Assessment and reporting on soil erosion

Background and workshop report

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Abbreviations

CAP	Common agricultural policy
Corine	Coordination of information on the environment
DPSIR	Driving forces — Pressures — State — Impact — Responses
DSR	Driving forces — State — Responses
EEA	European Environment Agency
EFMA	European Fertiliser Manufacturers' Association
EIONET	European Environmental Information and Observation Network
ETC/S	European Topic Centre on Soil
ETC/TE	European Topic Centre on Terrestrial Environment
Glasod	Global assessment of human-induced soil degradation
NDVI	Normalised difference vegetation index
OECD	Organisation for Economic Cooperation and Development
Pesera	Pan-European soil erosion risk assessment
RUSLE	Revised universal soil loss equation
UN	United Nations
UNCED	United Nations Conference on Environment and Development (Rio, 1992)
USLE	Universal soil loss equation

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Executive summary

This report has been prepared by the Katholieke Universiteit Leuven under contract to the European Environment Agency (EEA) and is the final result of a working group on indicators for soil erosion. The working group was established by the EEA in order to progress with the work on soil in the interim period before the new European Topic Centre on Terrestrial Environment (ETC/TE) started in July 2001.

In 2001 the EEA carried out a peer review of its work on soil, with particular reference to the development of policy-relevant indicators and the identification of probable problem areas for soil degradation ('hot spots') (1). The review was in particular focused on work on indicators for soil erosion and soil sealing, and two associated technical workshops were held in March 2001 to facilitate this review.

This report provides the background on and analyses the work done by the EEA on soil erosion in the period to 2001 and summarises the conclusions of the workshop on indicators for soil erosion, held in Copenhagen on 27–28 March 2001.

The purpose of the workshop was to identify a set of recommendations concerning reporting on soil erosion (as part of the wider theme of soil degradation) that could then be considered for inclusion in the work programme for the new ETC on Terrestrial Environment.

Soil erosion is a natural process, occurring over geological time. Most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activities such as changes in land cover and management. This report focuses on accelerated erosion caused by water.

Runoff is the most important direct pressure of severe soil erosion. Processes that influence runoff must therefore play an important role in any analysis of soil erosion intensity, and measures that reduce runoff are critical to effective soil conservation.

In Europe, soil erosion is caused mainly by water and, to a lesser extent, by wind. In the Mediterranean region, water erosion results from intense seasonal rainfall on often fragile soils located on steep slopes. The area affected by erosion in northern Europe is more restricted and moderate rates of water erosion result from less intense rainfalls falling on saturated, easily erodible soils.

According to the Glasod assessment, in Europe, excluding the Russian Federation, about 114 million ha or more than 17 % of the total land area is affected by soil erosion, of which more than 24 million ha or approximately 4 % show high or extreme degradation and nearly 70 million ha or 11 % are affected by moderate degradation.

The various regions of Europe show different patterns, for example in the EU and EFTA countries the area subjected to soil erosion is about 9 % of the total land area. It increases to 26 % in the candidate countries and to 32 % in the rest of Europe (excluding the Russian Federation). However, these findings are based on fragmented and non-standardised information and hence may not be consistent.

Soil erosion: a priority at the European level

In April 2002, the European Commission adopted a communication on soil protection, endorsed by the Council of Ministers in June 2002. The communication considers soil erosion as one of the major threats to Europe's soils and a priority for action.

Increasing the awareness amongst scientists and policy-makers about the problem of soil degradation through erosion in Europe is now an urgent requirement. The identification of areas that are vulnerable to soil erosion can be helpful for improving our knowledge about the extent of the areas affected and, ultimately, for developing measures to keep the problem under control.

(1) 'Hot-spot' maps of soil degradation in Europe were first published in EEA, 2000 and EEA, 2001a. The results of a EIONET review of the 'hot-spot' analysis and maps produced are discussed in EEA, 2002b.

In a long-term perspective, the implementation of the work on indicators discussed in this report should certainly contribute to improving the information basis needed to prepare, implement and monitor a sound European strategy on soil, in line with the priorities set down in the sixth environmental action programme (EAP) and the communication on soil protection.

