A.A. Orio, 164-166. Edinburgh: C.E.P.

McLaughlin, C. 1979. Current soil conservation policies and institutions: A farmer's assessment. In: Soil conservation policies: An assessment, 75-78. Ankeny, Iowa: Soil Conservation Society of America.

McRae, S.G. & Burnham, C.P. 1981. Land evaluation. Oxford: Clarendon Press.

Margalef, R. 1975. Diversity, stability and maturity in natural ecosystems. In: Unifying concepts in ecology, edited by W.H. van Dobben and R.H. Lowe- McConnell, 151-160. Wageningen: Centre for Agricultural Publishing and Documentation (Pudoc).

Martin, M.H. & Coughtrey, P.J. 1987. Cycling and fate of heavy metals in a contaminated woodland ecosystem. In: Pollutant transport and fate in ecosystems, edited by P.J. Coughtrey, M.H. Martin and M.H. Unsworth. Oxford: Blackwell.

May, R.M. 1975. Stability in eocsystems: some comments. In: Unifying concepts in ecology, edited by W.H. van Dobben and R.H. Lowe-McConnell, 161-168. Wageningen: Centre for Agricultural Publishing and Documentation (Pudoc).

Meister, A.D. 1977. Issues in the use of natural resources: land use planning. Discussion paper in Natural Resource Economics No. 2, 19 pp.

Meister, A.D. 1982. The preservation and use of agricultural land: land use policies and their implementation, a survey. Discussion paper in Natural Resource Economics No. 5, 42 pp.

Meiwas, K.J., Khanna, P.K. & Ulrich, B. 1986. Parameters for describing soil acidification and their relevance to the stability of forest ecosystems. For. Ecol. & Manage, **15**, 161-179.

Miles, J. 1981. Effect of birch on moorlands. Cambridge, UK: Institute of Terrestrial Ecology, 18 pp.

Moen, J.E.T. & Brugman, W.J.K. 1987. Soil protection programmes and strategies in other community member states: examples from The Netherlands. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 429-436. London; New York: Elsevier.

Moen, J.E.T., Cornet, J.P. & Evers, C.W.A. 1986. Soil protection and remedial actions: criteria for decision making and standardization of requirements. In: Contaminated soil, edited by J.W.. Assink and W.J. van den Brink, 441-448. Dordrecht: Martinus Nijohff.

Moen, J.E.T. & Cramer, W. undated. Implementation of a soil protection policy in The Netherlands. Typewritten conference paper.

Moen, J.E.T. & Hosman, A.P.M. 1987. Introduction: Difficulties of application in the field of the directive on the protection of groundwater against pollution caused by certain dangerous substances. In a seminar 'The EEC Directive 80/68 on the protection of groundwater against pollution caused by certain dangerous substances', 10-11 December 1987, Como.

Molloy, L.F. 1980a. Urban expansion and rural subdivision. In: Land alone endures. Land use and the role of research. NZ DSIR Discussion Paper No. 3, 237-246.

Molloy, L.F. 1980b. Present land use planning. In: Land alone endures. Land use and the role of research. NZ DSIR Discussion Paper No. 3, 263-269.

Morgan, R.P.C. 1985. Assessment of soil erosion risk in England and Wales. Soil Use & Manage., 1, 127-131.

Morgan, R.P.C. 1986. Soil erosion and conservation. Harlow, England: Longman.

Morgan, R.P.C. 1987. Sensitivity of European soils to ultimate physical degradation. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. L'Hermite, 147-157. London; New York: Elsevier.

Moss, G. & Neate, S. 1987. Agriculture and rural land use including forestry. In: European environmental yearbook 1987, 25-28. London, UK: DocTer International.

MPG1 1988. Minerals Planning Guidance: General considerations and the development plan system. Department of the Environment and the Welsh Office. January 1988.

MPG (Draft) 1988. Minerals Planning Guidance: The reclamation of mineral workings. Department of the Environment and the Welsh Office. August 1988.

Muller, J. 1972. Identification des formes de la matière organique dans les sols de la champagne crayeuse. Ann. Agron. (Paris), **23**, 587-610.

Napier, T.L. 1988. Socio-economic factors influencing the adoption of soil erosion control practices in the United States. In: Agriculture: Erosion assessment and modelling, edited by R.P.C. Morgan and R.J. Rickson, 299-327. Luxembourg: Office for Official Publications of the European Communities.

National Swedish Environmental Protection Board 1985. Monitor (1985). Solna, Sweden, SNV.

Newbould, P. 1982. Losses and accumulation of organic matter in soils. In: Soil degradation (Proceedings of the land use seminar on soil degradation, Wageningen, October 1980), edited by D. Boels, D.B. Davies and A.E. Johnston, 107-131. Rotterdam: Balkema.

Nilsson, J. 1986. Critical deposition limits for forest soils. In: Critical loads for nitrogen and sulphur, edited by J. Nilsson, 36-69. Copenhagen: Nordic Council of Ministers.

Nilsson, J. (ed). 1986. Critical loads for nitrogen and sulphur. Copenhagen: Nordic Council of Ministers.

Nilsson, J. & Grennfelt, P. 1988. Critical loads for sulphur and nitrogen. Copenhagen: Nordic Council of Ministers.

Nolan, A.J., Lilly, A. & Campbell, C.G.B. 1984. Susceptibility of Scottish soils to acidification. Aberdeen: Macaulay Institute for Soil Research. (Restricted circulation).

Nowak, P.J., Timmons, J., Carlson, J. & Miles, R. 1985. Economic and social perspectives on T values relative to soil erosion and crop productivity. In: Soil erosion and crop productivity, edited by R.F. Follett and B.A. Stewart. Madison, Wisconsin: American Society of Agronomy.

Odum, E.P. 1971. Fundamentals of ecology. Philadelphia; London: W.B. Saunders, 3rd edition, 574 pp.

OECD 1985. OECD Environmental data. Compendium 1985. Paris: Organisation for Economic Co-operation and Development, 297 pp.

Ottevanger, W. 1986. Human cadmium intake in a contaminated region. In: Contaminated soil, edited by J.W. Assink and W.J. van den Brink, 247-250. Dordrecht: Martinus Nijhoff.

Page, G. 1968. Some effects of conifer crops on soil properties. Commonw. For. Rev., **47**, 52-62.

Pagliai, M., la Marca, M. & Lucamented, G. 1985. Relationships between soil structure and time of landspreading of pig slurry. In: Long-term effects of sewage sludge and farm slurries applications, edited by J.H. Williams, G. Guidi and P L'Hermite, 45-56. Barking, UK: Elsevier.

Patten, B.C. 1974. The zero state and ecosystem stability. Proc. 1st. int. Congr. Ecology.

Perrin, R.M.S., Willis, E.H. & Hodge, C.A.H. 1964. Dating of humus podzols by residual radiocarbon activity. Nature, **202**, 165-166.

Persson, T., Baath, E., Clarholm, M., Lundkvist, H., Soderstrom, B.E. & Sohlenius, B. 1980. Trophic structure, biomass dynamics and carbon metabolism of soil organisms in a Scots pine forest. In: Structure and function of northern coniferous forests - an ecosystem study (Ecol. Bull. 32), edited by T. Persson, 419-459. Stockholm: Swedish Natural Science Research Council.

Petersen, H. & Luxton, M. 1982. A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos, **39**, 287-388.

Pigott, C.D. & Taylor, K. 1964. The distribution of some woodland herbs in relation to the supply of N and P in the soil. J. Ecol., **52**, (Suppl.), 175-185.

PPG1 1988. Planning Policy Guidance: General policy and principles. Department of the Environment and the Welsh Office. January 1988.

PPG7 1988. Planning Policy Guidance: Rural enterprise and development. Department of the Environment and the Welsh Office. January 1988.

Prieur, M. 1988. Outline of the feasibility study on possible national and/or European actions in the field of soil protection (PE-SO (88) 6 Add). Strasbourg: Council of Europe (Restricted circulation).

Proudfoot, V.B. 1958. Problems of soil history. Podzol development at Goodland and Torr Townlands, Co. Antrim. J. Soil Sci., **9**, 186-198.

Pyatt, D.G. 1970. Soil groups of upland forests. Forest Rec. Lond., No 71, 51 pp.

Reichle, D.E. 1977. The role of invertebrates in nutrient cycling. In: Soil organisms as components of ecosystems (Ecol. Bull. 25), edited by U. Lohm and T. Persson, 145-154. Stockholm: Swedish Natural Science Research Council.

Reuss, J.O. 1980. Simulation of soil nutrient losses resulting from rainfall acidity. Ecological Modelling, **11**, 15-38.

Reuss, J.O. 1983. Implications of the calcium-aluminium exchange system for the effect of acid precipitation on soils. J. environ. Qual., **12**, 591-595.

Reuss, J.O. & Johnson, D.W. 1986. Acid deposition and the acidification of soils and waters. New York; Berlin; Heidelberg:Springer.

Roberts, B. 1987. Australian land degradation and its control. Ambio, **16**, 272-276.

Robertson, G.P., Huston, M.A., Evans, F.C. & Tiedje, J.M. 1988. Spatial variability in a successional plant community: patterns of nitrogen availability. Ecology, **69**, 1517-1524.

Rowell, D.L. & Wild, A. 1985. Causes of soil acidification: a summary. Soil Use & Manage, **1**, 32-33.

Rushton, S.P. 1986a. Development of earthworm populations on pasture land reclaimed from open-cast coal mining. Pedobiologia, **29**, 27-32.

Rushton, S.P. 1986b. The effects of soil compaction on Lumbricus terrestris and its possible implications for populations on land reclaimed from open-cast coal mining. Pedobiologia, **29**, 85-90.

Russell, E.W. 1973. Soil conditions and plant growth. London: Longman, 10th edition. 849 pp.

Sabbe, W.E. & Marx, D.B. 1987. Soil sampling: spatial and temporal variability. In: Soil Science Society of America Spec. Publ. No. 21, 1-14. Madison, Wisonsin: SSSA.

Sauerbeck, D.R. 1982. Influence of crop rotation, manurial treatment and soil tillage on the organic matter content of German soils. In: Soil degradation (Proceedings of the land use seminar on soil degradation, Wageningen, October 1980), edited by D. Boels, D.B. Davies and A.E. Johnston, 163-179. Rotterdam: Balkema.
Sauerbeck, D. 1987. Effects of agricultural practices on the physical chemical, and biological properties of soils: Part II - Use of sewage sludge and agricultural waste. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 181-210. London; New York: Elsevier.
Saunders, P.J.W. 1987. Soil protection programmes and strategies in other Community member states: The UK approach to soil and landscape protection. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 445-460. London; New York: Elsevier.
Schneider, G. 1987. Soil protection strategy in the Community. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 5-14. London; New York: Elsevier.
Schnoor, J.L. 1984. Modelling of total acid precipitation impacts. London: Butterworth, 222 pp.
Seastedt, T.R. 1984. The role of microarthropods in decomposition and mineralization processes. Annu. Rev. Entomol., **29**, 25-46.
Skiba, U., Cresser, M.S., Derwent, R.G. & Futty, D.W. (1989). Peat acidification in Scotland. Nature, **337**, 68-69.
Slatyer, R.O. 1977. Dynamic changes in terrestrial ecosystems: patterns of change, techniques for study and applications to management. Paris: UNESCO, 30 pp.
Snaydon, R.W. 1962. Micro-distribution of Trifolium repens L. and its relation to soil factors. J. Ecol., **50**, 133-143.
Somerville, L., Greaves, M.P., Domsch, K.H., Verstraete, W., Poole, N.J., van Dijk, H. & Anderson, J.P.E. 1985. Recommended laboratory tests for assessing the side-effects of pesticides on the soil microflora. Bristol, UK: Long Ashton Research Station.
Sparrow, H.O. et al. 1984. Soil at risk. Canada's eroding future. Ottawa, Canada: Senate of Canada.
Steen, E. 1983. Soil animals in relation to agricultural practices and soil productivity. Swedish J. agric. Res., **13**, 157-165.
Steenvoorden, J.H.A.M. & Bouma, J. 1987. Optimizing the use of soils: New agricultural and water management aspects. In: Scientific basis for soil protection in the European Community, edited by H. Barth and P. L'Hermite, 389-408. London; New York: Elsevier.
Sverdrup, H.U. & Warfvinge, P.G. 1988. Assessment of critical loads of acid deposition on forest soils. In: Critical loads for sulphur and nitrogen, edited by J. Nilsson and P. Grennfelt, 81-130. Copenhagen: Nordic Council of Ministers.
Tamm, C.O. & Holman, H. 1967. Some remarks on soil organic matter turn-over in Swedish podzols. Meddr norske SkogsforsVes., No 85 (33) 69-88.
Thompson, T.R.E. & Loveland, P.J. 1985. The acidity of Welsh soils. Soil Use & Manage., **1**, 21-24.
Thornton, I. 1986. Metal contamination of soils in UK urban gardens: implications to health. In: Contaminated soil, edited by J.W. Assink and W.J. van der Brink, 203-209. Dordrecht: Martinus Nijhoff.
Thornton, I., Culbard, E., Moorcroft, S., Watt, J., Wheatley, M. & Thompson, M. 1985. Metals in urban dusts and soils. Environ. Technol. Lett., **6**, 137-144.
Timmons, J.F. 1979. Agriculture's natural resource base: Demand and supply interactions, problems, and remedies. In: Soil conservation policies: An assessment, 53-74. Ankeny, Iowa: Soil Conservation Society of America.

Tipping, E. & Hurley, M.A. 1988. A model of solid-solution interactions in acid organic soils, based on the complexation properties of humic substances. J. Soil Sci., **39**, 505-520.

Tomati, U., Grappelli, A. & Galli, E. 1985. Soil microorganisms and long-term fertility. In: Long-term effects of sewage sludge and farm slurries applications, edited by J.H. Williams, G. Guidi and P L'Hermite, 14-21. Barking, UK: Elsevier.

Turkington, R. & Harper, J.L. 1979. The growth, distribution and neighbour relationships of Trifolium repens in a permanent pasture. I. Ordination, pattern and contact. J. Ecol., **67**, 201-218.

Turnbull, R.G.H. & Aitken, P. 1985. A review of the EEC Directive on Environmental Impact Assessment (EIA). Glasgow: The Planning Exchange.

Tyler, G. 1973. Heavy metal pollution and soil eynzymatic activity. Pl. Soil, **41**, 303-311.

UK Terrestrial Effects Review Group. 1988. First Report: The effects of acid deposition on the terrestrial environment in the United Kingdom. London: HMSO.

Ulrich, B. 1981. Ökologische Gruppierung von Böden nach ihrem chemischen Bodenzustand. Z. PflErnähr. Bodenk., **144**, 289-305.

Ulrich, B. 1983. Soil acidity and its relations to acid deposition. In: Effects of accumulation of air pollutants in forest ecosystems, edited by B. Ulrich and J. Pankrath, 127-146. Dordrecht: Reidel.

Unwin, R.J. & Lewis, S. 1986. The effect upon earthworm populations of very large applications of pig slurry to grassland. Agricultural Wastes, **16**, 67-73.

Usher, M.B. 1976. Aggregation responses of soil arthropods in relation to the soil environment. In: The role of terrestrial and aquatic organisms in decomposition processes, edited by J.M. Anderson and A. Macfadyen, 61-94. Oxford; London: Blackwell.

van Breemen, N., Driscoll, C.T. & Mulder, J. 1984. Acidic deposition and internal proton sources in acidification of soils and waters. Nature, **307**, 599-604.

van Breeman, N., Visser, W.F.J. & Pape, T. 1988. Biogeochemistry of an oak woodland ecosytem in the Netherlands affected by acid atmospheric deposition (Agricultural Research Report No 930). Wageningen: Centre for Agricultural Publishing and Documentation (Pudoc), 197pp.

van Dobben, W. H. & Lowe-McConnell, R.H. (Eds). 1975. Unifying concepts in ecology. Wageningen: Centre for Agricultural Publishing and Documentation (Pudoc), 302pp.

van de Westeringh, W. 1972. Determination of soil structure in worm free orchards. Pedobiologia, **12**, 6-15.

van der Maarel, E. 1978. Ecological principles for physical planning. In: The breakdown and restoration of ecosystems, edited by M.W. Holdgate and M.J. Woodman, 413-450. New York; London: Plenum Press.

van der Zee, S.E.A.T.M. & van Riemsdijk, W.H. 1986. Sorption kinetics and transport of phosphate in sandy soil. Geoderma, **38**, 293-309.

van Riemsdijk, W.H., Boumans, L.J.M. & de Haan, F.A.M. 1984. Phosphate sorption by soils: I. A model for the phosphate reaction with metal-oxides in soil. J. Soil Sci. Soc. Am. **48**, 537-541.

van Rhee, J.A. 1969. Inoculation of earthworms in a newly drained polder. Pedobiologia, **9**, 128-132.

Vegter, J.J. (undated). Soil quality criteria, present situation in The Netherlands and future developments. Typewritten paper.

Vegter, J.J., Roels, J.M. & Bavinck, H.F. 1988. Soil quality standards: Science or science fiction. Draft of a paper to be presented at the Second International TNO/BMFT Conference on Contaminated Soil, Hamburg, April 1988.

Verhoef, H.A. & de Goede, R.G.M. 1985. Effects of collembolan grazing on nitrogen dynamics in a coniferous forest. In: Ecological interactions in soil, edited by A.H. Fitter, D. Atkinson, D.J. Read and M.B. Usher, 367-376. Oxford, UK: Blackwell.

Vossbrinck, C.R., Coleman, D.C. & Woolley, T.A. 1979. Abiotic and biotic factors in litter decomposition in a semi-arid grassland. Ecology, **60**, 265-271.

Wang, C. & Coote, D.R. 1981. Sensitivity classification of agricultural land to long term acid precipitation in eastern Canada (LRRI contribution 98). Agriculture Canada Research Board.

Webber, M.D., Kloke, A. & Tjell, J.C. 1984. A review of current sludge use guidelines for the control of heavy metal contamination in soils. In: Processing and use of sewage sludge (CEC symposium Brighton, UK, September 27-30, 1983), edited by P.L'Hermite & H. Ott, 371-386. (EUR 9129). Dordrecht: Reidel.

Webster, R. & Cuanalo de la C, H.E. 1975. Soil transect correlograms of North Oxfordshire and their interpretation. J. Soil Sci., **26**, 176-194.

Whitehead, P.G., Bird, S., Hornung, M., Cosby, J., Neal, C. & Paricos, P. 1988. Stream acidification trends in the Welsh uplands - a modelling study of the Llyn Brianne catchments. J. Hydrology, **101**, 191-212.

Whitehead, P.G., Reynolds, R., Hornung, M., Neal, C., Cosby, J. & Parkos, P. 1988. Modelling long term steam acidification trends in upland Wales at Plynlimon. Hydrological Processes, **2**, 357-368.

Whittaker, R.H. 1975. The design and stability of plant communities. In: Unifying concepts in ecology, edited by W.H. van Dobben and R.H. Lowe-McConnell, 169-181 Wageningen: Centre for Agricultural Publishing and Documentation (Pudoc).

Wiklander, L. 1974. The acidification of soil by acid precipitation. Grundforbattring, **26**, 155-164.

Wilkinson, C.F. 1987. Soil conservationists and the uses of law. J. Soil & Water Conserv., **42**, 304-311.

Williams, B.L., Cooper, J.M.. & Pyatt, D.G. 1979. Effects of afforestation with Pinus contorta on nutrient content, acidity and exchangeable cations in peat. Forestry, **51**, 29-35.

Witkamp, M. & Ausmus, B.S. 1976. Processes in decomposition and nutrient transfer in forest systems. In: The role of terrestrial and aquatic organisms in decomposition processes, edited by J.M. Anderson and A. Macfadyen, 375-396. Oxford: Blackwell.

Yarn, J. 1979. Natural resources in an age of uncertainty. In: Soil conservation policies: An assessment, 47-52. Ankeny, Iowa: Soil Conservation Society of America.

Yassoglou, N.J. 1987. The production potential of soils: Part II - Sensitivity of the soil systems in southern Europe to degrading influxes. In: Scientific basis for soil protection in the European Community, edited by H. Barth & P. l'Hermite, 87-22. London; New York: Elsevier.

APPENDIX 1 GLOSSARY

The definitions given here refer to the way in which terms have been used in this report.

Acceptable level The value of any specified soil property which is within the specified limit value.

Acceptable load Any rate of application of a degrading influence which does not exceed the maximum level.

Activity Management, practices or events causing or leading directly or indirectly to an 'impact' (q.v.) are referred to as activities. Thus the application of fertilizers to land or the leaking of a sewer are activities which can lead to nitrate reaching groundwater (impact).

Bio-availability There is usually not a simple relationship between the total amount of a compound in soil and its biological action. The term bio-availability refers to the availability of the compound to living organisms. It involves considerations of both quantity and intensity, i.e. electrochemical potential (de Haan 1987 pp233-234).

Buffering capacity The buffering capacity of a soil, in a general sense, may be defined as its capacity to delay the effects of a degrading influence. For pollutants, this may involve inactivation either by bonding onto soil constituents or sometimes the conversion into insoluble and inactive compounds. The extent of the soil buffering capacity varies widely for different substances, and reflects the vulnerability of a soil to degradation (de Haan 1987 p229). See also Fränzle (1987 p139).

If the buffering capacity is exceeded, a soil system will show directional change, passing through a series of transitional states towards a new steady state condition the nature of which is determined by the new external conditions. The changes will be more rapid in the more sensitive soil systems than in the less sensitivies systems.

Because of the complexity of soil systems, we need to know what are the important variables which indicate the state of, and trends within, those systems. Such variables will assume the nature of indicator variables (Fränzle 1987).

Capability The main aim of the American (USDA) method for land capability assessment is to assess the degree of limitation to land use or potential imposed by land characteristics, on the basis of permanent properties. There is a scale of land capability classes, each of which is defined by a degree of limitation and hazard. As the degree of limitation (and capability class) increases, so the range of land use options decreases.

The Soil Survey of England and Wales Land Use Capability Classification is modelled on the USDA scheme. Land capability assessment utilizes information on slope angle, climate, flood and erosion risk, as well as soil properties.

Capability and suitability classifications are complementary, and overlap to some extent.

Compound speciation Usually, it is not the total content of a contaminant which governs its effect, but rather its active form. The total amount of a contaminant in a soil may be distributed in various chemical forms: as a mineral, adsorbed on to the solid phase, or dissolved in the soil solution (de Haan 1987 p230). The behaviour of compounds in soil is also affected by soil heterogeneity.

Conservation In general, soil conservation means prevention of loss of soil, i.e. erosion.

Criterion A definition or standard which is used to test or judge a property. The criterion may be a limiting value.

Critical load The highest rate of application of a degrading influence that will not cause changes leading to long-term harmful effects on the most sensitive ecological systems. This is the maximum concentration or level of an 'impact' (q.v.) that can be sustained by such a soil before degradation occurs.

Degradation Really, this means any change which we consider undesirable. Soil degradation is the product of a number of phenomena, including water and wind erosion, salinisation and alkalisation, physical degradation, chemical degradation, and biological degradation (Fedoroff 1987 p66).

Heterogeneity It is a fundamental property of soils that they show vertical differentiation. However, for a given depth soil properties also vary laterally. Soil heterogeneity occurs on a number of scales, from that of soil particles to that of regional soil maps. Heterogeneity greatly influences the behaviour of compounds in soils, and must therefore be taken into account in soil quality evaluation (de Haan 1987 pp231-233).

Homeostasis The capacity of an ecosystem to maintain or re-establish a particular pattern of structure and function, by biological mechanisms in the face of some disturbing influence.

Impact A form of degradation such as soil compaction or nitrate in groundwater.

Improvement The reverse of degradation.

Index A number which expresses some property which is of interest. The property itself may not be readily measured, in which case the index will be a property which is known to be related to the one of interest. For example, possible indices of soil organic matter content are percent loss-on-ignition and carbon content.

Limit value The maximum permitted value of an undesirable soil property, or maximum permitted content of a pollutant, or the minimum permitted value of a desirable soil property. According to Table 7 in Sauerbeck (1987), the CEC uses the term limit value where it means maximum load.

Maximum load This is the maximum permitted rate of application of a degrading influence, i.e. the maximum rate of addition which does not cause the limit value to be reached. It depends on a number of soil properties, for example for pollutants it depends on whether the substance of interest is retained in the soil or not, and if it is retained in the soil, whether it is inactivated or remains in a bio-available form. It is related to the limit value and buffer capacity.

In Germany, the maximum loads of heavy metals which may be applied to soil in sewage sludge are (g/ha/annum):Cd 33, Cr 2, Cu 2, Hg 42, Ni 333, Pb 2, Zn 5. The corresponding soil limit values are (ppm): Cd 3, Cr 100, Cu 100, Hg 2, Ni 50, Pb 100, Zn 300 (Sauerbeck 1987).

Mor A humus form in which organic matter accumulates on the soil surface, generally because of a low level of soil faunal activity. Its chemical properties and biological activity differ from those in mull (q.v.), in particular, the soils are more acid and have low levels of many plant nutrients. Although the organic matter contains nitrogen, little of it is available to plants.

Mull A humus form in which organic matter is intimately incorporated into the upper mineral soil by the activities of soil fauna, chiefly earthworms. Its chemical properties and biological activity differ from these in mor (q.v.), in particular the soils are less acid and have greater contents of many plant nutrients, especially nitrogen.

Multifunctionality The range of uses to which a given soil may be put depends upon its inherent properties and those of the site in which it occurs. Some soils may be suitable for a wider range of uses than others. The properties of a soil which is suitable for a wide range of uses may be changed under one particular use to such an extent that the range of possible uses decreases. The multifunctionality concept involves preserving the properties of a given soil which are important for the widest possible range of functions so as to keep all options open for future generations.

Multifunctionality is a complex concept. A complete and unambiguous description of a multifunctional soil in terms of measurable chemical, physical, and biological characteristics may be a long and arduous task. However, the development of a soil protection policy does not depend fully on the availability of such a complete description. It may be focussed primarily on those human activities which have irreversible effects on the structure and composition of the soil and which may endanger any use of the soil by human beings, plants, or animals (Moen & Brugman 1987).

Optimization Optimization involves the consideration of all relevant soil and environmental properties when deciding upon a management practice. For example, in applying nitrate to crops, the conditions for crop uptake of nitrate must be optimal. In some cases, this may involve irrigation. Shallow groundwater transport may be responsible for an important extra P load in surface waters. Lowering the ground water table will reduce the risk of removal of applied P in surface run-off and shallow ground water movement (Steenvoorden and Bouma 1987).

Parameter An unknown quantity which may vary over a certain set of values. In common use, synonymous with variable. Therefore 'indices' are values of parameters.

Primary causative factor These are factors that often result from 'activities' and are the direct causes of 'impacts'. Thus, the growing of an autumn cereal crop is an activity that results in bare ground over winter (primary causative factor) that leads to a higher risk of erosion by water (impact).

Protection The prevention or control of activities which lead to soil degradation. Because soil is a part of an ecosystem, and has links with other components such as the atmosphere, hydrosphere, biosphere, or lithosphere, it is not helpful to protect soil in isolation. It is necessary to control all potential sources of pollution and risks from all forms of land use.

Quality Soil quality is extremely difficult to define. The use of this term implies that some soils are of "good" quality and some are of "poor" quality. However, these terms only have meaning in terms of some specific use. "A pre-requisite for the establishment of rules and measures for soil protection is a means for soil quality evaluation" (de Haan 1987 p211).

Because of the variety of soil types and soil properties, a quantitative soil quality evaluation cannot be based on single values. Under the multifunctionality concept, a soil of good quality may be defined as one which poses no harm to any use by human beings, plants, and animals, which can function without restriction in natural cycles, and which does not contaminate other parts of the environment.

Resilience In everyday use, this is defined as: the act of rebounding or springing back; the power of resuming the original shape or position after compression etc. In the context of soil protection, we can define it as the ability of a soil to return to its original state after some degrading influence has been removed. A highly-resilient soil would return quickly.

Reversibility If the properties of a soil have been changed by some degrading influence, the effect is said to be reversible if the properties can be returned to their original values either naturally or by some form of recovery operation. Some changes are irreversible. If the properties of interest can be reversed easily, they may be said to have a high reversibility. In such a case, the soil may be said to have a high resilience with respect to that particular degrading influence.

Risk assessment This is the establishment of the quantitative relationship between exposure to a degrading influence and its effect. This is related to soil buffering capacity and soil heterogeneity. For pollutants, it is also related to compound speciation and bio-availability of the compound (De Haan 1987).

Sensitivity (i) May be defined as the tendency for the properties of a soil to deteriorate and for the soil itself to be subject to degradation (Federoff 1987 p67). (ii) Could be defined as the rate of variation of dependent properties caused by given influxes (Yassoglou 1987 p92). The assessment of soil sensitivity is a very complex and difficult task (Yassoglou 1987 p96). The sensitivity of a soil is determined mainly by its primary properties, such as the texture at various depths; mineralogical properties of the clays; quantity and type of organic matter; intensity and type of biological activity. These give rise to secondary properties such as aggregation, stability of structure, permeability and porosity. Site factors such as topography, which affects drainage, are also important. Fedoroff (1987) made a preliminary attempt to evaluate the sensitivity, on a scale of 0 to 5, of various soil types in NW Europe to intensive agriculture. Fränzle (1987) defined sensitivity of soils to pollution as the velocity of sequential change in soil properties as related to the impact of pollutants. Its assessment requires a knowledge of the relevant physical and chemical transformation mechanisms and their specific boundary conditions. This is related to buffering capacity; the greater the buffering capacity the smaller the change and therefore the lower the sensitivity. Morgan (1987) discussed the sensitivity of European soils to erosion.

Soil loss tolerance or T factor is the maximum soil erosion loss which is acceptable on a continuing basis at any particular cropping site. It is expressed in weight per unit area, either tons/acre or tonnes/ha, and is calculated by means of the Universal Soil Loss Equation.

Suitability According to the FAO Framework for Land Evaluation 1976, land suitability is the fitness of a given type of land for a defined use. The term "suitability" is used rather than "capability" to avoid confusion with the American, and other, capability schemes. The assessment of suitability involves soil and environmental properties. One of the principles upon which it is founded is the comparison of benefits with inputs. Another is that the implementation of a land use proposal must not result in severe or progressive degradation. The Soil Survey of England and Wales (now the Soil Survey and Land Research Centre) followed these principles in establishing suitability classifications for a range of agricultural crops. Lee (1987) discussed suitability classifications for grassland and arable use in EEC countries. Suitability and capability classifications are complementary, and overlap to some extent.

Susceptibility The susceptibility of a soil system to a stress may be defined as the likelihood of a given form of degradation occurring. Thus, a soil may be susceptible to erosion, and erosion results from a soil's sensitivity to rainfall. That sensitivity is determined largely by soil texture, slope, and surface cover.

Threshold value Synonymous with limit value.

Trafficability A measure of the ability of land to support wheeled vehicular traffic without there being damage to soil structure.

Universal Soil Loss Equation is a simple equation, used especially in the USA, for predicting the annual estimated soil loss A (weight per unit area)

$$A = R \times K \times L \times S \times C \times P$$

R is the rainfall and runoff factor for a specific location in average annual erosion index units.

K is the soil erodibility factor for a specific soil horizon , expressed as soil loss per unit area per unit of R for a unit plot (which is 72.6 feet long with a uniform 9% slope, maintained in continuous fallow, with tillage when necessary to break surface crusts).

L is a dimensionless slope-length factor, not actual slope length, expressed as the ratio of soil loss from a given slope length to that from a 72.6 foot slope length in the same conditions.

S is a dimensionless slope-steepness factor, not actual slope steepness, expressed as the ratio of soil loss from a given slope steepness to that from a 9% slope in the same conditions.

C is a dimensionless cover and management or cropping-management factor, expressed as a ratio of the soil loss from the condition of interest to that from tiled continuous fallow.

P is a dimensionless supporting erosion-control practice factor, expressed as a ratio of the soil loss with practices such as contouring, stripcropping, or terracing, to that with farming up-and-down slope.

In application, for a specific location, A is calculated and compared with the established soil loss tolerance value T. Alternatively, T is set equal to A and the equation is solved for the maximum C P value that will keep the expected average annual soil loss within the required tolerance limit.

Workability Soil workability is the ease with which a soil can be cultivated or worked to produce the desired result. It depends on a number of soil properties and is markedly influenced by moisture content.

Appendix 2: Soil protection/conservation in other countries.

	Page
The Netherlands: soil protection policies	197
The Federal Republic of Germany: soil protection and the Bodenschutzkonzeption	206
France: soil protection	218
Switzerland: soil protection policies	219
Denmark: environmental protection policy	228
The United States: soil conservation	239
Canada: land protection legislation	249
Australia: environmental conservation	256
New Zealand: water and soil conservation	260

The Netherlands: soil protection policies

In the Dutch legislation, the definition of 'soil' includes the groundwater, gases, and soil organisms. A central concept in Dutch environmental policy is that of being "a guest in our own environment". There are two tracks of policy. The first is effect-oriented, and emphasis is laid on defining quantitative parameters for a 'good soil quality'. The second track is source-oriented, and distinguishes between local sources and diffuse sources. Local sources have to meet the criteria of isolation, monitoring, and control. For diffuse sources, a link is made between the application of substances and the maintenance of a 'good soil quality' (Moen & Brugman 1987).

The effect-oriented policy defines the objectives which are to be pursued with respect to the quality of the environment in the Netherlands, and the tasks for target groups, such as industry and agriculture, implied by those objectives. In the effect-oriented policy, the goal of ensuring the health and well-being of people and the preservation of animals, plants, goods, and forms of use has been translated into the task of preserving the properties of the soil which are important for various possible functions, the so-called 'multifunctionality' concept. This aims at keeping all options open for future generations. From a purely scientific viewpoint, multifunctionality is a complex concept. A complete and unambiguous description of a multifunctional soil in terms of measurable chemical, physical, and biological characteristics may take some time. However, in the short term attention may be focussed on those human activities which have irreversible effects on the structure, composition, and function of a soil and might endanger any use by human beings, plants, and animals. Examples are pollution of the soil with heavy metals, several organic chemicals, and nitrates in groundwater.

The source-oriented policy indicates the manner and the pace in which the behaviour of the target groups will be adjusted with respect to the environmental quality objectives and tasks formulated in the framework of the effect-oriented policy. In the source-oriented policy, a desired soil quality sets goals such as the reduction of emissions from sources of soil contamination. Sources of pollution are classified as local (point) sources or diffuse (non-point) sources. For local sources, only a remote link with soil quality is made, as the approach for these sources is isolation. To be able to standardize isolation, monitoring, and control provisions for different materials and different soils, general and source-specific standards for the acceptable risk levels of a possible failure of such provisions are being developed. Diffuse sources have to meet other criteria. One objective is to define a link between the application of substances and the maintenance of a 'good soil quality'.

For the long-term preservation of soil quality, an acceptable equilibrium between input and output of substances must be reached, and that may only be possible with non-accumulating or non-persistent substances which are degraded naturally, or with substances that are removed by crops. Most heavy metals and many organic pollutants which do not meet specified requirements concerning persistence and biodegradability are placed on a 'black list' of substances that should not be allowed to enter the soil. This list is based on the EC guideline on groundwater protection, and forms one of the bases for the selection of 'priority substances'. For these substances, so-called criteria documents are being prepared. They contain the present knowledge on emissions, risks, behaviour in air, water and soil, effects on man, animals, plants, and ecosystems, financial and technical aspects of emission reduction and monitoring strategies. These documents provide the scientific basis for measures concerning emissions to soil, air, and water.

An important step in defining 'good soil quality' in quantitative terms is the formulation of reference standards. The Dutch government has published a discussion note on provisional reference values for certain parameters that take into account the heterogeneity of the soil environment. For some major pollutants, such as nitrate and phosphate, provisional values which indicate the desired quality of the upper levels of groundwater have been published in the Environmental Programme 1986-90.

Soil policy in the Netherlands is embedded in general environmental policy, and is characterized by an integrated approach, measures taken to maintain the desired quality of one part of the environment should not lead to problem-shifting to another part. One important instrument in general environmental and soil policy is planning. Another is research and monitoring of environmental data. A national groundwater monitoring network has been completed, and a monitoring programme for soil quality is in preparation. In The Netherlands, soil protection research has become a priority area of Dutch science policy.

The Implementation of Soil Protection Policies in The Netherlands

In January 1987 the Soil Protection Act became operative. It provides the structural basis and the necessary administrative implements for the implementation of the soil protection policy. The priorities defined for following the two tracks, effect-oriented policy and source-oriented policy, are formulated in a yearly Environmental Programme.

The Soil Protection Act distinguishes two levels of protection, the general protection level and a specific protection level. They differ only in the size of the acceptable risk-level for soil pollution caused by certain activities. The general protection level is formed by regulatory measures to be set by the national government. These concern the regulation of activities that may lead to pollution or impairment of the soil, and the formulation of soil quality standards.

A specific protection level must be effected in special areas, the so-called soil protection areas and groundwater protection areas. In such areas, the acceptable risk level of soil pollution is lower and potential harmful activities are not tolerable, or additional preventive measures are necessary.

Although sufficient knowledge exists to provide a basis for the implementation of a soil protection policy, much research will be needed, especially concerning ecological aspects, the natural regeneration potential of soils, risk analysis, and remedial action in the event of pollution. In the Netherlands, soil protection research has become a priority area, and often requires a multi-disciplinary approach. Monitoring, modelling, and mapping are considered to be important tools (Moen & Cramer undated).

The progress of the Dutch environmental policy is presented in Environmental Programme of the Netherlands 1987-1991. Emissions of acidifying substances into the air are being abated partially with an eye to ecological effects in water and soil, and all environmental consequences of substances such as benzene, cadmium, and polychlorinated biphenyls (PCB's) are being taken into account regardless of where in the environment they occur.

A planned approach to environmental policy is beginning to be given substance at the national level. The first phase in establishing a system of environmental policy for the national government will be closed with the publication of the National Environmental Policy Plan, expected in the spring of 1988. At the same time, discussions are proceeding concerning an integral approach with the provinces.

The sectoral environmental legislation has been virtually completed with the publication of the Soil Protection Act, which came into force on January 1st 1987. Two other Acts also came into force in 1987, the Environmentally Dangerous Substances Act and the bill for expanding the General Environmental Provisions Act with rules regarding environmental impact assessment. The Air Pollution Act has been expanded with the possibility for setting environmental quality standards, which is important for the effect-oriented policy to be implemented.

In order to strengthen the relevance for policy, the research programmes are being attuned to the central themes, the signalled environmental issues, and the priority target groups. The research into environmental standards will also be intensified in connection with risk analysis, especially radiation risks. Other research effort focusses on the monitoring of the environment, and various monitoring networks already exist. Research is also being done on models and indicators for describing the development of environmental quality. Many national research institutes, research agencies, and universities participate in environmental policy research.

Acid deposition is considered to be an important environmental problem because of its effect on soil, vegetation, surface waters, and materials. The provisional deposition objective in the IMP-Air 1985-1989 was 1400 acid equivalents per hectare per year. To protect the most sensitive soils, this figure may be reduced to between 100 and 750 acid equivalents per hectare per year in the long run. In order to protect an average forest ecosystem from becoming saturated with nitrogen, the maximum deposition of nitrogen can be 700 to 1400 nitrogen equivalents per hectare per year, or 400 on the very poorest soils. The IMP-Air 1985-1989 stated that sulphur dioxide, nitrogen oxides (NO_x) and ammonia emissions in the Netherlands must be reduced by factors of 3.5, 1.5, and 2 respectively, relative to the situation in 1980. Similar measures are expected to be taken in other countries to reduce deposition in the Netherlands. In certain regions with high ammonia emissions, greater reductions will be necessary.

A policy for NO_x is currently being prepared in the EC. A 30% reduction in sulphur dioxide emission by 1993 has already been agreed to in the EC framework.

Emission limitation at source is considered to be essential in controlling the effects of acidification. Where emission limitation is not reducing the effects quickly enough, temporary management measures will need to be taken. Possibilities for regenerating acidified surface waters are being examined.

With regard to fertilizers, provisional quality levels for phosphorus and nitrogen were given in IMP-Environment 1986-1990 (p39). A document on nitrate has yet to be published, and when it appears the provisional quality levels may need to be modified. The EC guide level for nitrate-N in drinking water is 5.6 mg per litre, the maximum permissible level is 11.3 mg per litre. In the Netherlands, the guide level was exceeded at 6 pumping stations in 1980. In several private wells concentrations of more than 20 mg per litre have been reached (Moen & Cramer undated). Nitrate problems in the Netherlands have been reviewed by several authors. The source-oriented policy on these substances concerns animal manure, detergents, sewage water purification, and release of chemicals into rivers. Several models are being developed to predict future nitrate concentrations in groundwater in relation to different manuring practice scenarios. High application rates of manure may eventually cause phosphate leaching. In the Netherlands, the capacity of the soil to adsorb phosphate is already exhausted at several locations (Moen & Cramer undated).