Policy-relevant indicators on soil erosion

Objective and measurable criteria with potential to compare between areas and monitor changes over time are needed to describe the condition and management of soil erosion. The driving forces–pressure–state–impact and responses (DPSIR) assessment framework in combination with the multi-function and multi-impact (MF-MI) approach provides a methodology for the integrated assessment of the soil environment, enabling the inclusion of cause–effect relationships into policy-relevant indicators. The application of the DPSIR assessment framework to soil erosion is discussed in this report.

Following the DPSIR assessment framework, a set of soil erosion indicators have been proposed by the EEA and are reviewed in Part I of this report. A major difficulty in the development of these indicators is availability of data. The proposed pressure indicators link to the driving force ‘agricultural intensification’ and all have in common that they are complex and not directly linked to the phenomenon of soil erosion. The identified indicators of state and impact are difficult or expensive to measure and the data are usually not readily available. Indicators of response are prevention and control measures, which are rarely in place at present.

Land cover / use and management are the most important factors that influence soil erosion. Some of the indicators proposed are related to land use. These can be regarded as a basis for assessing pressures that may result in soil erosion but they require further analysis and inclusion of other factors. Human activities that affect land use and determine land use intensity include agriculture, infrastructure, recreation, mining activities or forest management. It is therefore recommended that regularly updated Corine land cover data are used in combination with earth observation derived products such as the normalised difference vegetation index (NDVI) in order to capture seasonal variations in land cover. Existing policies for the protection of soils and the degree of enforcement of such policies should also be monitored.

Regional soil erosion assessment is needed on a European scale in order to make objective comparisons that may provide a basis for further environmental analysis, economic statements or policy development. Some methods for carrying out regional assessments are based on the collection of distributed field observations, others on an assessment of factors, and combinations of factors, which influence erosion rates, and others primarily on a modelling approach. None of the reviewed methods presents state-of-the-art regional soil erosion assessments. The Glasod and hot-spot maps can be classified as methods based on distributed point data, while the RIVM and Corine maps can be classified as factor- or indicator-based maps. Other current developments are model-based risk analysis, such as Pesera.

Workshop findings

At the workshop the following topics were discussed: assessment and reporting framework; regional and spatial assessment methods for soil erosion and data availability; and indicators for soil erosion. Indicators should be developed according to the following properties and procedures: quantitative, objectively calculated, validated against measurements and evaluated by experts.

The formulation of suitable remediation measures and mitigation strategies requires a regional assessment of soil erosion; the extent and magnitude of areas at risk is essential to prepare soil conservation policies. The method should combine all four strategies of regional erosion assessment, i.e. measured data, expert mapping, factor (thematic) mapping and regional modelling. Factor- and model-based approaches offer the advantages of repeatability and transparency. However, the results need to be validated against measurements and evaluated by experts so that the models or factor approaches can be adapted to reflect the reality.

Recommendations

A set of specific recommendations for the EEA and ETC / TE was developed with the purpose to contribute to the EEA work programme and to the discussion at the European level. These recommendations are related to the general reporting and networking mechanism, to the DPSIR assessment framework, to the proposed indicators by the EEA, to the explicit incorporation of land use into soil erosion indicators, and to the implementation of regional erosion assessments.

In particular, since soil erosion has impacts on several media, such as water quality, working links should be developed with other ETCs and specifically with the ETC on Water. Links with other international initiatives and with data providers should also be maintained.

A revised scheme for soil erosion within the DPSIR assessment framework is proposed. It is advised to better explore the dynamics of the factors involved in this scheme and to undertake a stakeholder analysis on the proposed scheme.

The area affected by erosion is an important indicator for the state of soil erosion, and should be complemented with an indication of the magnitude of erosion in particular areas. Actual soil erosion measurements, such as those collected for the hot-spot map, should continue to be compiled. However, the difficulty of making truly objective comparisons between, and often within, areas calls for a standardised approach to record and particularly map the observations. Therefore, a Europe-wide monitoring network for soil such as proposed by the EEA (2001b) should include monitoring of soil erosion.