Attempts will be made to develop a model which can provide better insight into the connection between effect- and source-oriented measures and the integrated environmental quality.

The Environmentally Dangerous Substances Act (EDSA) aims to control the diffusion of both new and existing substances. A list of priority substances has been drawn up (IMP-Environment 1987-1991 pp24-25), but policies have been formulated only for phosphate, NO_x, sulphur dioxide, and carbon monoxide. Basis documents are being drawn up, and those for benzene,cadmium, and dichloromethane will be published shortly. There is also an "attention substances" list (IMP-Environment 1987-1991 p26) which covers a range of substances on which more information is needed.

Provisional reference values for soil quality have been presented in a discussion memorandum. An interim Act on Soil Sanitation exists, and deals with the cleansing of already-polluted soils. The Leidraad Bodemsaniering (soil clean-up guideline) gives guide values for assessing soil contamination by organic substances (Table 22).

Among the criteria published in the guideline is the ABC list, which gives numerical values for concentrations of chemical substances commonly found in polluted soil and groundwater. The list is intended to give some indication to the local authorities if observed values are (A) quite normal, (B) somewhat exceptional and require further investigation or (C) indicate a dangerous level of pollution. As the values given in the list should be used in conjunction with other, site-specific, criteria and the choice for appropriate remedial actions is restricted to the more dangerously-polluted sites, no further differentiation of numerical values, e.g. with respect to soil type, was considered necessary (Vegter undated).

Various Acts and guidelines exist, or are in preparation, on the treatment of wastes. An EC guideline on beverage packing exists, and one on the disposal of mercury oxide batteries is in preparation. A list of chemical wastes is being assembled. A radiological standards system for the storage of radioactive waste is being drawn up

Source-oriented measures are aimed at reducing or preventing the direct negative environmental impacts of society's activities. A list of target groups has been prepared (IMP-Environment 1987-1991 p57). Measures have been proposed to reduce the nitrogen, phosphorus, cadmium, copper, and zinc contents of animal fodder. A preliminary draft decree gives norms for the use of manure in kilograms per hectare. Manure is also covered by the regulations governing ammonia in air.

Research has begun into hydrocarbon emissions from the storage and trans-shipment of crude oil and oil products. Attention is to be paid to the problem of coal residues.

In March 1988 there were four General Administrative Orders concerning (i) Materials used in building, (ii) Storage of materials and chemicals, (iii) Industrial cooling water etc., and (iv) Manure application. Each of the orders refers to the list of reference values for soil quality. Scientifically, a major problem is that the reference values have no standard errors and there is no allowance for soil heterogeneity. This could lead to difficulties.

The provinces apply the Soil Protection Act and deal with appeals, not necessarily uniformly. Provinces are more inclined to listen to appeals on grounds of economics. There is a band of hygiene inspectors, and the agriculture ministry has its own protection group. Reference values are applied more strictly in protection areas than in other areas. Farmers can be fined for dumping too much manure, or for spreading it in the wrong conditions. Exemptions are granted only in special circumstances. It is essential for any rules to be simple. This makes it easier for farmers to comply and inspectors to inspect.

The number of soil and groundwater protection areas varies from province to province, and the provinces are working on this problem. Too much protected land in a province is an economic restriction. At present, work is being done on criteria for defining protection areas. It is the responsibility of the provinces, prompted by central government, to carry out such surveys. This is a hot issue at the provincial level. For every square metre of land in the Netherlands there is a multiplicity of conflicting requirements.

Although special attention is being paid to the problem of nitrates, phosphates, and metal and organic pollutants, acid rain research gets a lot of money, with consequent spin-off to fundamental research. The possibilities for soil regeneration are also being investigated. There is a need for research on ecological aspects, the natural regeneration potentials of soils, and risk analysis. There is a combined project on artificial soils which result from clean-up operations. This includes soil biological aspects, e.g. earthworms.

Harbour sludge is also a problem. It is polluted by materials released into rivers. If it is dumped into the North Sea it migrates northwards to the Waddensee, an important wildlife site.

Table 22

Guide values for assessing soil contamination by organic substances (in mg kg^{-1} dry matter)
(Source: Leidraad Bodemsanering 1983 - Soil clean-up guideline)

A = Reference value. B= Test requirements. C = Clean-up limit
Rough guide only; the precise values will depend on the use made of the soil and on the specific conditions.
(From Sauerbeck 1987)

Category	A	B	C
Polycyclic aromatic hydrocarbons (PAH)			
Naphthalene	0.1	5	50
Anthracene	0.1	10	100
Phenanthrene	0.1	10	100
Fluoranthene	0.1	10	100
Pyrene	0.1	10	100
Benzo(a)pyrene	0.05	1	10
PAHs-total	1	20	200
Chlorinated hydrocarbons (CH)			
Aliphatic CHs ind.	0.1	5	50
Aliphatic CHs total	0.1	7	70
Chlorobenzenes ind.	0.05	1	10
Chlorobenzenes total	0.05	2	20
Chlorophenols ind.	0.01	0.5	5
Chlorophenols total	0.01	1	10
CH-total	0.05	1	10
PCBs	0.05	1	10
EOCl-total	0.1	8	80
Pesticides			
Organochlorine ind.	0.1	0.5	5
Organochlorine total	0.1	1	10
Pesticides-total	0.1	2	20
Aromatic compounds			
Benzene	0.01	0.5	5
Ethyl benzene	0.05	5	50
Toluol	0.05	3	30
Xylol	0.05	5	50
Phenol	0.02	1	10
Aromatics-total	0.1	7	70
Other organic compounds			
Tetrahydrofuran	0.1	4	40
Pyridine	0.1	2	20
Tetrahydrothiophen	0.1	5	50
Cyclohexanone	0.1	6	60
Styrol	0.1	5	50
Gasoline	20	100	800
Mineral oil	100	1000	5000

The Federal Republic of Germany: soil protection and the Bodenschutzkonzeption

Soil protection in western Germany is increasing in importance for three main reasons (Delmhorst 1987): (i) because of the importance of soil as a resource; (ii) because Germany's population density and industrial activity place heavy demands on its environment and natural resources; (iii) not enough has been done to prevent soil pollution.

Current legislation "provides a framework for striking a balance between the demands made on the soil by the various uses and the prevention of damage, hazards, and long-term risks. At the same time it states clearly that, irrespective of their use to mankind, natural resources are worth saving for their own sake". The idea behind the Soil Protection Plan is to establish soil protection as the central component of an environmental policy which puts ecological considerations first.

In the consideration of the areas of environmental policy which have an impact on the soil, two central lines of action have emerged: (i) minimization of inputs of substances from industry, commerce, transport, agriculture, or the domestic sector which pose a problem either because of their quality or because of the quantities involved; (ii) changing the pattern of land use. More must be done to use land for purposes to which natural conditions at the site are best suited. Raw materials must be used sparingly and efficiently. As a general rule, any remaining undisturbed areas, or areas still in an almost natural state, should be safeguarded. Before any more land is built upon, schemes should be promoted to maintain and regenerate disused land in urban areas, to make more careful use of land when building, and to upgrade existing transport links where possible. More careful use of land would reduce the demands made on the soil and also soil pollution. To achieve this, greater importance must be attached to ecological considerations throughout all the planning procedures. Such considerations include the protection of groundwater resources against any further damage by nitrogenous compounds in fertilizers or by plant protection agents.

Soil protection must be the decisive restraint whenever human activity could lead to pollution of the food chain or groundwater resources, or to lasting disturbance of other functions dependent on the soil. This implies, among other things, the setting of limit values for persistent pollutants from all sources.

The 1985 Bodenschutzkonzeption recognised that "Despite all efforts to reduce injurious pollution, serious damage and long-term risks with respect to quality cannot be precluded. For this reason, a durable protection of the basic environment including soil and its functions requires a comprehensive interdepartmental approach in environmental policy". Soil was considered to be:

- basic environment and habitat for man, animals and plants
- a part of the ecosystems with their metabolisms, particularly with respect to water balance and balance of nutrients
- a determining element for nature and landscape

Soil was considered to serve man as:

- growing area for the production of food, feedstuffs, and vegetable raw materials
- area for settlement, manufacturing, traffic, and communications
- deposit ground for waste and filter for emitted substances
- groundwater reservoir
- location of mineral resources and energy sources
- recreation area
- archives of natural history and history of civilization

These functions of soil, their protection requirements, the claims for use imposed on them, as well as the resulting hazard potentials, formed the basis for the soil protection policies of the Federal Government. "Soil protection must set standards for maintaining the soil's functions within nature in order to prevent hazards for natural ecosystems and ecosystems close to nature and for ecosystems dominated by agriculture and forestry as well as to reduce existing hazards".

The Bodenschutzkonzeption also noted that "Agriculture and forestry affect large parts of the ecosystem. They are well organized if they, inter alia, permanently conserve the fertility of the soil, especially by maintaining a normal balance of nutrients and humus. At the same time agriculture and forestry must, inter alia, observe the interactive effects of soil functions in agricultural and forest ecosystems and natural ecosystems to an extent which does not pose a threat on the stability of nature in general. Soil protection must restrict interferences of the effective relations of soil, flora and fauna to an ecologically sound level by limiting the effects of substances to the soil (nutrient supply and reduction, application of plant protection agents) and changes of the soil's structure and at the same time equally observe the requirements for a sufficient long-term supply with agricultural and forest products".

Furthermore "Land use must observe long-term ecological requirements by selecting the most beneficial distributions and allocations as well as with respect to its type and extent. Here, soil protection includes the observation and evaluation of social requirements of soil functions, considering environmental compatibility standards as well as the assessment of the effects to the area".

It was recognized that the complexity of ecosystems, expansion of and dynamics of changes in ecosystems as well as the irreversibility of some processes are reasons why, according to the present state of knowledge, it is often impossible to specify exactly when, and because of which effects, a serious threat to soil's functions exists or will come into existence. Furthermore, threats are often not recognized by analyzing the status quo, but can only be recognized through long-term forecasts.

The task for a soil protection concept of the Federal Government was established in a Joint Declaration on 23 February 1983 by the Federal Ministers of the Interior, of Food, Agriculture and Forestry, for Regional Planning, Building and Urban Development, of Defence, for Youth, Family Affairs and Health, and for Research and Technology, who were all responsible for the protection of soil. "The Federal Ministers have decided that in future soil protection shall be carried out as comprehensively as protection of nature, and landscape conservation, air pollution control, noise prevention, maintenance of water balance, and waste disposal. The numerous ecological and economic relations and interactions must be included from the beginning".

The Integrated Departmental Working Group on Soil Protection (IMAB - Interministerielle Arbeitsgruppe Bodenschutz), established on 7 January 1983, was divided into five sub-groups in order to evaluate the following subjects:

- agriculture and protection of nature
- water balance
- mineral resources
- land use
- strains and demands for use

and to prepare a systematic soil protection concept. It also had to evaluate possibilities for enforcement.

Once the Bodenschutzkonzeption had been passed by the Federal Government, the plan was for the Federal Government to co-operate with the Länder (regional governments) on the basis of the Bodenschutzkonzeption and the final report of the Federal/Länder working group "Soil Protection Programme", and to define necessary protection measures with respect to subjects, priorities, time, and costs.

There were two general approaches.

i. The introduction of substances from industry, trade, traffic, farming, and households, which are considered to be critical with respect to their strength or quantity should be minimized.

ii. Land use should be more closely related to natural conditions.

Emphasis was placed on the need for preventative measures, and the responsibility of individuals and industry was recognized via the 'polluter pays' principle. The Federal Government extended as well as encouraged the participation of all forces and groups of society in solving environmental problems (the 'co-operation principle').

A major problem in most developed countries is that generally soil is private or public property. Because of the importance of soil to the nation, the Federal Constitutional Court, in a decision of 12 January 1967, gave special emphasis to the social commitment of property with regard to this legal asset. According to this decision, the utilization of one's real estate cannot be left to the incalculable free play of forces and the convenience of the individual.

The Bodenschutzkonzeption recognized that the existing law contained a large number of regulations which were of considerable relevance to soil protection. However, the majority of regulations which were relevant to soil protection were included in the Special Federal Administrative Law which, in many cases, has to be implemented by regulations of the Länder (provincial governments). As far as soil protection was concerned, the regulations showed different degrees of implementation and effectiveness. This, together with the partial and limited protective effect on soil of the existing regulations, made it necessary to harmonize the individual regulations in order that an overall protection may be achieved. This required a more detailed elaboration of rules of law with regard to soil protection and better utilization of existing provisions.

The measures which were required to improve the incorporation of soil protection into other environmental laws are to be found in "Massnahmen zum Bodenschutz" (catalogue of measures on soil protection) which was adopted by the Federal Government in December 1987 and published in January 1988. These are not laws, they are measures which the Federal Government would like the Länder to implement. However, the Ministers of the Länder decided not to move quickly on this issue because of the required extent of change in policy-making and legislation. There was little political support for action. The Federal Government could set up a Framework Law which would say that the Länder must implement some sort of soil protection measures. The Länder would then adopt measures which would suit their own conditions. At present, there is no such Framework Law and there appears to be no likelihood of it in the foreseeable future. On the other hand, there do seem to be reductions in the levels of various pollutants.

The Massnahmen zum Bodenschutz does not contain a list of soil quality standards, but in the chapter "Stoffliche Einwirkungen auf Boden und Grundwasser" (Impacts of substances on soils and groundwater) is a list of substances of which the contaminative properties and behaviour in soils are being investigated. At present, the only standards and limits are those in the Klärschlammverordnung (Sewage Sludge Ordinance):

Substance	Limits in soil mg kg^{-1} air dry	Limits in sludge mg kg^{-1} dry residue
Lead	100	1200
Cadmium	3	20
Chromium	100	1200
Copper	100	1200
Nickel	50	200
Mercury	2	25
Zinc	300	3000

The sensitivities of different soil types are being investigated. There are scientific as well as legal difficulties in setting soil quality standards. The setting up of soil standards differentiated according to soil types would require an official map of suitable scale covering any area of concern. These are not yet availabile (R. Schier, pers. comm.).

The Bodenschutzkonzeption recognized the need for soil information, as well as for more research and the development of methods and models. The Länder asked the Bavarian government to consider, on their behalf, the setting up of a soil information system. Their report "Bodeninformationssystem" (Materialien 47, published by the Bayerisches Staatministerium für Landesentwicklung and Umweltfragen) was published in December 1987.

An example of the tabulated effects of substances in soil, in Bodenschutzkonzeption der Bundesregierung

0	Substance	Nickel (Ni)
1	Natural content in geo- and biosphere	58 mg kg^{-1} (average content in the Earth's crust) 5 - 50 mg kg^{-1} (transferred from air to soil) 0.4 - 3 mg kg^{-1} TS (Plants)
2	Production/Consumption	Nil - 57800 t a^{-1} (1982) - 63000 t a^{-1} (1983)
2a	Tendency	Somewhat persistent
3	Amount in the environment in entry paths (t a^{-1})	Altogether about 1250
	exhaust air	670 (calculated from deposition)
	waste water/sludges	500
	agrochemicals	No application
	others	Sewage sludge: ca 120 Harbour sludge: not known
4a	Surface deposition	Average values: 55 g ha^{-1} a^{-1} (Nordrhein-Westfalen, Hessen) 26 g ha^{-1} a^{-1} (General precipitation; total deposition, Solling) 32.8 to 255 g ha^{-1} a^{-1} 26.29 g ha^{-1} a^{-1} Ni from precipitation sites away from industry)
4b	Removal (ground- and surface-water, air, crops)	Groundwater 17 - 63 g ha^{-1} a^{-1} Cultivated plants 1 - 50 g ha^{-1} a^{-1} 10 - 30 g ha^{-1} and harvest
5	Geographical significance	local ++ regional not known general ++ not known
6	Behaviour in the soil	
	persistence	+++ (not degradable)
	mobility	+ (pH-dependent)
	enrichment	++ to +++
7	Plant availability	+ to ++ (increases with decreasing pH) (very different for geological or anthropological origin)
8	Entry into food	Ni is an essential element for rats, chickens, and pigs. Less may be necessary for humans.
	Uptake in food	Uptake by humans in: Air (breathing) ca 0.5 µg d^{-1} Drinking water ca 10 µg d^{-1} Food 300 - 600 µg d^{-1}

9	Characterization of effects and their relevance for humans through oral uptake	Excretion in urine follows relatively quickly.
9a	Toxicity kinetics (uptake, distribution, metabolism, excretion, accumulation)	The HWZ of inhaled nickel oxide amounts in humans to about 30 - 40 days. Insoluble compounds are retained longer than soluble ones. No relevant enrichment of Ni in kidneys, liver, and lungs.
	ADl value	Not known
	provisional tolerable weekly intake	Not known
9b	Specific effects chronic/acute toxicity	Allergy from Ni ornaments, watches, etc. Nickel carboxyl is acutely toxic. Effects of oral intake of inorganic Ni compounds are not known.
	carcinogenicity	Fumes and dust are considered carcinogenous. Difficulty-soluble Ni compounds produce lung and nose cancers.
	mutagenicity	Not known
	teratogenicity	Not known
	foetoxicity	Not known
10a	Effects (ecotoxicology) on: animals	Oral resorption and retention are slight in warm-blooded animals. Toxicity to fish is unknown.
	plants	Injury in locations with high anthropogenic Ni content (up to 250 mg kg^{-1} exchangeable Ni; scarcely any in serpentine soils. Ni is not an essential element for plants.
	micro-organisms	In soil, toxic for nitrification at more than 50 mg kg^{-1} soil.
10b	Special behaviour in organisms	
	enrichment in living organisms	Enrichment in vegetative plant parts.
	enrichment in food chains	Not known
11	Special problems with analysis methods and measurement techniques	None
12	Peculiarities	Crop limiting value 20-30 ppm in plants. Toxicity limiting value for animal feed 50-60 ppm Sewage sludge value 333 g ha^{-1} a^{-1} Tolerable soil content 50 mg kg^{-1} (air deposition) Manure/Fertilizer value 30 mg kg^{-1} (organic-minèral mixed fertilizers)

+ small
++ medium
+++ large

Summary of the Report on Environmental Problems of Agriculture March 1985

The Council of Environmental Advisors (of the Federal Republic of Germany)

The Council of Environmental Advisors (Der Rat von Sachverständigen für Umweltfragen) was established in December 1971 by the Federal German Government as part of a series of measures to improve the conditions for effective environmental policies. The Council was charged to review the state of the environment in the Federal Republic of Germany and to recommend strategies for improvement. Moreover, it is the Council's tack to analyze and produce reports on specific environmental problems.

In March 1985 the Council published a special report on the environmental problems of agriculture, a subject which in view of the surpluses of agricultural products, the losses of species and the pollution of the ground water is being discussed with increasing intensity. A 58-page English summary of the report is available, the general overview follows.

General overview of the demands made by the Council

The continuation of intensive farming requires that drastic environmental and agricultural policy measures are introduced with the object of reversing the pollution trend and restoring the biotope function of the agrarian landscape. Restrictions must not be imposed in a schematic manner; any measures must be tailored to differentiate between production methods which have little impact on the environment, those which have a distinct impact and those which have a heavy impact.