A regional assessment using modelling, expert estimates and other methods should be developed in order to provide a general view and identify the hot-spot areas where a detailed soil erosion monitoring programme should be undertaken.

The temporal and spatial patchiness of soil erosion favours a risk analysis approach in order to make comparisons between regions and to complement field measurements and observations. Modelling efforts should be thoroughly validated against erosion measurements, and a clear distinction should be made between modelled erosion risk and present-day erosion rates. A programme to monitor soil erosion across different agro-ecological regions and under different land uses should underpin both mapping exercises and regional soil erosion risk assessment methods. Only then a sound approach is ensured of estimations and mapping features that are directly validated and compared with measurements. Moreover, measuring campaigns may lead to new insights and therefore to both better mapping and risk assessments.

1. Introduction

1.1. Scope of the report

This report has been prepared by the Katholieke Universiteit Leuven (Catholic University of Leuven) under contract to the EEA and is the final result of a working group on indicators for soil erosion. The working group was established by the EEA in order to progress with the work on soil in the interim period before the new ETC on Terrestrial Environment (ETC/TE) started in July 2001.

In 2001 the EEA carried out a peer review of its work on soil, with particular reference to the development of policy-relevant indicators and the identification of probable problem areas for soil degradation ('hot spots'). The review was in particular focused on work on indicators for soil erosion and soil sealing, and two associated technical workshops were held in March 2001 to facilitate this review. A separate document was prepared for the workshop on soil sealing and the 'hot-spot' review (EEA, 2002b).

Soil erosion is a natural process, occurring over geological time, and may be caused by water or wind. Most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activities such as changes in land cover and management. This document focuses on accelerated erosion by water.

A workshop on assessment and reporting on soil erosion was held in Copenhagen on 27–28 March 2001. The purpose of the workshop was to identify a set of recommendations concerning reporting on soil erosion (as part of the wider theme of soil degradation) that could then be considered for inclusion in the work programme for the ETC/TE.

The report provides the background, analyses the work done by the EEA on soil erosion (Part I) and summarises the conclusions of the workshop on indicators for soil erosion (Part II).

1.2. Background

The EEA was established by Council Regulation EEC (No) 1210/90 in May 1990 and started its operations in Copenhagen in July 1994. The EEA mission is to contribute to the improvement of the environment in Europe and to support sustainable development through the provision of relevant, reliable, targeted and timely information to policy-makers and the general public. This should enable the Community and Member States to take the necessary measures to protect the environment, to assess the results of such measures and to be supported with the necessary technical and scientific issues. The EEA mandate is to provide information to Community institutions and member countries required to frame, identify, prepare, implement and evaluate sound and effective policies on the environment and to ensure that the public is properly informed.

The EEA's main tasks are:

1. to report on the state and trends of the environment;

2. to establish, develop and make use of the European Environmental Information and Observation Network (EIONET);

3. to facilitate access to data and information supplied to, maintained and emanating from EEA and EIONET, together with access to other relevant environmental information developed by other national and international sources.

The role of the EEA, as defined by its mission and mandate, is therefore to provide policy-makers and the public with quality information, and to do so through a range of products and services. The agency works as a facilitator or bridge between member countries ([2]), the Community institutions (in particular the Commission, Parliament and Council) and other environmental organisations and programmes to bring together, use, make available and thereby

(2) To date EEA membership counts 30 countries, comprising the EU-15, three EFTA countries (Iceland, Liechtenstein, Norway) and 11 of the 13 candidate countries (Turkey is expected to join shortly).

improve the quality of information on the environment relevant at the European level for policy-making and assessment. This is done through basic activities, including the support to national monitoring, the gathering and storage of existing information and currently accessible and reliable data, the analysis and assessment of data to produce policy-relevant information and indicators, the reporting of results to the policy-makers and the dissemination of information to the general public (Envision model, monitor to reporting —MDIAR — core activities) (Gentile, 1999a).

The European Topic Centre on Soil (ETC/S) ([3]) was established by the EEA in 1996 with the objective to provide and develop information and data on soil aspects, covering all EEA member countries, in order to increase the understanding of soil as a natural resource, document soil degradation processes and improve the level of reliable and comparable information about contaminated sites, thus contributing to the development of the EEA work programme.

ETC/S operated until December 1999. A new Topic Centre on Terrestrial Environment (ETC/TE) started operations in July 2001. The ETC/TE is carrying out the work initiated by the ETCs on Soil, Land Cover and Marine and Coastal Environment (terrestrial part of coastal environment).

On the basis of the results of the first EIONET workshop on soil (EEA, 2001a,b) and a wider review of the EEA work on soil (October 1999), in the period 2000–mid-2001 the implementation of the work programme progressed through three working groups on indicators for:

- soil contamination (from local and diffuse sources);
- soil sealing; and
- soil erosion.

This report is the final product of the working group on soil erosion.

1.3. Policy developments

Since 2001 important progress took place at the policy level. In fact, the sixth environmental action programme (6EAP) has introduced a new strategy on soil protection for the European Union. The programme, proposed by the European Commission in 2001, lays down the Community action programme for the period 2001–10 in the field of the environment.

The 6EAP recognises that 'little attention has so far been given to soils in terms of data collection and research. Yet, the growing concerns on soil erosion and loss to development as well as soil pollution illustrate the need for a systematic approach to soil protection ...'.

Moreover, 'given the complex nature of the pressures weighing on soils and the need to build a soil policy on a sound basis of data and assessment, a thematic strategy for soil protection is proposed ...' (European Commission, 2001).

In April 2002, the Commission adopted a communication on soil protection, endorsed by the Council of Ministers in June 2002. The communication considers soil erosion as one of the major threats to Europe's soils and a priority for action.

A communication on soil erosion, soil organic matter decline and soil contamination, containing detailed recommendations for future measures and action, has been planned. To facilitate this process, a conference on soil erosion and organic matter decline in the Mediterranean with the participation of the major stakeholders is being organised by the Commission and expected to take place in 2003 (European Commission, 2002).

In a long-term perspective, the implementation of the work on indicators discussed in this report would certainly contribute to improving the information basis needed to prepare, implement and monitor a sound European strategy on soil, in line with the priorities set down in the 6EAP and the communication on soil protection.

1.4. Objectives and methodology of the review

The specific objectives of this report are the following:

(3) ETCs are consortia of organisations that are assigned to carry out specific tasks concerning an environmental theme. They help the EEA develop its multi-annual and annual working programmes.

- provide a summary overview of EEA work on soil erosion indicators;
- review the EEA European framework for the assessment and monitoring of soil and the proposed soil erosion indicators in relation to data availability and analytical soundness;
- discuss the link between soil erosion indicators and land use or land use intensity;
- review methods for assessing soil erosion on a regional scale;
- present options for future development with particular reference to existing European data sources; and
- present the results of the workshop on indicators on soil erosion.

The methodology adopted in the review process consisted first of all in the evaluation of EEA work carried out by a group of experts and the preparation of a background report (included in Part I). An analysis of existing approaches for a regional assessment of the extent of soil erosion in Europe was also carried out (see Section 4). A selection of national experts was asked to evaluate the results of EEA work on soil erosion and invited to discuss the results of the evaluation at the workshop. Questions to guide the review were provided (see Annex II). The main items of the discussion and the conclusion of the workshop are summarised in Part II.

1.5. Soil erosion in Europe

The main problems for soils in the European Union are irreversible losses due to increasing soil sealing and soil erosion, and continuing deterioration due to local and diffuse contamination. It is envisaged that Europe's soil resource will continue to deteriorate, probably as a result of changes in climate, land use and other human activities. A policy framework is needed which recognises the environmental importance of soil, takes account of problems arising from the competition among its concurrent uses, both ecological and socioeconomic, and is aimed at maintaining its multiple functions (EEA, 2000).