The Council summarises its most important demands as follows:

i. The highest priority is given to the demand that action be taken to counteract the progressive disappearance of species, as well as biotopes, from the agrarian landscape. It is therefore recommended that an interconnected network of biotopes is created which covers an average of 10% of each rural area. The first step would be to designate some of the larger areas as ecological priority areas. These should then be interconnected by smaller strips and plots of land to re-create a state of biotic continuity. Finally, measures must be introduced to restrict certain types of land usage along the perimeters of these biotopes. The responsibility for developing such a system of interconnected biotopes lies with the regional landscape planning authorities. The initial task is to provide effective protection for those biotopes which already exist. A major prerequisite for the realisation of such a system is that the authorities responsible for the re-allocation and consolidation of land holdings also participate in the relevant planning.

ii. The intensive use of commercial fertilizers and farm manure's is causing problems for the water sector. Steps must be taken in particular to prevent the further nitrate pollution of groundwater. The usual quantitites of fertilizer used by agriculture in the past and the actual quantities required by the crops must no longer be the sole criteria for deciding on future usage. The most urgent requirement is that the water legislation restricting the use of manures within protected water extraction areas, and also outside these areas, is fully enforced and thus able to assert itself against common agricultural practice. Furthermore, a nitrogen charge must be levied in order to counteract the current trend towards overdressing (see below). In the case of regional concentrations of specialised stock-keeping, a variety of measures must be introduced to combat the problem of liquid manure.

iii. According to the principle of prevention, reducing the overall quantity of plant protection products used, ie. in order to reduce soil, groundwater and surface water pollution, the risks to living creatures and biological communities and the level of residues in foodstuffs down to an absolute minimum, is of paramount importance. In addition, there are a number of potentially dangerous practices which can only be curbed effectively by applying targeted measures in connection with the approval, usage and monitoring of plant protection products which are more effective than those used in the past; prime examples of where these measures should be aimed are incorrect usage, incorrect dosing, as well as improper disposal of residual material. The yardstick for the application of plant protection products must never be based on the threshold between profit and loss alone, but must also give due consideration to biotope, water and soil protection criteria. Approval certificates for new plant protection products should be issued initially for a preliminary period of five years.

iv. The danger of soil erosion has been underestimated in the past. Farming operations must therefore be better adapted to the appropriate local conditions. Over and above this, a number of general measures relating to landscape planning, landscape management and cultivation techniques must be taken.

v. The general trend towards further specialisation on farms and the resulting trend towards the disintegration of natural cycles and impoverished landscapes must be brought to a halt. The objective must therefore be to re-introduce combined systems of animal and plant production wherever possible. In crop cultivation the aim must be to expand crop rotation in order to improve the biological activity in the soil and hence maintain an effective anti-phytopathogenic potential. The agricultural policy instruments for promoting integrated production systems must be developed further.

In order to realise these demands, the Council recommends that the following political decisions are taken.

- The public agricultural consultancy services must be further extended and improved. Environmentally compatible farming methods call for a high degree of expertise on the part of the individual farmer. The main objective is to transfer the latest findings in the field of agricultural science into practical reality whilst at the same time taking into account the diversity of local conditions. Agricultural advisory bodies must provide a better service for the farmer than hitherto, particularly with regard to aspects such as manuring, the use of plant protection products, the correct crop rotation systems and measures to combat soil erosion.

- Development must continue on the variety of basic concepts for an agricultural information and monitoring system. The environmentally conscious farmer and the public agricultural consultancy bodies are dependent on the provision of data as a decision aid in gauging pollution toleration limits, for example the nutrient content in the soil, pollution levels in groundwater, the presence of pathogens and other harmful organisms and substances and the potential danger of soil erosion at individual locations. The results of the supra-regional, regional and local pollution monitoring and the landscape development must be pooled and evaluated.

- In order to bring about an improvement in the relationship between agriculture and the environment, a change in the legal boundary conditions is called for. The clauses relating to agriculture in the nature conservation legislation of the federation and individual federal states must be abolished. They should be replaced by paragraphs defining the fundamental obligations of the individual farmer. Those who are engaged in crop cultivation and stock-keeping must make every effort according to individual circumstances to ensure that the natural environment is kept as free from pollution as possible, particularly by respecting natural and semi-natural biotopes and by limiting emissions. Insofar as such rules on environmentally compatible agricultural practices are developed, the individual farmer is obliged to respect them. Such rules must be drawn up by the State with the cooperation of suitable technical associations working in the field of agricultural science.

- Last but by no means least, an improvement in the relationship between agriculture and the environment must be preceded by a revision of the agronomic boundary conditions. One measure in this direction is the introduction of a levy on nitrogenous substances in order to halt the continuing trend towards intensive crop cultivation. The increased cost of nitrogenous commercial fertilisers should be coupled with an annual compensatory payment to the individual farmer in the form of a fixed sum per hectare of land used for agricultural purposes. This will ensure that only farmers who practice particularly intensive manuring are affected to any great degree. New approaches must also be made in the field of agricultural structure policy. During the course of the reform of the joint Federation/Federal states Programme "Improvement of the Agrarian Structure and Coastal Protection", the funds must be administered in such a way that management contributions can be made to farmers as a reward for effective efforts in the field of landscape conservation. The purchase of ecological priority land should also be financed from this source.

France: Soil protection

French soil protection policies are concerned only with agricultural land. Deterioration of agricultural land may be caused by (Gomez & Juste 1987):

i. unsuitable farming practices e.g. forest clearance leading to erosion; deep ploughing bringing polluted subsoil to the surface and/or causing excessive dilution of organic matter with mineral soil.

ii. the use of toxic compounds (point pollution) e.g. the use of fertilizers rich in heavy metals; pesticides which contain pollutants; sewage sludge and household waste compost containing pollutants.

iii general airborne pollution (diffuse pollution).

In 1982-83, INRA carried out a study on the feasibility of setting up an "observation network for soil quality". The conclusions of this study stressed that

i. The term 'soil quality' must be taken in its broadest sense, and covers physical and chemical degradation and toxicity problems.

ii. The observation network should study physico-chemical and chemical properties, biological properties, heavy metals, plant health products (pesticides, fungicides), erosion, and physical degradation other than erosion.

iii. The observation network should monitor quality, and, in time, predict developments. It should have a permanent structure and finance.

Priority has been given to the study of heavy metals because their accumulation in soils presents a serious problem, and because they are easy to measure. In 1987, 37 sites in northern France were being monitored for heavy metals, physico-chemical properties, and content of plant health products, and methodological problems were being studied. Gomez and Juste (1987) pointed out that there should be a harmonization of the different types of network already set up or under consideration.

Switzerland: Soil protection policies

The Swiss population of 6.4 million occupies about 41 000 km^2 of the country's area. Population density is greatest in the Plateau region, a depression between the Alps and the Jura, and the large alpine valleys, which cover about a quarter of the area. Population density is low in the Jura and the Pre-alps, which represent another quarter of the area. Because of the pressures on the usable land, current Swiss legislation is concerned largely with controlling pollution, protecting farmland, and with using land 'economically', i.e. efficiently and non-destructively.

Five tasks have been identified:

i. The extension of settlements is to be restricted; agricultural land and "largely undisturbed natural environments" are to be protected.
ii. Emissions from all sources must be limited.
iii. Pollution from agriculture must be limited.
iv. Damaging forms of cultivation must be avoided.
v. The level of soil pollution must be monitored; where limit values are exceeded, stricter measures must be taken.

The Federal Land-use Planning Act has been in force since 1980. The amended Land-use Planning Order of 1 May 1986 has improved the level of protection for good agricultural land. The Cantons are required to draw up a land register for every community, charting and giving figures for the remaining suitable arable land. The Swiss Federal Government stipulates the minimum area of arable land to be secured and the distribution by Cantons. The Cantons take the necessary land-use planning measures to ensure that their allotted share of arable land is preserved permanently. If a Canton does not fulfil its obligations, the Federal Government has the power to implement the requisite measures right down to community and landowner level (Häberli 1987).

The Federal Environment Protection Act of 7 October 1983 came into force on 1 January 1985. It provides the legal basis for the regulations adopted by the Federal Government to protect man, fauna and flora, their communities and habitats from disturbance and harm, and to preserve soil fertility. All environmental protection measures are based on the combined principles of preventive action and maximum pollution tolerance. If pollution levels in an area exceed the stipulated limit, measures must be taken to prevent emissions at source.

Various Orders are issued under the Environment Protection Act. Thus, there is a Substances Order which contains inter alia provisions on plant protection products and fertilizers; certain substances are prohibited, and limits are set on others. There is a complete ban on the use of herbicides and fertilizers in forests. The Clean Air Order covers airborne pollution, and gives limit values for immissions as well as of lead in vehicle and aviation fuel and noxious substances in heating oil. The Sewage Sludge Order governs the use of sewage sludge on agricultural land and stipulates maximum limits for heavy metals. Other laws on nature conservation and forestry, and on the health and protection of the aquatic environment, supplement the Orders.

A national soil monitoring network is to be set up under the Soil Order, which covers the level of pollutants in soils. Soil samples will be collected every 5 years at 100 pre-selected points throughout the country, and will be analyzed for pollutants. In high-risk areas these monitoring positions will be supplemented by cantonal measuring stations. The Soil Order contains guide values for maximum acceptable levels of pollutants in soil (see Table at the end of this section). If the guide levels are reached or exceeded, the source of pollution must be identified and measures must be taken to reduce the emissions. These values are for 'normal' mineral soils. The values are not applicable to highly-organic soils, but such soils are not widespread in Switzerland. In February 1987 the Swiss Federal Government issued guidelines for the collection of soil samples and their analysis for pollutants.

Thus, the Swiss soil protection system comprises (i) measures to restrict settlement areas and give special protection to agricultural land, (ii) measures to limit pollutant imissions from both non-agricultural and agricultural sources, (iii) application rules and advisory schemes for farmers, (iv) a properly-organized waste management system. (v) a surveillance system to monitor pollution levels in soils.

Because of the pressures which threaten soils, the Swiss Bundesrat has announced a national research programme on land utilization in Switzerland. The programme will last 5 years, and will examine land in its role as a natural environment, for building, for providing settlement areas, and as a commercial and legal commodity. The Swiss consider that effective soil protection is possible only if general attitudes to nature and the environment change, hence the soil protection debate must be carried into politics, public life, and schools. Public relations work is an essential part of a soil protection strategy.

It is intended, that the research programme shall result in proposals for the economical use of land. It has 3 main aims (i) soil fertility must be preserved in the long run, (ii) losses of undisturbed soil must be reduced, (iii) land utilization must be more evenly balanced.

The research programme studies land in 3 contexts (i) soil as part of the natural environment, (ii) land for building and settlement, (iii) land as a commercial and legal commodity.

In 1987 there were 39 projects running in 3 phases. In the first phase, the problems will be analyzed and clarified, and their development will be forecast. In the second phase, the problems will be brought together and the main points worked on; in this phase, particular attention will be focussed on reciprocal effects and repercussions. The third phase is for the synthesis of the separate programmes. Proposals will then be drawn up for specific measures.

The state of the Swiss research programme in December 1987 was described in their Bulletin no. 6. In that Bulletin, two new projects were described. Project "Pedoflora" aims (i) to measure the effect of heavy metals and pesticides on mycorrhizal development; (ii) to evaluate the influence of mycorrhizas on the transfer of heavy metals and pesticides from soil to plant and (iii) to test mycorrhizas as indicators of soil pollution. Project "Transfer of substances" aims to formulate a quotient expressing the relationship between the heavy metal content of soil and its content in plants by taking into account such soil factors as pH, clay and humus content.

Bulletin no. 6 (December 1987) also introduced into the Swiss programme the concept of multifunctionality.

The state of the Swiss programme in May 1988 was described by Häberli (pers. comm.). Swiss priorities may well differ from those in other European countries. Important soils functions are to regulate water, to support agriculture, and for nature conservation.

Only about one-third of the land area of Switzerland is suitable for urbanization, intensive agriculture, and similar developments, the rest being mountainous or otherwise restricted in use. The effective population density is thus comparable with countries such as Belgium and the Netherlands. The main problem is preserving soil as a component of natural landscapes. Natural landscapes are being lost under buildings, because the land is too costly to preserve, and under agriculture because of intensification. The research programme will discuss the possibility of retaining natural landscapes in agricultural and building areas, for example the possibility of protecting flower meadows, by paying farmers to keep them, has already been discussed at the cantonal level.

Building is strictly controlled, but areas which have been set aside for building are larger than the need, so there is scope for protecting some areas within them. There are exceptions to building control, e.g. tourism and agriculture. One possibility is to zone land for planning purposes, so that for example building land would be surrounded by land of mixed types.

The Swiss public is very sensitive to forest death and general pollution. Agricultural use of soils, and consequent pollution, are at present a low-level problem although they are discussed a lot and are becoming popular topics. There are locally high densities of pigs and cattle in areas of intensive livestock production. There are some signs of problems with nitrate and phosphate in waters (e.g. see Dettwiler 1986). Fifty communities have reached 40 mg $litre^{-1}$ and the number is growing. However, the problem can be alleviated by diluting this water by mountain water. Dr Häberli's programme is not concerned with nitrate or phosphate, which are dealt with by the federal agricultural research organisation who also deal with pesticides. Water pollution has been known to kill fish in lakes, and the use of phosphates in detergents is now forbidden.

The disposal of sewage sludge is now considered to have been solved satisfactorily. The sludge is now dried and burnt. Because nobody wants tips near them, the new approach to the general problem of waste disposal is burning at high temperatures. This is expensive and poses technical problems, but it is considered that pollution must be controlled.

There is an active soil monitoring network, at present concerned mostly with heavy metals. Although some places, such as areas around metal-processing factories, were known to have high soil heavy metal contents, the monitoring has revealed others. One such is in canton Bern, where a lead content of 500 g kg^{-1} soil was found near an old paint factory. The question arises, what is to be done about such a site? It poses technical, political and economic problems. Fortunately, most such problems are small-scale.

Häberli's (1987) paper noted that damaging forms of cultivation must be avoided. Over the past 20 to 30 years, soil structure has been deteriorating. Over the past 15 to 20 years erosion has become a problem in the settled areas, and there is visible and measurable erosion even on fields with 10 to 15% slopes. In places, the soil loss is 20 to 30 t ha^{-1} while soil production is only 5 t ha^{-1}.

With regard to multifunctionality, a new Swiss philosophy is that nothing must be allowed to accumulate in soils, i.e. inputs must be balanced by outputs. At the same time, if substances which pass through soils cause problems elsewhere the problem must be dealt with at the point of application. An exception is vineyards, which have so much copper (from fungicides) that little else will grow. This is accepted as a fact, but is not accepted ideologically. At present, the Swiss are content to leave the concept of multifunctionality as a philosophical background to their work. They will try to define it in two or three years' time.

The 39 projects in 1987 have now increased to 47, and there may be as many as 60 by the end of the programme in 1991-1992. Dr Häberli considers that a valuable feature of the programme is that it provides an opportunity for many people to work together for a common objective. Groups are now working together who would not otherwise have done so. In many cases this will continue after the programme ends. About 100 people are involved at present, and the money is spread rather thinly. However, reports on projects are beginning to appear. Ways of synthesizing the results are already being discussed, and the early indications are that things are going well. Dr. Häberli thinks that in the end the main problem will be not to be too superficial in the synthesis, as the breadth of the programme is large in relation to the cost. It may also be criticised from a political point of view, as it deals with some 'hot' topics.

One feature of this programme is its broad scope, it is by no means confined to scientific aspects. The original 39 projects were grouped into 3 themes: (i) soil as a natural object (ii) soil as building ground and (iii) soil as an economic commodity and a legal object. In the latter theme there is a project "Eigenrechte des Bodens" (Proper rights of soils), which is being carried out by a law professor at the University of Bern. For centuries there has been an anthropocentric view of the world, but it may be argued that although man has a right to live, he has no right to dominate the ecosystem. Man should therefore prove that any of his activities which impinge on the environment are essential. In Switzerland, nature protection groups already have the right to oppose building and other developments, so this new viewpoint is not that far ahead of the present. There may be other projects on ethical/religious aspects. There will undoubtedly be interesting discussions, perhaps involving the concepts of multifunctinality and inputs-outputs.

There is also an education project, as public awareness is an important part of the programme. The Swiss have a view of high technology, high standard of living and high environmental quality. They are highly attached to the view that it is intelligent to care for the environment. This is attractive at the intellectual level. The idea of being the leaders in environmental improvement is attractive to the Swiss, including their industrial leaders.

Press bulletins about the work of the soil programme are issued, and there are press conferences and television and radio reports. Relations with the media are good and there appear to be good reactions from the public. There is a project run by a public opinion group which aims to assess the reactions of the public to the work of the programme.

Bulletin No.7 (June 1988) introduced two new research projects. "Marché foncier et immobilier" concerns dealing in land and real estate, and is to specify the outlines and feasibility of an extensive study of this topic. "Opinion des Suisses" concerns the points of view of the Swiss population with respect to the utilization of soil. The project has four objectives:

i. To ascertain the knowledge, opinions, and attitudes of different groups of the population with regard to soil.

ii. To measure the capacity of those groups to adapt to new situations and to adopt new behaviour.

iii. To test the political instruments and the practical measures proposed.

iv. To draw conclusions with regard to the possibilities of influencing the utilization of soil.

Verordnung über Schadstoffe im Boden (VSBo)

Order concerning harmful substances in soil.

vom 9. Juni 1986

Der Schweizerische Bundesrat,

gestützt auf die Artikel 33 und 39 Absatz 1 des Bundesgesetzes vom 7. Oktober 1983[1] über den Umweltschutz (USG),

verordnet:

Art. 1 Geltungsbereich

Diese Verordnung regelt:

a. die Überwachung und Beurteilung der Belastung des Bodens mit Schadstoffen;
b. die weitergehenden Massnahmen, welche die Kantone nach Artikel 35 USG treffen, wenn die Massnahmen nach den Vorschriften des Bundes nicht ausreichen, um die Fruchtbarkeit des Bodens langfristig zu gewährleisten.

Art. 2 Begriffe

[1] Der Boden ist fruchtbar, wenn er:

a. eine artenreiche und biologisch aktive Tier- und Pflanzenwelt, eine für seinen Standort typische Struktur und eine ungestörte Abbaufähigkeit besitzt;
b. das ungestörte Wachstum und die Entwicklung natürlicher und vom Menschen beeinflusster Pflanzen und Pflanzengesellschaften ermöglicht und ihre charakteristischen Eigenschaften nicht beeinträchtigt;
c. gewährleistet, dass pflanzliche Erzeugnisse eine gute Qualität aufweisen und für Menschen und Tiere gesundheitlich verträglich sind.

[2] Schadstoffe im Sinne dieser Verordnung sind natürliche oder künstliche Stoffe, welche die Fruchtbarkeit des Bodens beeinträchtigen können. Dazu gehören namentlich Schwermetalle und chlorhaltige organische Verbindungen.

Art. 3 Beobachtung der Bodenbelastung durch den Bund

[1] Die Eidgenössische Foschungsanstalt für Agrikulturchemie und Umwelthygiene, Liebefeld (Forschungsanstalt), betreibt ein gesamtschweizerisches Messnetz zur Beobachtung der Belastung des Bodens mit Schadstoffen.

SR 814.12

[1] SR 814.01

[2] Die Forschungsanstalt legt die Orte, an denen Proben erhoben werden, und das Untersuchungsprogramm mit Zustimmung des Bundesamts für Umweltschutz (Bundesamt) sowie nach Anhören der übrigen interessierten Bundesbehörden und der betroffenen Kantone fest. Die Methoden der Untersuchungen bestimmt die Forschungsanstalt mit Zustimmung der Eidgenössischen Anstalt für das forstliche Versuchswesen, Birmensdorf, und den eidgenössischen landwirtschaftlichen Forschungsanstalten Changins, Reckenholz und Wädenswil.

[3] Die Forschungsanstalt und das Bundesamt werten die Untersuchungen aus und veröffentlichen die Ergebnisse. Sie informieren gleichzeitig die interessierten Bundesbehörden und die betroffenen Kantone.

Art. 4 Beobachtung der Bodenbelastung durch die Kantone

[1] Steht fest oder besteht Grund zur Annahme, dass der Schadstoffgehalt des Bodens über dem natürlichen Gehalt liegt oder dass im Boden vorhandene künstliche Schadstoffe die Bodenfruchtbarkeit gefährden können, so sorgen die Kantone in diesen Gebieten für eine eingehende Beobachtung der Bodenbelastung.

[2] Sie veröffentlichen die Ergebnisse ihrer Untersuchungen und teilen sie gleichzeitig dem Bundesamt mit.

[3] Die Forschungsanstalt berät die Kantone. Diese können die Forschungsanstalt gegen Gebühren zur Probenahme und zur Messung von Schadstoffgehalten beiziehen.

Art. 5 Beurteilung der Bodenbelastung

[1] Bund und Kantone beurteilen die Bodenbelastung anhand der im Anhang festgelegten Richtwerte für den Totalgehalt und den löslichen Gehalt von Schadstoffen. Ein Richtwert ist überschritten, wenn einer der beiden Schadstoffgehalte überschritten ist.

[2] Die Richtwerte gelten nur für Böden mit einem Humusgehalt bis 15 Prozent (mineralische Böden).