Soil erosion, in particular, is regarded as one of the major and most widespread forms of land degradation, and, as such, poses severe limitations to sustainable agricultural land use. Erosion reduces on-farm soil productivity and contributes to water quality problems as it causes the accumulation of sediments and agro-chemicals in waterways. The dynamic relationship between agriculture and the environment requires that erosion processes be quantified at different scales to monitor and evaluate the impact of agriculture and land use policies.

In Europe, soil erosion is caused mainly by water and, to a lesser extent, by wind. Prolonged erosion causes irreversible soil loss over time, reducing the ecological functions of soil: mainly biomass production, crop yields due to removal of nutrients for plant growth and reduction in soil filtering capacity due to disturbance of the hydrological cycle (from precipitation to runoff). The major reasons are unsustainable agricultural practices and overgrazing in medium- and high-risk areas of land degradation (EEA, 1999a), together with deforestation and construction activities (Yassoglou et al., 1998).

Soil losses are high in southern Europe, but soil erosion due to water is becoming an increasing problem in other parts of Europe (EEA, 2000). Box 1 provides an overview of the extent of soil degradation in Europe. Some of the findings are shown in Table 1.1, but the figures shown are only a rough approximation of the area affected by soil degradation.

However, Table 1.1 does indicate the importance of water erosion in Europe in terms of area affected. The most dominant effect is the loss of topsoil, which is often not conspicuous but nevertheless potentially very damaging since it affects the most fertile part of the soil profile. Physical factors such as climate, topography and soil characteristics are important in the process of soil erosion. In part, this explains the difference between the severe water erosion problem in Iceland and the much less severe erosion in Scandinavia where the climate is less harsh and the soils are less erodible (Fournier, 1972).

The Mediterranean region is considered to be particularly prone to erosion. This is because it is subject to long dry periods followed by heavy bursts of intensive rainfall, falling on steep slopes with fragile soils and low vegetation cover. According to present-day information (EEA, 2000, 2001), soil erosion in north-west Europe is considered to be slight because rain is falling on mainly gentle slopes, is evenly distributed throughout the year and events are less intensive. Consequently, the area affected by erosion in northern Europe is much more restricted in its extent than in southern Europe. However, these findings are based on fragmentised and non-standardised information.

In parts of the Mediterranean region, erosion has reached a stage of irreversibility and in some places erosion has practically ceased because there is no more soil left. In the most extreme cases, soil erosion leads to desertification. With a very slow rate of soil formation, any soil loss of more than 1 t/ha/year can be considered as irreversible within a time span of 50–100 years (EEA, 1999a). Losses of 20 to 40 t/ha in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t/ha in extreme events (Morgan, 1992). It may take some time before the effects of such erosion become noticeable, especially in areas with the deepest and most fertile soils or on heavily fertilised land. However, this is all the more dangerous because, once the effects have become obvious, it is usually too late to take remedial steps.

Increasing awareness amongst scientists and policy-makers about the problem of soil degradation through erosion in Europe is now an urgent requirement. The identification of areas that are vulnerable to soil erosion can be helpful for improving our knowledge about the extent of the areas affected and, ultimately, for developing measures to keep the problem under control.

Attention is focused mainly on rill- and interrill erosion because this type of erosion affects the largest area. Other forms of erosion are also important, for example, gully erosion, landslides and, to a lesser extent, wind erosion. Some of these, particularly gully erosion and landslides, have serious consequences for land use systems and populations, but in overall terms are still relatively localised (see Annex IV for a description of the different types of erosion).