[3] Fehlen Richtwerte, so wird anhand der Kriterien in Artikel 2 Absatz 1 im Einzelfall beurteilt, ob die Fruchtbarkeit des Bodens langfristig gewährleistet ist. Die Forschungsanstalt berät die Kantone.

Art. 6 Massnahmen der Kantone

[1] Sind in einem Gebiet die Richtwerte überschritten, steigt der Gehalt eines Schadstoffs deutlich an oder ist die Fruchtbarkeit des Bodens aus andern Gründen nicht mehr langfristig gewährleistet, so ermitteln die Kantone die Schadstoffquellen.

[2] Sie klären ab, ob die Massnahmen nach den Vorschriften des Bundes in den Bereichen Luftreinhaltung, umweltgefährdende Stoffe und Abfälle genügen, um im betroffenen Gebiet den weiteren Anstieg der Schadstoffgehalte zu verhindern.

³ Genügen diese Massnahmen nicht, so treffen die Kantone weitergehende Massnahmen nach Artikel 35 USG. Sie teilen diese dem Eidgenössischen Departement des Innern vorher mit.

⁴ Die Kantone führen die Massnahmen innert fünf Jahren, nachdem die Bodenbelastung festgestellt wurde, durch. Sie legen die Fristen nach der Dringlichkeit des Einzelfalls fest.

Art. 7 Verschärfung der Bundesvorschriften

Erachtet es das Eidgenössische Departement des Innern als notwendig, zur Erhaltung der Bodenfruchtbarkeit neben den weitergehenden kantonalen Massnahmen oder an deren Stelle die Vorschriften des Bundes in den Bereichen Luftreinhaltung, umweltgefährdende Stoffe oder Abfälle zu verschärfen, so stellt es dem Bundesrat Antrag.

Art. 8 Inkrafttreten

Diese Verordnung tritt am 1. September 1986 in Kraft.

9. Juni 1986

Im Namen des schweizerischen Bundesrates

Der Bundespräsident: Egli

Der Bundeskanzler: Buser

Guide values for contents of harmful substances in soil.

Anhang (Art. 5)

Richtwerte für Schadstoffgehalte des Bodens

Schadstoffe	Schadstoffgehalte in lufttrockenem, mineralischem Boden (Gramm je Tonne)	
	Totalgehalt (HNO_3-Auszug)	löslicher Gehalt ($NaNO_3$-Auszug)
Blei (Pb)	50	1,0
Cadmium (Cd)	0,8	0,03
Chrom (Cr)	75	–
Cobalt (Co)	25	–
Fluor (F)	400	25[1]
Kupfer (Cu)	50	0,7
Molybdän (Mo)	5	–
Nickel (Ni)	50	0,2
Quecksilber (Hg)	0,8	–
Thallium (Tl)	1	–
Zink (Zn)	200	0,5

[1] Wasserlöslicher Gehalt.

Die Richtwerte gelten für den Schadstoffgehalt einer Mischprobe der obersten 20 cm des untersuchten mineralischen Bodens, die in Umluft von 40 °C bis zur Gewichtskonstanz getrocknet wurde. Bei Böden, die tiefer als 20 cm gepflügt wurden, muss das Ergebnis der Untersuchungen wie folgt korrigiert werden:

$$\text{Massgebender Gehalt} = \frac{\text{Gemessener Gehalt} \times \text{Tiefe der Pflügung in cm}}{20\text{ cm}}$$

Zur Bestimmung des Totalgehalts von Schwermetallen wird als Lösungsmittel 2molare Salpetersäure (HNO_3) verwendet. Das Gewichtsverhältnis von Bodenprobe zu Lösungsmittel beträgt 1 zu 10.

Zur Bestimmung des löslichen Gehalts von Schwermetallen wird als Lösungsmittel 0,1molares Natriumnitrat ($NaNO_3$) verwendet. Das Gewichtsverhältnis von Bodenprobe zu Lösungsmittel beträgt 1 zu 2,5.

Denmark: Environmental protection policy

Danish soil and water protection is dominated by eutrophication of ground and surface waters. There is also concern over acidification of terrestrial ecosystems, largely through dry deposition of NH_3 and NO_x compounds, and of groundwaters through oxidation of pyrite in shallow sandy aquifers. While not problematic, heavy metals and pesticides are being controlled and monitored.

In 1981, the Minister of the Environment reported to the Parliament that there was a serious threat to ground and surface waters (including the coastal waters) from inputs of nitrogen and phosphorus salts. In 1984, the Ministry's National Agency of Environmental Protection submitted a major summary of monitoring and research work in the field - the NPO report. This gave figures for inputs, described the effects of these and recommended remedial measures. Very briefly, fertilisers and manures were being added to land in excess of the soil's and crop's abilities to absorb them. Groundwater beneath sandy soils, and river systems were increasingly polluted. These inputs together with output from urban sewage and fish farms were resulting in the death of river and coastal marine ecosystems.

The Environmental Protection Act, last amended in 1987, forms the general framework and is aimed at:

i. the prevention and combatting of pollution to the air, water and soil
ii. prevention and combatting of noise nuisance
iii. establishment of environmental regulations based on considerations of hygiene
iv. the provision of the necessary administrative basis for the planning and implementation of pollution control.

A number of sections are important in the context of this report.

Section 1.3 states that "when determining the scope and nature of anti-pollution measures, the character of the physical environment and the impact of pollution thereon shall be considered".

Section 2.1 states that the Act shall apply to "all activities which, by emission of solid, liquid or gaseous substances, vibrations and noise may cause pollution of the air, soil, watercourses, lakes or sea."

Section 3.1 indicates that any person who proposes to commence potentially polluting activities shall "choose such site for the activities that the pollution risk is minimised". 3.2 states that consideration shall be given "to the nature of the area and the possibilities of appropriate disposal of waste water and other wastes in choosing the site".

Section 8.1 enables the Minister, for the guidance of local authorities, to lay down provisions as to the quality of surface water, of air and of soil. 8.2 states that "to fulfil international obligations, the Minister for the Environment may lay down binding regulations as to the quality of surface water, of air, and of soil".

Section 11.1 states that "liquids and substances likely to pollute the ground water shall not without a licence issued by the Minister of the Environment be placed in or on the soil, or discharged onto the soil, or into the subsoil through percolation systems, borings or in any other way".

Section 12.1 enables regional councils to designate a protection zone around groundwater abstraction points within which "cesspools etc. receiving W.C. effluent, and other buried containers for liquids or other substances likely to pollute groundwater shall be prohibited after the expiration of a fixed period of time".

Section 13.1 enables a regional council allowing abstraction of water from a watercourse to fix a protection area within which "industrial enterprises, institutions, camping sites etc. must not be carried on, and substances likely to pollute the water supply must not be stored". 13.3 allows for compensation payments where the land owner is ordered to alter or discontinue an existing activity.

Section 17.1 states that "substances likely to pollute water shall not be discharged into watercourses, lakes or the sea, or stored so close to such waters as to cause danger that the substances enter watercourses, lakes or the sea".

In most cases, violation of the Act leads to a fine but some offences can lead to up to a year's imprisonment.

Following strong public pressure, the NPO report was converted to two Action Plans with the publication of the NPO Action Plan in 1985 and the Water Environment Action Plan in 1987. Enabling legislative Statutory Orders issued under the Environmental Protection Act are bringing the recommendations into force.

The main thrust of the legislation is that pollution from all sources must be reduced within certain deadlines. Agriculture must reduce its nitrogen and phosphorus outputs by 49% by 1990. Effectively this means reducing national fertilizer use by 127 000 tonnes N yr^{-1} For P, it is assumed that the bulk comes from manures and the thrust is for better and much stricter control of manuring practice.

Thus, by 1990 farmers will have to keep a yearly schedule of their nitrogen use including all inputs and outputs from the farm. This schedule will have to be seen but not inspected by officers from the Ministry of Agriculture.

They will have to increase the winter crop area by set amounts to 'catch' mineralized N. By 1990 this will probably be set at 65% of farmland. At present there is little use of winter crops.

They will have to cease all direct discharges from farmyards into rivers.

All farms with more than 31 livestock units will have to increase their slurry and manure storage capacity to 9 months output and have a closed tank to contain the volatilisation of NH_3. The yards will be so designed that storm water and manures are kept separate and various other design requirements will have to be met. Silage clamps will also have to comply with design standards.

There are regulations governing the amounts of manure spread on any farm, the location of spreading operations and their timing. Manure and slurry spread on bare ground will have to be ploughed in within 12 hours and none may be spread while snow is lying on the ground.

These regulations must be complied with by 1990 for larger farms and by 1992 for smaller farms.

Under the Pesticides Action Plan it is proposed to evaluate or re-evaluate all pesticides used in Denmark. Using standard adsorption and leachability tests adopted from Germany all will be tested for mobility and the most mobile banned from use. The EC 0.1 and 0.5 ppb groundwater limits have been adopted.

There are regulations concerning the use of pesticides around extraction points but the most fundamental new proposal is for the reduction in overall use of pesticides by 25% in 3 years and 50% within 10 years.

1984 regulations within the general Environmental Protection Act govern the disposal of sewage sludge to land. The permitted metal loadings and concentrations are as for the EEC Directive on this subject. All sludge must be limed or sterilized or buried at least 10 cm within the soil. No food crop for human consumption may follow an application of sludge because of possible bacteriological contamination.

An immediate outcome of the legislation is that 8 billion crowns (roughly £800 M) have already been allocated to improving sewage treatment to bring these outputs in line with legislation.

Within agriculture, the technical departments of the Communers (local councils) have made some 50 000 farm visits to check on any direct outfalls from farmyards to rivers. it is with these same departments that inspection of storage facilities will lie but little of this work has yet begun. It is worth pointing out that both Amtcommuner, of which there are 14, and Communer, of which there are 250, have well-staffed technical departments with biologists, hydrologists and hydrogeologists.

Currently some 40% of sewage sludge is spread on land, the rest is landfilled or incinérated. The intention is to increase the proportion spread. For sludge spreading, Communers agree with farmers over the land to be spread. Every batch of sludge is analysed for dry matter content, lime content, metals and N and P content. The receiving farmers, while not having to enter the sludge on their nitrogen schedule, must report to the Amtcommuner the area spread and the crop that they intend to plant following the application.

There is no perceived problem with pesticides at present but some pesticides will be banned because of their mobility and the threat they present to groundwater.

Much of this legislation is fairly recent and the real effects have yet to be felt.

The NPO Research Programme 1986-90 (p 235) is a major initiative funded and administered by the Ministry of the Environment and aimed at achieving a greater understanding of the entire nutrient cycling system within Denmark. Worth 130 M Crowns per annum, work is being concentrated on particular sites and sub-catchments. All major rivers will be regularly sampled to asess inputs to the various coastal areas. Six small 5-10 km^2 sub-catchments will be closely monitored to identify the movements of nutrients within them and to provide data for computer modelling. The ultimate goal is to be able to model the nutrient cycles for the whole of Denmark.

Eutrophication of streams and seas, and the contamination of groundwater with nitrate dominate the environmental protection scene in Denmark. Volatilized NH_3, which is possibly the major source of nitrogen in the shallow coastal water ecosystems, also enters natural terrestrial systems, woods, heaths and wetlands, to their detriment. Soils become artificially acidified and inorganic aluminium levels are enhanced. Acidification is also a problem in certain shallow sandy aquifers where pyrite is present. Nitrate in such water leads to conversion to sulphate and more acid conditions. There is a survey of the extent of such conditions. The one benefit is the balancing denitrification that occurs. Nitrate can also be denitrified bacteriologically in groundwaters contained within organically-rich strata. Lignites are present within some aquifer zones and act as a substrate for denitrifying bacteria - conditions common to parts of the Netherlands.

Soil erosion is not perceived as a problem but there is a feeling now that the phosphate bound to suspended solids in rivers may be more important than previously thought. This would imply that soil erosion was an important process if only from the phosphate cycling standpoint. There is some evidence that soil compaction may be a coming problem in the eastern arable areas on heavier soils. The heavy metal loading of soils is low and well under control.

The Danish approach has been to legislate for blanket controls on pollutant ouput from agriculture, industry and society. This appears to have been politically possible by highlighting pollution in the communications media. It was the steadily rising mean nitrate levels in groundwater that led to political pressure and eventual action. There is also a strong Conservation Union formed from all the naturalist and ecologist groups. Rearguard action by the farming lobby may yet win some concessions in terms of the minimum manure storage capacity required in that some farmers have already received derogations to only 6 months capacity.

While the Ministry of the Environment do not have access to the farm nitrogen schedules, they have won access to information on fertilizer purchases and farm livestock and other production data on a parish basis. They are working on a mass balance model that will interpret this information in terms of amounts of nitrogen and phosphorus lost from the farming system i.e. leached or volatilised. Come 1990, they are confident they will know wehther, broadly speaking, the law is being complied with. The towns will have put their sewage house in order at considerable cost and townspeople will justly expect the farming community to have done likewise. Even stiffer legislation will be called for if they have not.

It should be said that while pollution containment is the first objective, reductions in output are a planned second conceptual stage to the environmental clean-up programme.

Soil protection in Denmark is enshrined in environmental protection and is strongly orientated to the prevention of soil contamination. The Environmental Protection Act is aimed at limiting the degradation of soil, air and water quality. While no actual quality standards are set, the Act does enable the Minister so to do. No attempt is made to define 'good quality' soil, air or water.

One interviewee commented that the fight over the maintenance of river quality had been between farmers, who felt that rivers were there to drain land, and conservationists who believed rivers were there to support aquatic ecosystems. The Danish approach is essentially function- not use-oriented and a strongly process-oriented monitoring and research programme underlines this emphasis.

Inherent within the Environmental Protection Act is the concept that land use should be related to the capacity of the land to support it, and that the nature of the land should influence end use. Here is the embryo of an environmentally-sensitive land use policy.

FOR ADDITIONAL INFORMATION ON THE NPO-PROGRAMME CONTACT:

Miljøstyrelsen
NAtional Agency of Environmental Protection
NPO-Secretariate
Strandgade 29
DK-1401 Copenhagen K

Phone: +45 1 578310
Telefax: +45 1 572449

THE NPO RESEARCH PROGRAMME

1986-90

Environmental impacts of manure, slurry and fertilizer application in agriculture

Miljøstyrelsen

National Agency of Environmental Protection Denmark

Environmental impacts of fertilizers

Nitrogen and phosphorus are important plant nutrients, which are assimilated by growing plants and released anew when plants die. Both nutrients are, to a larger or smaller extent, transported from the soil to the surrounding environment.

Under present agricultural practices in Denmark, large amounts of organic and mineral fertilizers are applied to guarantee high cropping yields. Accordingly the nutrient load of the environment has increased significantly through recent years. Now, adverse environmental impacts are becoming more and more apparent.

GROUNDWATER: Throughout the past decades, a steady increase of the nitrogen content in the groundwater has been observed. In many places there are growing problems in observing standards for nitrate in drinking water.

LAKES AND STREAMS: Severe eutrophication has affected the diversity of flora and fauna and deteriorated the recreational value of Danish inland waters.

COASTAL WATERS AND THE SEA: The load of nutrients - in particular nitrogen - has gradually become so heavy that exceptional climatic periods result in depletion of oxygen and fish mortality in the open Danish waters.

ATMOSPHERE: The nitrogen content of precipitaion has increased significantly due to losses to the atmosphere from manure, slurry, fuel combustion etc.

The NPO research programme

The NPO-research programme was initiated by a decision of the Danish Parliament on 31st May 1985. A budget of 50 mio.D.kr. was made available for the period 1986-1990. The National Agency of Environmental Protection was put in charge of the programme, joining the capabilities of about 25 Danish research institutes.

PROGRAMME OBJECTIVE: The overall objective of the NPO-programme is to conduct studies of the transport and transformation of Nitrogen, Phosphorus and Organic matter in the environment. The programme aims at an integrated description of the nutrient transport from farm through soil, groundwater, streams and lakes to the ocean.

PROGRAMME CONTENT: **The programme includes studies of:**

1. Nitrogen and phosphorus-processes in agricultural soils.
2. Vulnerability of groundwater aquifers to fertilizer leaching losses.
3. Phosphorus transport to surface waters by soil erosion.
4. Environmental impacts of nutrients on lakes, streams and the sea.
5. Environmental effects of establishing noncultivated areas around streams.
6. Ammonia-losses to the atmosphere from manure and slurry.
7. Environmental aspects of biogas production.
8. Ecology of abandoned agricultural lands.
9. Nutrient pollution and agricultural practices.

NPO-projects on Agricultural systems

The studies primarily aim at describing nitrogen losses from the farming system, either as nitrate leaching from the rootzone or as ammonia volatilazation from manure and slurry.

Extensieve field- and laboratory studies of the nitrogen cycle are conducted under various soil-, crop- and farming conditions. Special attention is given to development of operational models of nitrogen flows in agricultural systems.

Presently initiated studies include:

FIELD- AND LABORATORY STUDIES:

- Nitrogen processes in soils under different soil, crop and fertilization conditions.
- Nitrogen leaching from soils with natural noncultivated vegetation cover.
- Nitrogen processes i wetlands and meadows.
- Nitrate leaching from the rootzone in actual farming practices.
- Nitrogen losses from plants.
- Dry deposition of ammonia.
- Bulk deposition of ammonia.
- Fertilizing practices of Danish farmers.
- Ammonia losses from manure- and slurry storage.
- Ammonica losses from manure- and slurry application.

MODEL STUDIES:

- Mathematical model of nitrogen processes in the rootzone.
- Regional mathematical model of nitrate leaching from the rootzone.
- Mathematical model of fertilizer production in animal producing farming systems.

NPO-projects on Groundwater systems

The aim of the groundwater studies is to obtain an improved understanding of the transport- and denitrification processes in the saturated and unsaturated zone. The results of extensive data collection programmes are synthesized in mathematical models of the hydrological and geochemical processes in catchments in agricultural areas.

Presently initiated studies include:

FIELD- AND LABORATORY STUDIES:

- Nitrogen processes in a catchment with aluvial deposits.
- Nitrogen processes in a catchment with moraine clay deposits.
- Acidification of groundwater by fertilizer leaching
- Denitrification in the saturated and unsaturated zone.
- Ground water pollution in relation to land use practices.
- Vulnerability-mapping of aquifers.
- Regional distribution of nitrate and phosphate in groundwater.
- Regional monitoring of ground water quality.

MODEL STUDIES:

- Geochemical modelling of nitrogen processes in the saturated zone.
- Integrated hydro-chemical modelling of nitrogen transport in agricultural watersheds.

NPO-projects on Fresh-and marine water systems

The aim of the studies is to determine how changes in the nutrient load of Danish surface and marine water affect the biological structure.

In streams, lakes and the sea studies of the interaction between nutrients, flora and fauna are carried out under a large variety of conditions. Mathematical modelling is applied to account for transport and transformation of nitrogen and phosphorus through streams and lakes to the sea.

A special investigation is directed towards determination of the phosporus load related to surface erosion of agricultural soils.

Presently initiated studies include:

FIELD AND LABORATORY STUDIES:

- Nutrient pocesses in streams with different nutrient loads.
- Phosphorus processes in lakes.
- Vegetation in lakes in relation to nutrient load.
- Production of organic matter in coastal waters.
- Vegetation development in coastal waters.
- Production of organic matter in the open sea.
- Denitrification processes in the sea bed.
- Transport of nutrients along the west coast of Jutland.
- Surface erosion of phosphorus.

MODEL STUDIES:

- Model of nutrient proceses in streams.
- Model of nutrient processes in lakes.
- Integrated model for transport and transformation of nutrients in the streams and lakes of an agricultural catchment.

Participating Research institutes

AGRICULTURAL RESEARCH:

- Ministry of Environment:
  - Center for Terrestrial Ecology
  - Air Pollution Laboratory
- Ministry of Agriculture:
  - Danish Research Service for Plant and Soil Science
  - Danish Agricultural Engineering Institute
  - Bureau of Land Data
- Royal Veterinary and Agricultural University:
  - Institute of Soil and Water and Plant Nutrition
- Danish Land Development Service

GROUND WATER RESEARCH:

- Ministry of Environment:
  - Geological Survey of Denmark
- University of Aarhus:
  - Department of Ecology and Genetics
- Technical University of Denmark:
  - Institute of Tecnhnical Geology
  - Institute of Hydrodynamics and Hydraulic Engineering
- Ministry of Agriculture:
  - Danish Research Service for Plant and Soil Science
- Academy of Technical Sciences:
  - Danish Hydraulic Institute
  - Danish Isotope Centre
- Danish Land Development Service

FRESH AND MARINE WATER RESEARCH:

- Ministry of Environment:
  - Freshwater Laboratory
  - Marine Pollution Laboratory
- Ministry of Fishery:
  - Danish Institute for Fisheries and Marine Research
- University of Copenhagen:
  - Freshwater- Biological Laboratory
  - Institute of Geography
  - Institute of Population Biology
- University of Aarhus:
  - Department of Ecology and Genetics
  - Botanical Institute
- University of Odense:
  - Institute of Biology
- Academy of Technical Sciences:
  - Water Quality Institute
- Danish Land Development Service

The United States: Soil conservation

The USA approach arose from problems with soil erosion. In 1928, the United States Department of Agriculture (USDA) published a bulletin "Soil Erosion - A National Menace" and Congress provided funds under the Agricultural Appropriations Bill to: (i) set up ten regional experiment stations for measuring the rate of soil and water losses, (ii) survey the extent of erosion damage and locate the worst areas, and (iii) work out methods of control and prevention.

In the Dust Bowl of the 1930's huge amounts of topsoil were lost from agricultural land by wind erosion. In 1933, the National Industry Recovery Act established the Soil Erosion Service in the Department of the Interior to utilize Civilian Conservation Corps' help in establishing soil conservation demonstrations on farmlands. In 1935, Public Law (PL) 74-46 created the Soil Conservation Service (SCS) and utilized the organization of the Soil Erosion Service. The basic purpose of the SCS programme has been to help bring about physical adjustments in land use and treatment that will conserve natural resources, establish a permanent and balanced agriculture, and reduce the hazards of floods and sedimentation.

The Flood Control Act of 1936 was the first attempt to treat upstream watersheds as a flood-prevention measure. Although 200 plans were partially completed, interest declined and the projects were dropped during the Second World War.

The soil and water conservation programme in the USA continued to evolve from many legislative acts. In 1936, a standard Soil Conservation District Law was drawn up to initiate the concept of local self-help programmes rather than Government action programmes. In the same year, the Agricultural Conservation Programme was established. The Case-Wheeler Act of 1937 included a water-utilization programme in the western states, with provision for irrigation and drainage surveys. In the same year the first Soil Conservation District was organized.

In the 1950's, soil conservation was promoted by radio programmes (Carlson 1956), as well as by a number of books, television programmes, and films (see J. Soil & Water Conser., 13, 1958) and slides. Adult education was considered important (Carlson 1960).

After the Second World War various other legislative acts followed (Christy 1971) and attention returned to upstream watershed protection and flood prevention. In 1956 the president signed Public Law 1021, the Great Plains Conservation Program, which enabled the SCS to enter into long-term conservation contracts with farmers and ranchers in parts of the ten Great Plains States. More than thirty conservation practices are included in the programme, all designed to protect soil and water and reduce the impact of drought. However, millions of acres remain vulnerable to the droughts and winds of future years (Berg 1979).

The work of the SCS and the nature and function of Soil Conservation Districts are described by Christy (1971). The USDA, of which SCS is a part, has also developed Resource Conservation and Development (RC & D) projects. Today, these form one of 34 conservation programmes in USDA and RC & D areas cover millions of acres. No single programme, and no single agency or organization, can claim to have rescued America's soil and water resources from disaster. No single approach, federal, state, or local, has proved to be a panacea nor was any expected to be. Today, despite 47 years of USDA, state, and local soil conservation programmes, soil erosion remains the greatest single threat to the continued productivity of the USA. In many places soil is being lost at twice the soil loss tolerance, with consequential problems to water quality, fish habitat, and often wetland management (Berg 1979).

Because each state in the USA is sovereign, it has the complete responsibility and the power to govern itself, and to conserve and develop its basic resources of land, soil, and water. In all of the 50 states substantially uniform soil conservation district laws have been adopted. In addition, more than half the states have authorized their districts to regulate private land use through conservation ordinances. These regulatory powers are used very little for two main reasons; (i) the number of private landowners that want to cooperate with their districts and request assistance from them has always exceeded the manpower and equipment that the districts have available, leaving no time or motivation to deal with unwilling landowners, (ii) the district laws have all hedged their grants of power to adopt conservation ordinances with requirements for their approval, by majority vote or large, in district-wide referenda. These powers depend upon funds being made available by the co-operating local, state, and national agencies (Glick 1979).

With many statutes and conservation activities moving in simultaneous operation, and many national, regional, state, and local agencies at work, usually in cooperation but sometimes, inevitably, working at cross purposes, it became clear that a process was needed for better harmonization and unification. Therefore, Congress enacted the Soil and Water Resources Conservation Act of 1977. In this, the term "resource base" is defined as including "the conservation and use of soils; plants; woodlands; watershed protection and flood prevention; the conservation, development, utilization and disposal of water; animal husbandry; fish and wildlife management; recreation; community development; and related resource uses". The Act ties the entire nationwide conservation effort directly into the budgeting and appropriation process, and to accomplish this three things are needed: (i) continuing appraisal of the resource base, (ii) the formulation of a periodically-updated program for conserving, protecting, and enhancing that base, and (iii) the giving to Congress and the public a continuing series of reports on what is happening to that base. Beginning in October 1981 the president was required to submit, with each annual budget, a report "expressing in qualitative and quantitative terms the extent to which the programs and policies projected under the budget" meet the needs stated in the conservation programs. This report must also state "the reasons for requesting Congress to approve the lesser program or policies presented in the budget" whenever the budget is, in fact, below the requirements of the programs for conserving and enhancing the resource base. These provisions were to continue for a six-year trial period (Glick 1979).

However, obstacles rooted in institutions affect soil erosion control. Tenants with short-term leases possess short-term planning horizons that motivate them to emphasize immediate income. In the USA their rental arrangements usually do not encourage soil conservation investments with a long-term pay-off. Small-sized farms frequently force farm operators to press the land for a living regardless of effects upon soil erosion. Landlords who are interested in short-run returns on investment usually are not motivated to make long-term soil conservation investments. Farmers may not be convinced that the defined soil loss limits are necessary, and may not be fully informed on acceptable erosion control technologies or on the long-term economic consequences of these practices and investments (Timmons 1979).

From a farmer's point of view, McLaughlin (1979) thought that the policies and institutions devised for the implementation of a soil conservation ethic were frustrated by poor communication among elements within the agricultural sector. In many instances, legislation on the books was obsolete. Good intentions were negated by the short time-frame within which political leaders tend to operate. Inconsistencies between spoken principles and appropriate money salved the conscience while leaving the soil vulnerable to wind, water, and man. On the one hand, federal policy demanded increased production of feed grains for export, while on the other it cut personnel ceilings, funds for conservation operation, cost-sharing programmes, and other efforts that protect the resource base effectively.

Dechant (1979) was not optimistic that the USA would cope properly with the soil conservation needs of the succeeding five to ten years. Barlow (1979) was deeply discouraged with the prospects for success in safeguarding the USA resource base so that production could be sustained over time. He considered that the SCS had greatly underestimated the loss of topsoil, and that actual losses had reached crisis proportions.

The soil conservation legislation is aimed at erosion control. There is also a Federal Water Pollution Control Act which aims to control point and non-point sources of pollution.

A source of concern in the USA is the rate at which land is being withdrawn from agriculture and converted to other use, primarily urbanisation. Many areas lack any countrywide zoning or land use controls. A National Agricultural Lands Study has been set up to try to define the extent of agricultural land conversion and to identify tools which are available to state, local, and federal authorities for dealing with it. The study will also evaluate the costs and benefits of several alternative approaches (Yarn 1979).

Soil conservation policy in the United States is in a process of ferment. Farmers, ranchers, researchers, government officials, and politicians are all groping for policies that will improve conservation behaviour, and they are doing so in an era of shrinking budgets. Many long-established conservation programmes are being questioned, the Agricultural Conservation Program among them. Several policy alternatives are being discussed (Barrows & Olson 1981). The success of the American economic system has left in its wake a lot more sprawl and a lot less farmland and fewer natural areas for the public. An ecological approach is being looked at as a check on the effect of the economic system, having the potential to pull the country back to a more harmonious balance between people and nature (Kaufman 1980).

Ethical/philosophical/religious aspects have been discussed from time to time. Through the Middle Ages and into the nineteenth century, in Christian thought, there has been the view that the earth was useful to man because he could get from it physical sustenance and the religious inspiration to worship his Creator. It was assumed that, in the natural order of things, man would use the environment, changing it for his own ends and improving on its natural state. Man, considering himself to be the highest being in the creation, had responsibilities as well as privileges in using the earth. His role was often looked upon as that of a steward or a caretaker of God. Improvements in soil fertility through the use of manuring and marling were examples of the partnership of man and his Creator, not only in maintaining but in improving the earth. In addition to these ideas, observations that human activities brought about undesirable changes in nature also accumulated. It is these two trends, one aesthetic, philosophical and religious, the other practical and technical, that have characterized ideas of conservation throughout its history (Glacken 1956).

In the Middle Ages, European forests were important to the economics and amenities of life. Not only did they provide timber, but they were often centres of the beekeeping industry, which provided honey and beeswax, the latter being used in candle-making. Forests were also used for grazing sheep, cattle, goats, and especially pigs. Extensions of agriculture and industry at the expense of forests brought conflicts, which were recorded in John Evelyn's Silva, published in 1664. Glacken (1956) traced the evolution of conservation philosophy from such early beginnings to the USA's ideas on soil conservation at that time, and noted that there had been renewed attempts to create a conservation ethic and philosophy.

Forred (1956) also discussed religious/ethical/philosphical aspects of conservation and emphasized the concept of our stewardship of soil, water, and natural resources. Indeed, the North Dakota Association of Soil Conservation Districts adopted a movement, known as the North Dakota Plan, which consisted of seeking the assistance of the local clergy in presenting the stewardship side of the conservation programme. "When a man believes he is cooperating with an eternal purpose, when he feels that his efforts are to be long-lasting for his children and their children, he is more apt to see his part in a vaster part of God's program. We must help men to see that they are not only farming for today, but for all of posterity."

In 1977, the Piedmont Environmental Council (Virginia, USA) initiated a study of land use ethics. It assembled a group of eight scholars representing the disciplines of literature, history, jurisprudence, economics, sociology, political science, religion, and philosophy, and asked them to articulate the special contribution of their respective disciplines to an analysis of historical and contemporary land use ethics, to define value conflicts, and to suggest potential resolutions. The summary paper included a set of ten land ethic prescriptions (Barnes 1980)

i. You ought to consider land as a resource that may be yours for a time but is also held in trust for the future. Land is not a commodity that any of us can own in the ordinary sense of the word.

ii. You may be a trustee of the land and that will often confer private benefits on you, but you ought not to seek benefits that incur disbenefits on the community or other individuals.

iii. If you are presently trusted with the management of a piece of land, you ought to use it in a manner that benefits the land and does not damage it. Some land uses are abuses that have irreversible consequences, and you ought to avoid such abuses.

iv. You ought to accept that the use of land should be subject to public scrutiny and control and to exercise your responsibility, with others, in ensuring that no use is permitted that is damaging to society as a whole.

v. You ought to ensure that the land use controls developed in your area prevent irreversible damage, avoid waste, protect your natural and cultural heritage, stimulate visual order, regulate and control the unsightly, and safeguard individual liberties (such as mobility and a choice in housing and schooling, so long as those liberties do not impede the liberties of others).

vi. You ought to recognize that the exercise of land use controls in the interest of the community can result in costs and benefits to individuals, and be willing to see those costs and benefits equitably adjusted.

vii. You ought to recognize that these controls can only be exercised democratically through governmental operations. Hence, you ought to expect an extension of government to give proper expression to this new land use ethic.

viii. You ought to accept that the administration of the ethic must reflect local circumstances and needs, so it will vary from place to place.

ix. You ought to be ready to give time and talents to fight for this land use control that is vital for your continued freedom.

x. You ought to recognize that you may have to make some sacrifices, along with everyone else, for this control to be effective.

The subject of ethics reappears from time to time in the USA. Kaufman (1980) discussed land planning in relation to ethical principles, and pointed out that one of the knottiest problems in using an ethical perspective stems from the conflicts among competing 'goods' built into the perspective. Given the difficulty of coming up with a clear, internally-consistent ethical perspective on land resource issues, Kaufman saw the education of those who will shape future policy as a critical need, i.e. teaching them to think more carefully, systematically, and analytically, about ethics.

In 1949, in a decision concerning a state forest practices act, the Washington Supreme Court gave the opinion "Edmund Burke once said that a great unwritten compact exists between the dead, the living, and the unborn. We leave to the unborn a colossal financial debt, perhaps inescapable, but incurred, none the less, in our time and for our immediate benefit. Such an unwritten compact requires that we leave to the unborn something more than debts and depleted natural resources. Surely, where natural resources can be utilized and at the same time perpetuated for future generations, what has been called constitutional morality requires that we do." What matters about this doctrine is whether it can become a working part of federal and state policy (Wilkinson 1987).

However, there are practical problems in translating the concept of stewardship of the land into practice. Modern economic thinking stresses the use of market forces. This economic climate does not encourage those using soil to think about the future if it induces costs today. One possible approach to this is the use of charges for poor land practices that cause erosion or subsidies for good land use which protects soil. However, financial incentives are not always effective. For example, timber companies find it more cost-effective to ignore incentive programmes, while ranchers and farmers cannot always afford their advantages (Wilkinson 1987).

There is also the problem of attitudes. "As long as people believe that property rights transcend the public welfare, there will be no effective regulation of soil erosion on private land" (Wilkinson 1987). Wilkinson considered that land management requires a broad-based approach, but this would not work unless the public consciousness is changed. Ingrained attitudes and inter-institutional jealousies are often antagonistic to such an approach.

In Wilkinson's (1987) view, there is a need for more people who are willing to speak frankly in terms of ethics and morality when they speak of soil erosion and soil conservation. People like Fee Busby, who said, "I believe that allowing soil to erode is morally wrong and cannot be made economically right." Wilkinson considered that the time has come for a return to the moral and ethical principles espoused by the founders of the soil conservation movement in the USA.

Kaufman (1980) noted that there are two kinds of ethical principles, ends-oriented and means-oriented. An example of an ends-oriented principle is the view that land is held in trust for the future, and it should be used in a manner that benefits the land and does not damage it. This implies directions for a land policy to follow. An example of a means-oriented principle is that individuals should be prepared to fight for land use control. Hence, it is not enough to say that society should avoid abusive land uses (end) without also addressing the question of how public officials and others should conduct themselves (the means) in trying to achieve this, and other, ends.

Kaufman acknowledged the difficulty of finding a clear, internally-consistent ethical perspective on land resource issues. However, he saw the possibility of educating environmentalists, planners, developers, farmers, and public officials to think more carefully, systematically, and analytically, about ethics. At least one organization, the Piedmont Environmental Council, has been promoting public dialogue on such aspects (Barnes 1980).

As a result of increased understanding of the importance of organic matter in soils and of the relationship between the organic and inorganic components of the soil production systems, together with renewed interest coming from rapidly-developing changes in soil management, the emphasis of farm management on economic yields and pressures of pending environmental legislation and the Soil and Water Conservation Provisions of the 1985 Farm Bill, The American Society of Agronomy and the Soil Science Society of America sponsored a symposium "Soil Fertility and Organic Matter as Critical Components of Productions Systems" (Follett et al 1987). That publication documented the important role of soil, climate, and management in the prediction of nutrient availability and use, described controls on nutrient cycling and organic matter dynamics, and considered approaches for advisory services to use new technologies and to integrate information on organic matter dynamics and nutrient availability into models of crop production systems. In that symposium, Follett et al (p 48) concluded that "the development of improved conservation practices to decrease the total loss of on-site nutrients is a necessary and worthwhile goal and requires a full understanding of the role of soil fertility and organic matter as critical components of production systems".

In 1987, Congress enacted amendments to the Clean Water Act, which took up the long-stalemated question of non-point source water pollution. The result was a $400 million authorization and mandate to keep soil on farmland, rangeland, and timberland, and out of creeks, streams, and rivers. This gave Americans the basic legal tools for protecting the nations soils. However, Wilkinson (1987) noted that the law has never done much in this field before and there is no certainty that the new statutes and court decisions will be put to any better use. He considered that soil conservationists were to blame for this, because in the real world law is activated only by those who care passionately about a particular subject. Soil conservationists must insist that the laws be enforced. He urged soil conservationists not to allow state agencies simply to ratify the status quo, but instead to help to create new programmes with strong, workable components so that the spirit of the new law will become a reality.

Napier (1988) discussed socio-economic factors influencing the adoption of soil erosion control practices in the USA. As one might expect, it has been demonstrated that profits are seldom derived from the adoption of soil erosion control practices, and farmers are therefore reluctant to adopt them. However, the need for soil erosion control practices appears to be well understood. Traditional social science variables have been shown to be inadequate predictors of the use of soil conservation practices.

The Clean Water Act Amendment of January 1987 and the Safe Drinking Water Act Amendment of November 1986 provide a statutory link between things that are added to soil and their appearance in the ground water. Other Acts, such as the Disposal of Wastes Act, are covered by these two Acts. Further legislation will tie up any loose ends until all such activities are totally regulated.

States have to enforce standards set by the Environmental Protection Agency, which supervises the state activities. However, the states may set stricter standards if they wish. Each state must file with the Environmental Protection Agency a groundwater protection strategy, with specific plans for implementing it. These plans will include penalties and incentives.

This has not yet been done by all states. Nebraska regulates when N can be used, and gives guidelines. These are enforceable by state law. Arizona requires farmers to file a plan for the best management of fertilizers and manures. Farmers may choose from a menu of strategies. This procedure is enforceable by law.

So far, there is no protection for soil *per se*, only for surface waters, ground waters, and food.

Canada: Land protection legislation

Soil conservation was of minor concern in the early days of Canada's settlement, survival was often foremost in the minds of settlers. New farmers, learning by trial and error, took a great toll of the land. In 1910 the Canadian Parliament established a commission of conservation, and its immediate task was to prepare inventories identifying conservation problems in Canada. Its work focussed on forest, water, and fur-bearing resources. During the following 10 years, initial agricultural conservation measures were implemented in central and eastern Canada.

By the early 1920's farmers, using mostly European, eastern Canadian, or American technologies, found themselves at a disadvantage in coping with the arid land on the prairies. Dreams of quick riches gave way to mass migrations to the more humid regions or back whence they had come. Action was taken to prevent depopulation of the area. In 1922 a new research station was established at Swift Current, Saskatchewan, in the heart of the dust bowl, to conduct research on soil moisture conservation and wind erosion control. In 1935, the Prairie Farm Rehabilitation Administration (PFRA) was established to deal with the drought and soil erosion problems in the prairie regions. Using manpower, technology, and facilities provided by the research branch of the Canada Department of Agriculture through the experimental farms network, PFRA embarked on a series of activities that would ultimately label the agency as one of the great Canadian success stories in conservation (Dumanski et al. 1986).

When the drought ended in 1938, and the depression shortly after, conservation was accorded a lower priority. In 1941 a National Soil Survey Committee was formed, and it made recommendations on conservation issues. During the following 10 years several government agencies were established to deal, directly or indirectly, with Canada's soil resources. The Canadian Forestry Act was passed in 1944 to promote forest conservation and associated activities. In 1945 a farm planning service was set up by the Ontario Department of Agriculture through the Soil Science Department at the University of Guelph. Up to 10 specialists dealt with soil erosion problems. Probably the second most successful conservation initiative in Canada, next to PFRA, was the conservation authorities program of Ontario, established in 1946. Initially, it dealt with conservation, restoration, and development of natural resources for the prevention of floods and water pollution, and more recently was expanded to include land use, reforestation, and wildlife management. The Eastern Rocky Mountain Forest Conservation Act (1947) dealt with the management of certain forested watersheds to maximize flow in the Saskatchewan River and its tributaries. The Maritime Marshland Rehabilitation Act (1948) was among the largest projects in Atlantic Canada. By 1951, this programme had set up 99 dykeland rehabilitation projects involving 17 000 ha of marshland (Dumanski et al 1986).

In Canada the federal government is responsible for some aspects of land legislation, but the provincial governments are responsible for legislation concerning agriculture, exploration for, development, conservation and management of non-renewable natural resources and forestry resources, and the control of activities such as the production of electrical energy. Each province has had its own separate soil conservation programmes and regulations. In the east, these have dealt mainly with drainage, soil fertility, and reforestation. Western provinces have concentrated on land rehabilitation, erosion control, drainage, irrigation, and tillage. Many of the programmes were undertaken in co-operation with federal programmes. The Canadian approach has been to develop joint programmes under prescribed roles of federal-provincial cost-sharing, but with programme objectives that are responsive primarily to provincial concerns.