Box 1 — Soil erosion in Europe

Extent of human-induced soil degradation by erosion in Europe (million hectares) Table 1.1

	Erosion type	Light	Moderate	High	Extreme	Total
Accession countries	Water erosion	4.5	29.2	14.7	0.0	48.4
	Wind erosion	0.0	0.0	0.0	0.0	0.0
	AC total	4.5	29.2	14.7	0.0	48.4
EFTA countries	Water erosion	0.8	1.5	0.0	0.0	2.3
	Wind erosion	0.6	1.3	0.0	0.0	1.9
	EF total	1.3	2.9	0.0	0.0	4.2
Rest of Europe	Water erosion	0.8	19.3	6.5	1.0	27.7
	Wind erosion	0.0	5.8	0.0	0.7	6.5
	ER total	0.8	25.1	6.5	1.7	34.2
European Union	Water erosion	12.8	11.9	1.4	0.0	26.2
	Wind erosion	1.0	0.1	0.0	0.0	1.1
	EU total	13.8	12.0	1.4	0.0	27.3
Europe (excl. the Russian Federation)	Water erosion	18.9	62.0	22.6	1.1	104.6
	Wind erosion	1.6	7.2	0.0	0.7	9.5
	All Europe total	20.5	69.2	22.6	1.8	114.1 (17.4 % of total land area)

Note: Any mismatch between totals and disaggregated figures is due to the rounding process.

Source: EEA data elaboration from Glasod (Oldeman, 1991; Van Lynden, 1995; data: UNEP and ISRIC through UNEP/GRID Geneva, 2001).

According to the Glasod assessment, in Europe, excluding the Russian Federation, about 114 million ha or more than 17 % of the total land area is affected by soil erosion, of which more than 24 million ha or approximately 4 % show high or extreme degradation and nearly 70 million ha or 11 % are affected by moderate degradation. The major type of degradation is erosion by water (about 16 % of the total land area), while erosion by wind interests only 1.5 % of the territory.

The various regions of Europe show different patterns, for example in the EU and EFTA countries the area subjected to soil erosion is about 9 % of the total land area. It increases to 26 % in the candidates countries and to 32 % in the rest of Europe (excluding the Russian Federation).

Part I — Assessment and reporting on soil erosion

2. A European framework for the assessment and monitoring of soil

The degradation of the environment through soil erosion is an important concern for policy-makers.

Objective and measurable criteria with the potential to compare between areas and monitor changes over time are needed to describe the condition and management of land resources and the pressures exerted upon the land.

There is now a requirement for environmental protection agencies to periodically report on the state of the environment and particularly whether this is deteriorating, stable or improving. Agencies are dealing more commonly with a degrading environment, hence the search for 'indicators' that can quantify this degradation in some way.

International organisations such as the EEA, OECD and UN have initiated programmes on developing measurable and policy-relevant agri-environmental indicators to assess and monitor progress in reaching sustainable development, as defined in Agenda 21 by the United Nations Conference on Environment and Development (UNCED).

2.1. The assessment framework

An update of the state of progress of the EEA soil work programme and the relevance of indicator development including the reporting system were presented at the EIONET workshop on indicators for soil contamination in Vienna, 18–19 January 2001 (EEA, 2002a, b).

The concept of multiple soil functions and competition is crucial in understanding current soil protection problems and their multiple impacts on the environment. The EEA considers soil with its multiple ecological and socioeconomic functions and multiple impacts as having a fundamental role in Europe's environment (EEA, 1999a). The ecological functions comprise production of biomass; filtering, buffering and transforming; gene reserve and protection of flora and fauna. The socioeconomic functions include support to human settlements; source of raw materials, including water; and protection and preservation of cultural heritage. Soil degradation means loss or deterioration of its functions (Blum, 1998). Soil losses due to erosion can be considered as irreversible in relation to the time needed for soil to form or regenerate itself.