Several acts, both federal and provincial, deal with environmental matters such as pollution and some of them refer to land degradation, such as those which forbid dumping waste substances or removing soil. However, few of the acts refer to soil explicitly. The federal Pesticide Residue Compensation Act does not contemplate compensation for damage to soil per se, but compensation may be recoverable as long as the control product remains in the ground and contaminates crops thereon. The Alberta Agricultural Chemicals Act controls fertilizers, pesticides, and soil supplements. Inspectors have the right to check for compliance with the Act and regulations, and may take soil samples for analysis. Conviction for infractions may result in a $1000 fine or 90 days imprisonment, or both. The Alberta Land Surface Conservation and Reclamation Act gives wide powers of regulation in respect of land degradation, including mining, pipe-lines, waste disposal or land-fill sites. The Public Lands Act prohibits accumulation of waste or the creation of conditions likely to lead to soil erosion. British Columbia has a Soil Conservation Act, which prohibits the unauthorised removal of soil from, or placement of fill on, land in a designated agricultural land reserve (Girling 1983).

A notable exception to the general lack of special soil legislation is the Clean Environment Act of Manitoba, which forbids the contamination of soil beyond prescribed limits. In New Brunswick, the Ecological Reserves Act permits the Cabinet to establish reserves to preserve, among other things, areas containing unique or rare examples of pedological or geological phenomena. In Newfoundland, the Department of Consumer Affairs and Environment Act makes the Minister responsible for the protection and enhancement of soil quality, and authorizes the Cabinet to make regulations concerning the constitution and prescription of pollution and the control of sewage or waste discharge into the soil. The provisions of the Ontario Environmental Assessment Act encompass the protection, conservation, and wise management of the environment, which is defined to include both land and subsoil. The Environmental Protection Act provides for the protection and conservation of land, including surface land and all subsoil, and generally prohibits contamination of the environment. The Environmental Quality Act of Quebec makes the minister responsible for the preservation and depollution (sic) of the environment, including soil. No one may contaminate the environment beyond standards set by regulation or to the degree that damages soil quality (Girling 1983).

Current Canadian land degradation problems were discussed in Agricultural Land (1981). Urban sprawl, erosion, and salinization are causing serious concern. The overall objective of the symposium was to define as precisely as possible the kinds of soil deterioration currently occurring in the agricultural lands, as to both processes and the effect on productive capacity. Apart from evident topics such as urban sprawl, acidification, and salinization, others such as organic matter loss, erosion, and loss of structure are also important. Summarizing the papers in the symposium, Bentley urged that a resolution should be submitted to the Executive Council of the Government of Alberta and each political party in Alberta urging changes in Alberta's land use regulations so as to give the provincial government the primary role and responsibility for retention of prime agricultural lands for continuing agricultural use, insofar as is practical. He considered that legislation with at least similarities to the legislation of British Columbia and Quebec should be requested.

"Canada is facing the most serious agricultural crisis in its history and unless action is taken quickly, this country will lose a major portion of its agricultural capability". Because of the evident problems, the Standing Senate Committee on Agriculture, Fisheries and Forestry was authorized to examine the subject of soil and water conservation throughout Canada. The Committee travelled extensively in Canada, examining the issue of soil degradation (erosion, loss of soil organic matter, salinization, acidification, contamination by various types of chemicals, compaction). The Committee made a number of recommendations designed to raise public awareness of the problem and to improve the dialogue between the public, farmers, governments and environmental experts. It was noted that there were co-ordination problems arising, in part, from the fact that ministries of natural resources, environment, agriculture and fisheries, among others, with their different mandates, are all involved in the soil conservation issue. Unfortunately, individual departments or ministries often develop soil conservation policies or programmes which duplicate those in other departments or which contradict programmes developed elsewhere. Many witnesses identified as a drawback to soil conservation the absence of an overall government commitment to soil conservation and the consequent lack of a comprehensive policy. Indeed, some government policies actually discourage soil conservation (Sparrow et al. 1984).

Many witnesses emhasized the economic problems, because of poor returns, volatile prices, rising input costs, and generally a lack of economic stability, farmers have not been able to practice what they know they should. Farmers have no direct incentive to change their operations and commit the necessary capital to adopt soil conservation practices. The need for public awareness of the issues was also emphasized. The Committee presented four case-studies of farming families who had devised practices to overcome, or at least minimize, soil problems. Any successes provide a valuable demonstration to surrounding farmers.

Canadian soil scientists are concerned about the fact that profound soil quality changes are resulting from current cropping practices. The changes include the loss of half of the organic matter and one-third of the nitrogen reserves, associated deterioration in soil structure resulting in soil crusting, declining soil resistance to wind and water erosion, and a dramatic spread of salinity (Chanasyk 1986). Both old and new agricultural practices have contributed to the problem. Costs of erosion to farmers in western Canada were calculated as $440 million, loss of organic matter $326 million, and salinity $212 million. The cost of soil degradation on prairie farms has been calculated as equal to 16.7% of operating expenses, 106% of the cost of chemicals, 122.5% of the cost of the long-term debt, and 79% of farmers' net income. Chanasyk noted that over 40 years have passed since any form of concerted effort towards soil conservation has existed in Canada.

The best management practices would allow the use of soil indefinitely without causing its deterioration, yet providing a gainful return to the user. Few Canadian farmers manage their land in this way. Most are caught between it and maximizing production. The level of soil conservation is often lower than that which society would prefer. The major reasons for this are short-term and economic in nature. The rewards of agricultural land protection are broadly dispersed over space and time. Because so much of the benefit of soil conservation is realized by future generations, the immediate benefits are dispersed in very small increments and thus there is no strong incentive for individuals to support conservation policies.

In order for decisions to be made about soil degradation, the general public must understand the complex nature of the problem, as well as the economic realities. Chanasyk (1986) considered that the following are necessary

i. To create and maintain public awareness of the need for the long-term protection of the nation's soil and water resources.

ii. To ensure that the results of soil and water research and related technological developments are understood and considered by both producers and policy makers.

iii. To implement public programs which promote soil and water conservation either directly or indirectly, while avoiding the introduction or continuation of public programs which may indirectly promote the degradation of soil and water resources.

Over the past 40 years, Canadian agriculture has changed dramatically. Once, the nation's agricultural horizons seemed boundless, but now it is recognized that the limits of agricultural land expansion have about been reached. Over the past decade a great deal of public concern has arisen about land quality and its maintenance. Canada's agricultural land base is small in proportion to the nation's area (7% is farmland, less than 5% is improved land), but the land is reasonably productive. However, it is at the climatic margin of economically viable agriculture. Soil formation is rather slow and the topsoil is thin and vulnerable to abuse. Prime agricultural land (Class 1) occupies only 0.5% of the land area. 'Dependable' agricultural cropland (Classes 1, 2 and 3) occupies about 5%. The area of improved land has declined throughout central Canada and the Atlantic region, but has increased in the Prairie and Pacific regions. Some losses represent a phasing-out of marginal lands, but much good-quality land has been converted to urban uses (Dumanski et al 1986).

Although there is no immediate crisis, there is some cause for concern. Land degradation has become a problem in all regions since World War 2. Changes in production practices have achieved gains in productivity at considerable cost to the environment and to the natural fertility of many soils. Water and wind erosion are the most widespread problems, and have received the most attention. Another problem is soil compaction, which is generally induced by crop and soil management practices. It occurs most commonly with row crops such as potatoes, corn, and sugar beets, which require intensive tillage and field traffic when the soil is wet. Clay soils and soils low in organic matter are particularly vulnerable. Increasing compaction produces decreases in drainage and aeration and an increased risk of erosion. Crop yield may be reduced by as much as 50%. Salinization is a major problem in certain areas. Other forms of degradation also occur. Acidification is widespread on many soils, particularly in high-rainfall areas. Although much acidity is natural, agricultural practices, and especially the application of nitrogen fertilizers, have contributed. The impact of acid rain is thought to be less than that of fertilizers. Chemical contamination and subsidence of organic soils are other forms of soil degradation. Various activities have educated the farmers and the general public, but Dumanski et al (1986) considered that the outlook for agricultural land quality was not good, and that "If government policies, production practices, and market conditions remain as they are now, land quality will continue to deteriorate".

In recent years there has been a rapid development of government response to soil conservation challenges, and few people appear to be fully up-to-date on the state of legislation in this area. However, Soil Conservation Canada is in the process of preparing an updated inventory of provincial soil conservation legislation across Canada. It was not available at the time this report was written.

Australia: Environmental conservation

The Australian continent is unusually susceptible to erosion and salinization problems. Susceptibility of the natural land surface to erosion results from the combined effects of prolonged droughts and the consequent reduction in protective ground cover vegetation. The arid climate and the resultant sparse grass cover are additional factors in the vast inland area of the country. The effects of land use on land stability and production potential are greatest under the more intensive forms of land use, e.g. cropping (6.1 per cent of the area).

Until the early 1930's, agricultural development in Australia was exploitative. Forest and scrub were cleared and burned to provide space for crops and pastures. In 1938 the Soil Conservation Service of New South Wales was inaugurated, followed by the Soil Conservation Authority in Victoria in 1942. The dust storms of the mid 1940's carried red dust from central Australia to the capital cities of all the eastern states, which resulted in an increased awareness of the problem of soil erosion. Although the Premier's Conference of 1946 set up a Standing Committee on Soil Conservation (SCSC), it did little for the next 25 years. The individual States put only what they could afford into conservation. In 1964, the SCSC initiated a study on the need for soil conservation. The study was published in 1971.

Following this study, and consideration of the possible costs involved, the Commonwealth Government agreed to fund a joint Commonwealth-States Study, which was conducted from 1975 to 1977 and resulted in two reports. These reports recognized that different approaches would be required in the better-watered areas and the arid Rangelands, which occupy two-thirds of the country. The study analyzed the forms of degradation in five broad categories: (i) water erosion, (ii) wind erosion, (iii) water and wind erosion, (iv) dryland salinity, and (v) badly-degraded vegetation. In their reports, the study team correlated surveys of land degradation taken in each state and attempted to estimate the costs of measures required to bring erosion and degradation under control. The Government accepted the report, but instead of providing funds specifically for soil conservation, it gave each State its own allocation, to be spent according to its priorities. The plan languished, and nothing further was done until 1983, when the new Government revived the plan and provided funds to cover the costs.

The problems vary from State to State. In Victoria and Western Australia there is continued expansion of areas affected by dryland salinity. In New South Wales and Queensland the major problem on farmland is water erosion. Of the land under extensive cultivation that was stated in the 1975-1977 survey to require protection, 17.4% is now protected in New South Wales, 42.9% in Queensland, and 9.4% in South Australia. The present rate of progress will not allow all the land needing protection to be protected by the end of this century, but in Queensland there is hope that 75% of the land at risk will be protected. The Australian community has accepted that any form of land degradation is a bad thing, and the development of group conservation projects is spreading rapidly (Hallsworth 1987).

The Australian federal government has attempted to develop a basis for meeting the needs of both economic development and environmental conservation. The National Conservation Strategy aims to establish principles for development in such a way as to protect landscape values other than utilitarian economic values. However, since the late 1960's the nation has become increasingly aware of a decline in the quality of the Australian environment. The large-scale clearing of trees has destabilized the landscape in many districts, resulting in wind and water erosion together with extensive increases in the salinity of irrigation- and dry land-production systems (Roberts 1987).

The most recent national survey of land degradation has indicated that 51 percent of Australia's cropping and grazing land has been subjected to at least moderate erosion or salinization through a combination of degradation processes which usually begin with the disturbance of the vegetation cover through tree removal, overgrazing, or injudicious burning.

Today, all states have some form of soil conservation legislation, although implementation is less than satisfactory in some states. The past two decades have seen a wide-ranging extension of legislation aimed at controlling environmental degradation and land use (see Roberts 1987).

The National Soil Conservation Program acts as a catalyst in funding projects in research, education, and demonstration. Its objectives are that: (i) all lands in Australia be used within their capability, (ii) land-use and management decisions be based on whole catchment/regional land-use planning concepts, (iii) all land users and levels of government meet their respective responsibilities in achieving soil conservation, (iv) effective co-operation and co-ordination occur between all sectors of the community, disciplines and agencies involved in the use and management of land and water resources, (v) the whole community adopt a land-conservation ethic. The implementation of soil conservation is a state function; and each state has the autonomy to legislate and implement policy in its jurisdiction.

Problems such as soil structure decline, soil acidity increase, and design of earthworks on cracking clay soils still await practical technical solutions. Most soil erosion can be controlled adequately and economically by well-tried methods. Political solutions include the formulation of policy which provides for financial incentives and educational programmes, and legislation on land use guidelines and co-ordination of catchment schemes.

Land degradation in Australia, including social and legal aspects, was discussed in Chisholm and Dumsday (1987). There appears to be a view held within some sections of the farming community that title to land carries with it the individual right to farm the land as one pleases. It is asserted that responsibility should be, and is, assumed voluntarily to manage land carefully because it is in the landholder's own long-term interests so to do. However, the adequacy of self-interest in dealing with land degradation is being questioned increasingly. There is also a resurgent recognition of the legitimate public interest in the problem. These factors give rise to consideration of the appropriate means for ensuring that soil degradation is dealth with. Agriculture and pastoralism are major contributors to land degradation.

Bradsen and Fowler (in Chisholm and Dumsday 1987) made numerous criticisms of existing legal and institutional constraints on land degradation, and suggested some fresh directions for the future. They urged a departure from the long-established model of poorly-defined regulatory obligations sanctioned by criminal penalties in favour of a more precise scheme of civil regulation based on clear statements of statutory objectives; the prescription of land management guidelines on a regional basis; co-operative land management techniques; and civil remedies or restraints where landlords fail to co-operate or to meet basic land care standards established by legislation.

New Zealand: Water and soil conservation

In New Zealand, soil information is an important feature of the basic survey data required for town and country planning, as the productive soils are the country's greatest natural asset. Hence, there is a close association between the Soil Bureau of the Department of Scientific and Industrial Research (DSIR) and the Town and Country Planning Branch of the Ministry of Works. Close and continuous collaboration is particularly necessary because the most productive soils are under constant threat from urban expansion (Cox 1968). The proportion of good land is fairly small, 69% of New Zealand is hilly and steep land on which cultivation and other practices requiring wheeled machinery are not practicable (Gibbs 1968).

From the end of the 1930's the population increase was mostly urban, and absorbed thousands of acres of farmland annually. Two aspects were of special concern to the economy. The first was the very low residential densities, due to the almost universal development of the detached house on its individual plot of land. The second was the fact that most of the towns were located or expanding on limited areas of good arable land. Legislative recognition of the need to conserve the good soils for primary production was not obtained until 1953, when the Town and Country Planning Act replaced the Town Planning Act 1926. The Act and Regulations laid down the principle that every planning scheme "shall provide as far as is practicable for all land of high actual or potential value for production of food to be included in a rural zone, for the avoidance of encroachment of urban development on that land, and for the concentration of urban development within existing urban areas in preference to expansion of urban development into rural areas" (Cox 1968).

In practice, the administration of this requirement depends on the precise definition of what is "land of high actual or potential value for production of food", and equally precisely, where it is located. Hence the importance of the New Zealand soil classifications for land use. Classifications of soils for fruit growing, cropping, forestry, and pastoral use were prepared. Most New Zealand soils are used for grassland farming, and were classified by a scheme of limitations. Classes 1, 2, and 3 comprise soils on flat and rolling lands, classes 4, 5, and 6 comprise soils on hilly and steep lands. Soils in classes 1 and 4 have slight limitations to pastoral use, soils in classes 2 and 5 have moderate limitations, and those in 3 and 6 have severe limitations (Gibbs 1968). Leamy (1974) showed that 3% of the nation's soils were elite in terms of productivity and versatility, and 10% of the land area was occupied by soils of high value for food production.

When expansion of existing urban areas is proved to be necessary, the aim is to direct it onto soils of lesser value. Cox (1968) provided an example of this process. He thought that there was an urgent need in New Zealand for regional planning authorities with a much wider territorial responsibility. Meanwhile, decisions on urban development affecting soil conservation tended to be made in the light of the immediate local circumstances rather than the needs of the future.

The discussion of the preservation and 'best' use of agricultural land continues. Meister (1982) discussed:

i. rural/urban land conversion
ii. small rural holdings
iii. 'best' use of remaining agricultural land

Increasing amounts of the small stock of the best, highly-productive, soils are being swallowed up by the expansion of cities, displacing horticulture and agriculture. Meister considered that, contrary to a report published by the NZ Ministry of Agriculture and Fisheries, small holdings do not necessarily have a detrimental effect on agricultural production, and can lead to innovative changes, greater diversity in enterprises, and greater productivity. The question of 'best' use of remaining agricultural land is connected with methods for motivating land owners to make decisions which coincide with society's objectives, and hence to measures which guide and implement land use policies. Meister discussed the latter under four headings:

i. Agricultural zoning
ii. Land banking
iii. Taxation measures
iv. Development rights manipulation

Molloy (1980a) discussed the problems of growth within existing urban areas, expansion of towns on the surrounding productive land, and the subdivision of farms into small rural lots. Each topic involves the way in which individual people wish to lead their lives, but they also bear on communal values such as social amenities or the productivity of good farm land. Not surprisingly, they are among the most contentious issues in land use judgements. They also present a challenge to planners and scientists because they require high-quality, detailed scientific information and interpretation.

There are many statutes in New Zealand dealing with the use and management of water and soil resources. A major review and consolidation of the legislation was in progress in 1982. The major acts are

i. Soil Conservation and Rivers Control Act 1941. This established the Soil Conservation and Rivers Control Council and local catchment authorities. The functions of these bodies are the promotion of soil conservation, the prevention or mitigation of soil erosion, and the prevention of damage by floods. It gives the Council power to make grants from Government funds for these purposes and enables catchment authorities to promote schemes of works using local funds.

ii. Water and Soil Conservation Act 1967. This act established the National Water and Soil Conservation Authority and, by later amendment, the Water Resources Council. The National Authority advises the Minister on water and soil matters, makes recommendations on policy, legal and similar issues, and oversees the work of its two subordinate councils. Within limits set by the Government, the Authority can authorise various water and soil conservation works.

iii. Town and Country Planning Act 1977. This act established a system of local planning implemented by local authorities and regional planning implemented by United and Regional Councils. Regional plans are intended to provide the basis for wise use and management of the resources and the direction and control of development of a region. Land and water are clearly two of the most important natural resources in any region, and consequently the guidelines and policies established in the regional planning scheme are of particular concern to the water and soil authorities. District schemes are concerned with the detailed planning ordinances covering land use and related matters and are of similar importance from a water and soil point of view. Catchment authorities are represented on the regional bodies'planning committees.

iv. Public Works Act 1981 provides the authority for constructing various classes of 'public work' and for acquiring any necessary land (Howard 1982). Outside of soil conservation districts, all of New Zealand is declared Catchment Territory, in which the Soil Conservation and Rivers Control Council can do all that catchment boards may do in districts. A third classification is soil conservation reserve, which is public land. Specific permission of the Council is required for any exploitation of reserve land. Animal trespass, mining, and destruction of vegetation are specifically mentioned as activities to be controlled (Christy 1971).

The problem of land use planning has been debated for some time in New Zealand. Meister (1977) stated that whereas for a long time they have relied principally on market forces for the allocation of resources, in recent years resource use conflicts had shown that the market system does not always perform in the way that society wants. This had led to a greater demand for some planning of resource use, and he discussed various possibilities.

Molloy (1980b) reviewed briefly the current NZ land planning process. Land use decisions were controlled or affected by over 45 Acts. Some Government policies and "matters of national importance" (Town and Country Planning Act 1977) also influence land use. Two Acts of particular importance to land use are the Water and Soil Conservation Act 1967, and amendments, that control soil erosion and damage by floods, and the Town and Country Planning Act 1977, that requires the preparation, implementation, and administration of regional, district, and maritime, schemes which, locally and nationally, shall provide for the "...wise use and management of the resources in such a way as will most effectively promote and safeguard the health, safety, convenience, and the economic, cultural, social, and general welfare of the people..."

Responsibility for planning schemes lies with local authorities. Of primary importance are the regional schemes which are to be prepared by regional or united councils constituted under the Local Government Act

1974. The need for integrated planning for land and water management is recognized by the Town and Country Planning Act 1977, which requires that each catchment authority whose district is entirely within a region must be represented on the corresponding regional planning committee. Legislation available to territorial authorities seems to provide adequate legal and procedural powers to regulate and guide land use, provided that the authority is aware of actual or potential problems and is prepared to use the legislation.

It is still not clear how the Town and Country Planning Act will achieve satisfactory land use planning when regional and central government have conflicting land use objectives. Already there are signs of impending conflict between central government (charged with managing most of the nation's natural resources under statutes such as the Forest Act and National Park Act) and emerging regional government which may wish to circumscribe such activities (Molloy 1980b).

Statutory responsibility for land use decisions is spread widely among a number of ministers and their departments. Co-ordinating and advisory bodies also have responsibility for, or advise government on, various land-related matters. Local authorities manage most land. Territorial local authorities comprised (at 1 April 1978) 95 county, 5 district, and 134 borough, town, and city councils. Each local authority must produce a district scheme plan which conforms to the regional planning scheme. Special-purpose local authorities (about 880) work under special legislation. Molloy (1980b) asked if all the Acts and regulations were really necessary, and if they were, were all the organisations really needed?

In 1988 the legislation which governs land use planning and use of natural resources and of protected areas is being reviewed completely, and great changes are possible. Laws relevant to soil protection which are being considered in this Resource Management Law Reform include:

- Town and Country Planning Act 1977
- Water and Soil Conservation Act 1967
- Soil Erosion and Rivers Control Act 1941
- Mining Act 1971
- Coal Mines Act 1979

Laws being considered in the Protected Areas Legislation Review include:

- Conservation Act 1987
- Queen Elizabeth II National Trust Act 1977
- Reserves Act 1977
- Native Plants Protection Act 1934
- National Parks Act 1980
- Wildlife Act 1953
- Historic Places Act 1980.

Cloke (1988) discussed:

i. form - the structural link between society and the state
ii. function - the roles which are necessary to reproduce that form
iii. apparatus - the instruments through which functions are performed.

He noted, among other things, a need to understand more of both the hidden agenda of functions which planning performs and the political economic constraints within which rural policies are made and implemented.

Appendix 3:

European soil charter

World soil charter

COUNCIL OF EUROPE

COMMITTEE OF MINISTERS

RESOLUTION (72) 19

EUROPEAN SOIL CHARTER

(Adopted by the Committee of Ministers on 30 May 1972 at the 211th meeting of the Ministers' Deputies)

Preamble

The Committee of Ministers of the Council of Europe,

Having regard to the studies undertaken by the Council of Europe on aspects of soil conservation in the different climatic and pedologic regions of Europe;

Considering that soil is a complex and dynamic milieu, characterised by a given flora and fauna, by mineral and organic elements, and affected by the circulation of air and water;

Considering that soils influence vegetation and the water cycle and thus are at the origin of the main food resources for man and animals;

Having regard to the increasing biological deterioration of the soil in many parts of Europe and especially that used for agriculture and forestry which each year suffers the damaging effects of pollution, erosion and sometimes ill-chosen techniques;

Recognising that ecological principles are not always taken into consideration when, in the context of regional planning, decisions on land-use are made;

Believing that those responsible for land management should bear in mind not only the immediate needs of modern society (urbanisation, industry, agriculture, tourism) but also the part played by the soil in landscapes and vegetation of scientific, aesthetic and cultural interest to man,

Adopts and proclaims the principles of the European Soil Charter, prepared by the European Committee for the Conservation of Nature and Natural Resources of the Council of Europe, and set out below :

1. Soil is one of humanity's most precious assets. It allows plants, animals and man to live on the earth's surface

Soil is a living and dynamic medium which supports plant and animal life. It is vital to man's existence as a source of food and raw materials. It is a fundamental part of the biosphere and, together with vegetation and climate, helps to regulate the circulation and affects the quality of water.

Soil is an entity in itself. As it contains traces of the evolution of the earth and its living creatures, and is the basic element of the landscape, its scientific and cultural interest must be taken into consideration.

2. Soil is a limited resource which is easily destroyed

Soil is a thin layer covering part of the earth's surface. Its use is limited by climate and topography. It forms slowly by physical, physico-chemical, and biological processes but it can be quickly destroyed by careless action. Its productive capacity can be improved by careful management over years or decades but once it is diminished or destroyed reconstitution of the soil may take centuries.

3. Industrial society uses land for agriculture as well as for industrial and other purposes. A regional planning policy must be conceived in terms of the properties of the soil and the needs of today's and tomorrow's society

Soil may be put to many uses and it is generally exploited according to economic and social necessity. But the use made of it must depend on its properties, its fertility and the socio-economic services which it is capable of providing for the world of today and tomorrow. These properties thus govern the suitability of land for farming, forestry and other uses. Destruction of soil, in particular for purely economic reasons based on considerations of short-term yield, must be avoided.

Marginal lands raise special problems and special opportunities for soil conservation because, properly managed, they have great potential as nature reserves, re-afforestation areas, protection zones against soil erosion and avalanches, reservoirs and regulators of water systems and as recreation zones.

4. Farmers and foresters must apply methods that preserve the quality of the soil

Machinery and modern techniques permit considerable increases in yields, but, if used indiscriminately, they may disrupt the natural balance of the soil, altering its physical, chemical and biological characteristics. The destruction of organic matter in the soil by inappropriate methods of cultivation and the misuse of heavy machinery are important factors in impairing soil structure and hence the yield of arable crops. The soil structure of grassland may be similarly damaged by intensive stocking.

Forestry should put appropriate emphasis on methods for improved exploitation which will prevent soil deterioration.

Methods of tillage and harvesting should conserve and improve the properties of the soil. The introduction of new techniques on a wide scale should be undertaken only after its possible disadvantages have been studied.

5. Soil must be protected against erosion

Soil is exposed to the weather; it is eroded by water, wind, snow and ice. Careless human activity speeds up the process of erosion by damaging the soil's structure and its normal resistance to erosive action.

In all situations, suitable physical and biological methods must be applied to protect the soil against accelerated erosion. Special measures must be taken in areas liable to floods and avalanches.

6. Soil must be protected against pollution

Certain chemical fertilisers and pesticides, used without discernment or control, may accumulate in cultivated land and may thus contribute to the pollution of soil, groundwater, water courses, and air.

If industry or agriculture discharges toxic residues or organic wastes that could endanger the land and water, those responsible must provide for adequate treatment of water or the disposal of wastes in suitable places, as well as for the restoration of the dumping areas after use.

7. Urban development must be planned so that it causes as little damage as possible to adjoining areas

Towns obliterate the soil upon which they stand and effect neighbouring areas as a result of providing the infrastructure necessary to urban life (roads, water supplies etc.) and by producing growing quantities of waste which must be disposed of.

Urban development must be concentrated and so planned that it avoids as far as possible taking over good soil and harming or polluting soil in farmland and forest, in nature reserves and recreational areas.

8. In civil engineering projects, the effects on adjacent land must be assessed during planning, so that adequate protective measures can be reckoned in the cost

Operations such as the building of dams, bridges, roads, canals, factories or houses may have a more or less permanent influence on surrounding land, both close at hand and at a distance. Often they alter natural drainage and watertables. Such repercussions must be assessed so that suitable measures are taken to counteract damage.

Costs of measures to protect the surrounding area must be calculated at the planning stage and, if the installation is temporary, costs of restoration must be included in the budget.

9. An inventory of soil resources is indispensable

For effective land planning and management and to permit the establishment of a genuine policy of conservation and improvement, the properties of the different types of soil, their capabilities and distribution, must be known. Each country must make an inventory, as detailed as necessary, of its soil resources.

Soil maps, supplemented as appropriate by special maps on land-use, geology, real and potential hydrogeology of soils, soil capability, vegetation, hydrology, and the like, are necessary for this purpose. The production of such maps by specialised agencies working together is a basic necessity in each country. These maps should be prepared in such a way as to permit comparison at international level.

10. Further research and interdisciplinary collaboration are required to ensure wise use and conservation of the soil

Research on soil and its use must be supported to the full. On it depend the perfecting of conservation techniques in agriculture and forestry, the elaboration of standards for the application of chemical fertilisers, the development of substitutes for toxic pesticides, and methods of suppressing pollution.

Scientific research is essential to prevent the consequences of the wrong use of the soil in any human activity. Because of the complexity of the problems involved, such research must form part of the work of multidisciplinary centres. International exchange of information and co-ordination must also be encouraged.

11. Soil conservation must be taught at all levels and be kept to an ever-increasing extent in the public eye

Increasing publicity, adapted to national and local requirements, must be given to the need for conservation of the quality of the soil and the methods by which this aim can be achieved. Authorities should strive to ensure that the information given to the public by the mass media is scientifically correct.

Soil conservation principles must be fully included in teaching programmes at all levels as an element of environmental education as such : at primary, secondary and university levels. Techniques of soil conservation must be taught in faculties, engineering, agricultural and forestry schools and to adults in rural communities.

12. Governments and those in authority must purposefully plan and administer soil resources

Soil is an essential but limited resource. Therefore, its use must be planned rationally, which means that the competent planning authorities must not only consider immediate needs but also ensure long-term conservation of the soil while increasing or at least maintaining its productive capacity.

A proper policy of soil conservation is therefore needed, which implies an appropriate administrative structure necessarily centralised, and properly co-ordinated at the regional level. Appropriate legislation is also required to allow the planned apportionment of land for different uses in regional and national development, to control techniques of land-use which might cause deterioration or pollution of the environment, to protect the soil against the inroads of natural and human hazards and where necessary to restore it.

States which accept the principles set out above should undertake to devote the necessary funds to their implementation and promote a genuine soil conservation policy.

C

C 81/27
October 1981

conference

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS ROME

E

Twenty-first Session

Rome, 7-26 November 1981

WORLD SOIL CHARTER

Summary

A set of principles is presented, for consideration and adoption by the Conference, which should serve as a basis for a more rational utilization of the world's finite soil resources, thereby avoiding irreversible degradation.

Introduction

1. The drafting of a World Soil Charter as a set of agreed principles leading to improvement of productivity and conservation of soils was entrusted to FAO by Resolution VI of the World Food Conference (Rome 1974).

2. In preparing this document FAO has called upon the information it has gained in the preparation of the FAO-Unesco Soil Map of the World and the experience and data that it has built up in the execution of numerous projects which it has operated in many countries, under varying physical, social and economic conditions in such fields as soil survey, land use planning and soil conservation.

3. In addition to this, consultations have been held with Governments and with International Organizations on this subject and a draft document has been discussed by the Sixth Session of the Committee on Agriculture (Rome, 1981) and the Seventy-ninth Session of the FAO Council (Rome, 1981).

4. As a result of these consultations and discussions, and taking into account the Declaration of Principles and the Programme of Action presented at the World Conference on Agrarian Reform and Rural Development (Rome, 1979), the following revised draft Charter is submitted to the FAO Conference for consideration with a view to adoption.

Objectives of the World Soil Charter

5. The objective of the World Soil Charter is to establish a set of principles which should serve as a basis for the most rational use of the world's soil resources and their protection against irreversible degradation.

6. Soil degradation directly affects people by reducing the productivity of their land. It is proceeding at a rate which cannot be accepted because the survival and welfare of mankind depends on continued and expanded land productivity.

7. The Charter calls for a commitment on the part of Governments and International Organizations to pursue programmes of soil conservation and reclamation. It recommends that decisions about land use and management be made for long-term advantage rather than short-term expediency. Land use techniques should permit sustainable or improving levels of production. Special attention is called to the need for developing land use policies and legislation, to build up institutional capabilities, to conduct inventories, to organize training courses and public awareness campaigns, to initiate research programmes and to involve local populations in conservation activities.

8. It is stressed that favourable economic, social and institutional conditions are important for rational land resources management and conservation of soil. International Organizations have the responsibility to promote international awareness, to assist Governments upon request with specific conservation programmes and to support technical cooperation among developing countries.

DRAFT RESOLUTION FOR THE CONFERENCE

WORLD SOIL CHARTER

THE CONFERENCE,

Recalling Resolution VI of the World Food Conference (Rome, 1974), by which the Food and Agriculture Organization was urged to establish a World Soil Charter as a basis for an international cooperation towards the most rational use of the world's soil resources,

Realizing that land resources are limited and that of the total land area of the world only a small percentage is currently used to feed the world population which is likely to reach six billion by the end of the century,

Recalling further the Programme for Action adopted by the World Conference on Agrarian Reform and Rural Development, which called for "an efficient use of land ... with due regard for ecological balance and environmental protection",

Concurring that the food requirements of mankind including the eradication of malnutrition can be met by:

- the intensification of food crop production including multiple cropping, wherever this can be safely accomplished,
- the bringing into cultivation of new lands, wherever conditions for sustained cropping prevail, with a view to meeting food production requirements,
- the establishment and better utilization of grasslands and forests.

Sharing the concern caused by the dangers of soil degradation resulting from misuse of land and inappropriate measures for intensifying production, particularly in areas which are exposed to water and wind erosion, or salinity and alkalinity,

Noting the research carried out by FAO in conjunction with Unesco, UNEP, WMO, and other competent international organizations, and in consultation with Governments concerned, with a view to assessing the lands that can still be brought into cultivation, taking proper account of permanent vegetation cover for the protection of catchment areas and of land required for forestry, grazing and other uses, with particular reference to hazards of irreversible soil degradation as well as the order of magnitude of costs and inputs required,

Recognizing that decisive progress towards intensified assistance in the improvement of productivity and conservation of soils can be achieved by the adoption and implementation of appropriate principles and guidelines for action at the national and international levels,

Having noted the conclusions and recommendations adopted by the Committee on Agriculture at its Sixth Session and by the Council at its Seventy-ninth Session.

1. Hereby adopts the World Soil Charter;

2. Recommends to the United Nations and international organizations concerned to give effect, within their respective spheres of competence, to the Principles and Guidelines set forth below.

PRINCIPLES

1. Among the major resources available to man is land, comprising soil, water and associated plants and animals: the use of these resources should not cause their degradation or destruction because man's existence depends on their continued productivity.

2. Recognizing the paramount importance of land resources for the survival and welfare of people and economic independence of countries, and also the rapidly increasing need for more food production, it is imperative to give high priority to promoting optimum land use, to maintaining and improving soil productivity and to conserving soil resources.

3. Soil degradation means partial or total loss of productivity from the soil, either quantitatively, qualitatively, or both, as a result of such processes as soil erosion by water or wind, salinization, waterlogging, depletion of plant nutrients, deterioration of soil structure, desertification and pollution. In addition, significant areas of soil are lost daily to non-agricultural uses. These developments are alarming in the light of the urgent need for increasing production of food, fibres and wood.

4. Soil degradation directly affects agriculture and forestry by diminishing yields and upsetting water regimes, but other sectors of the economy and the environment as a whole, including industry and commerce, are often seriously affected as well, through, for example, floods, or the silting up of rivers, dams and ports.

5. It is a major responsibility of governments that land use programmes include measures towards the best possible use of the land, ensuring long-term maintenance and improvement of its productivity, and avoiding losses of productive soil. The land users themselves should be involved, thereby ensuring that all resources available are utilized in the most rational way.

6. The provision of proper incentives at farm level and a sound institutional and legal framework are basic conditions to achieve good land use.

7. Assistance given to farmers and other land users should be of a practical service-oriented nature and should encourage the adoption of measures of good land husbandry.

8. Certain land tenure structures may constitute an obstacle to the adoption of sound soil management and conservation measures on farms. Ways and means should be pursued to overcome such obstacles with respect to the rights, duties and responsibilities of land owners, tenants and land users alike.

9. Land users and the broad public should be well informed of the need and the means of improving soil productivity and conservation. Particular emphasis should be placed on education and extension programmes and training of agricultural staff at all levels.

10. In order to ensure optimum land use it is important that a country's land resources be assessed in terms of their suitability at different levels of inputs for different types of land use, including agriculture, grazing and forestry.

11. Land having the potential for a wide range of uses should be kept in flexible forms of use so that future options for other potential uses are not denied for a long period of time or forever. The use of land for non-agricultural purposes should be organized in such a way as to avoid, as much as possible, the occupation or permanent degradation of good quality soils.

12. Decisions about the use and management of land and its resources should favour the long-term advantage rather than the short-term expedience that may lead to exploitation, degradation and possible destruction of soil resources.

13. Land conservation measures should be included in land development at the planning stage and the costs included in development planning budgets.

GUIDELINES FOR ACTION

Acceptance of these Principles would require the following action:

By Governments

i. Develop a policy for wise land use according to land suitability for different types of utilization and the needs of the country.

ii. Incorporate principles of rational land use and management and conservation of soil resources into appropriate resource legislation.

iii. Develop an institutional framework for monitoring and supervising soil management and soil conservation, and for coordination between organizations involved in the use of the countries' land resources in order to ensure the most rational choice among possible alternatives.

iv. Assess both new lands and the lands already being used for their suitability for different uses and the likely hazards of degradation. Provide decision makers with alternative land uses which both satisfy communities' aspirations and use the land according to its capabilities.

v. Implement education, training and extension programmes at all levels in soil management and conservation.

vi. Disseminate as widely as possible, information and knowledge about soil erosion and methods of controlling it both at the farm level and at the scale of entire watersheds stressing the importance of soil resources for the benefit of people and development.

vii. Establish links between local government administrations and land users for the implementation of the soils policy and emphasize the need to put proven soil conservation techniques into practice.

viii. Strive to create socio-economic and institutional conditions favourable to rational land resource management and conservation. These conditions will include providing security of land tenure and adequate financial incentives (e.g. subsidies, taxation relief, credit) to the land user. Give encouragement particularly to groups willing to work in cooperation with each other and with their government to achieve appropriate land use, soil conservation and improvement.

ix. Conduct research programmes which will provide sound scientific backing to practical soil improvements and soil conservation work in the field, and which give due consideration to prevailing socio-economic conditions.

By International Organizations

i. Continue and intensify efforts to create awareness and encourage cooperation among all sectors of the international community, by assisting where required to mount publicity campaigns, conduct seminars and conferences and to provide suitable technical publications.

ii. Assist governments, on request, to establish appropriate legislation, institutions and procedures to enable them to mount, implement and monitor appropriate land use and soil conservation programmes.

iii. Promote cooperation between governments in adopting sound land use practices, particularly in the large international watersheds.

iv. Pay particular attention to the needs of agricultural development projects which include the conservation and improvement of soil resources, the provision of inputs and incentives at the level of the farm and of the watershed, and the establishment of the necessary institutional structures as the major components.

v. Support research programmes relevant to soil conservation, not only of a technical nature but also research into social and economic issues which are linked to the whole question of soil conservation and land resource management.

vi. Ensure the storage, compilation and dissemination of experience and information related to soil conservation programmes and of the results obtained in different agro-ecological regions of the world.

First published 1989
ISBN 1 870393 13 9

The INSTITUTE OF TERRESTRIAL ECOLOGY (ITE) is one of 15 component and grant-aided research organisations within the NATURAL ENVIRONMENT RESEARCH COUNCIL. The Institute is part of the Terrestrial and Freshwater Sciences Directorate, and was established in 1973 by the merger of the research stations of the Nature Conservancy with the Institute of Tree Biology. It has been at the forefront of ecological research ever since. The six research stations of the Institute provide a ready access to sites and to environmental and ecological problems in any part of Britain. In addition to the broad environmental knowledge and experience expected of the modern ecologist, each station has a range of special expertise and facilities. Thus, the Institute is able to provide unparallelled opportunities for long-term, multidisciplinary studies of complex environmental and ecological problems.

ITE undertakes specialist ecological research on subjects ranging from micro-organisms to trees and mammals, from coastal habitats to uplands, from derelict land to air pollution. Understanding the ecology of different species of natural and man-made communities plays an increasingly important role in areas such as improving productivity in forestry, rehabilitating disturbed sites, monitoring the effects of pollution, managing and conserving wildlife, and controlling pests.

The Institute's research is financed by the UK Government through the science budget, and by private and public sector customers who commission or sponsor specific research programmes. ITE's expertise is also widely used by international organisations in overseas collaborative projects.

The results of ITE research are available to those responsible for the protection, management and wise use of our natural resources, being published in a wide range of scientific journals, and in an ITE series of publications. The Annual Report contains more general information.

P J A Howard and M Hornung
Institute of Terrestrial Ecology
Merlewood Research Station
Grange-over-Sands
Cumbria LA11 6JU

Tel: 05395 32264