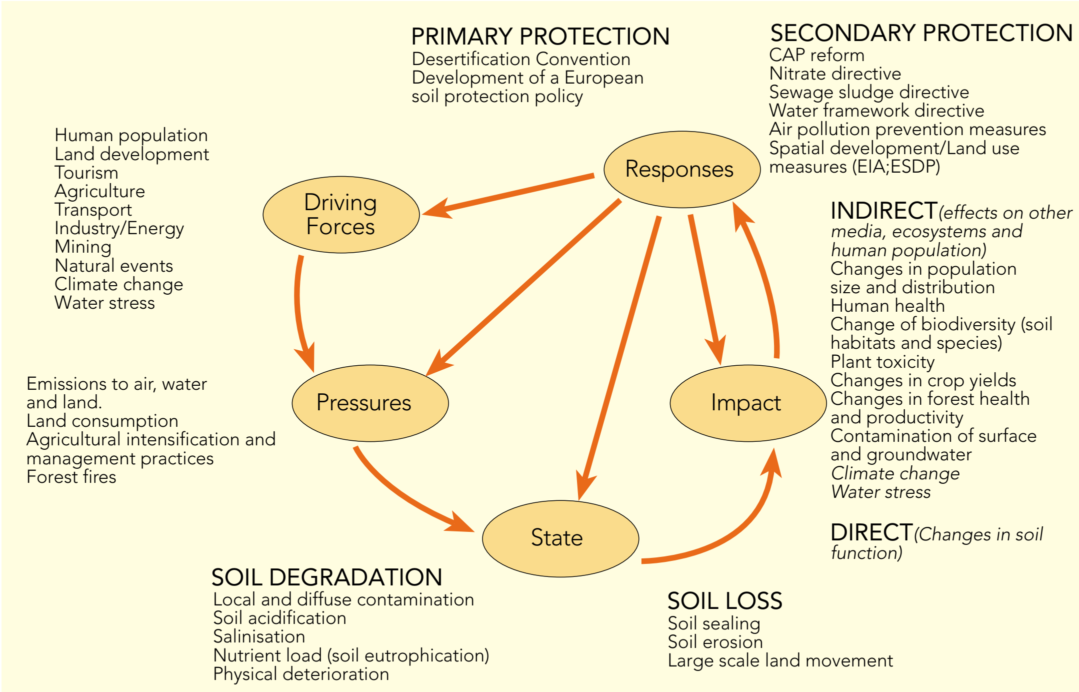
The OECD DSR framework (driving force–state–response) has established a holistic systems approach to include cause-effect relationships (OECD, 1993). The OECD model has been extended by the EEA to cover the causes (pressures) and the impacts on the environment (EEA, 1999b, 2000).

The DPSIR assessment framework shows a chain of causes–effects from driving forces (activities) to pressures, to changes on the state of environment, to impacts and responses (EEA, 1999, 2000). DPSIR is based on the assumption that economic activities and society's behaviour affect environmental quality. The relationships between these phenomena can be complex. DPSIR highlights the connection between the causes of environmental problems, their impacts and society's response to them, in an integrated way. The DPSIR applied to soil resources is shown in Figure 2.1.

In addition to the DPSIR, the EEA has defined the multi-function and multi-impact approach (MF/MI), based on the recognition of the role played by the soil multiple functions and the problems arising from the competition between these functions (see Figure 2.2).

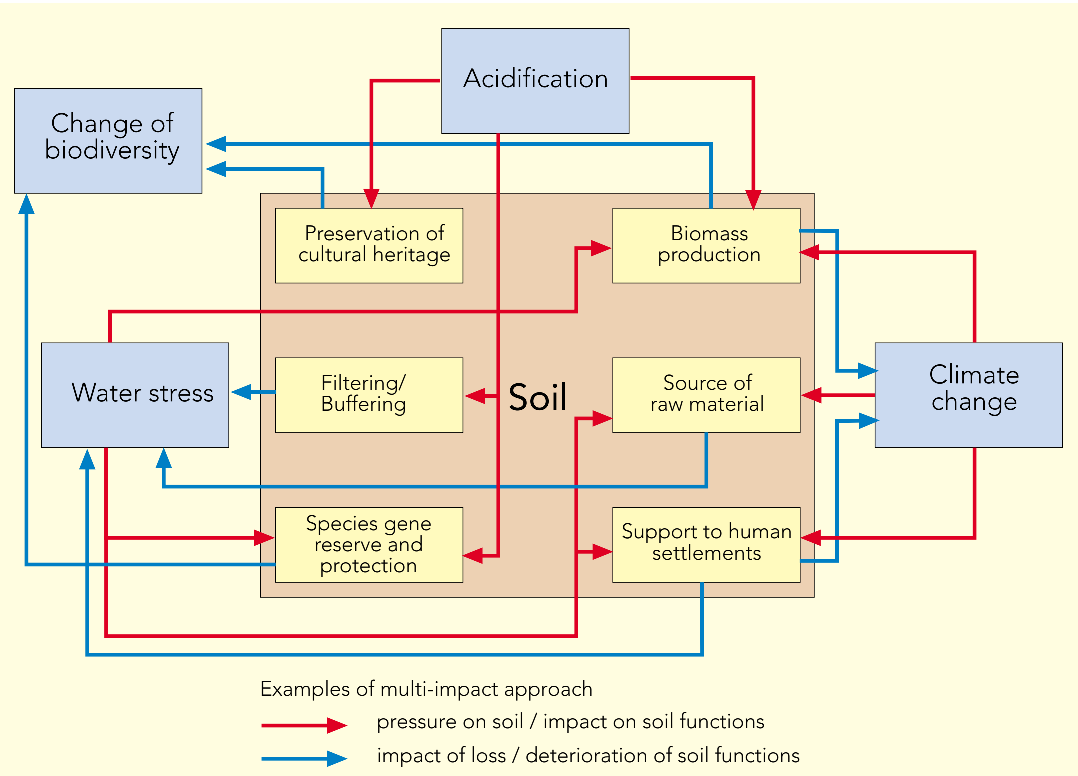
Both DPSIR and MF/MI are analytical tools for the definition of policy-relevant indicators to describe pressures placed upon soil resources, changes in the state of soil, and impacts or responses by society to these changes, within the context of policy and soil

The DPSIR assessment framework applied to soil (EEA 2000) Figure 2.1



Source: EEA, 1999a.

Examples from the multi-function/multi-impact approach Figure 2.2



Source: EEA, 1999a.

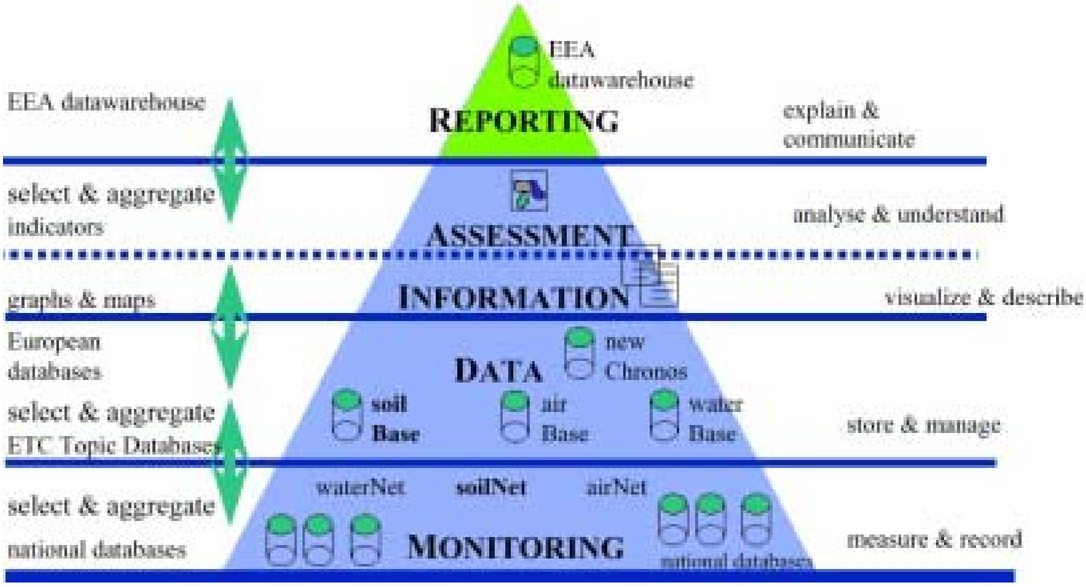
resource management (Gentile, 1999a). These tools also provide a framework for the subsequent interpretation and assessment of the indicators.

In environmental monitoring, indicators have been defined as 'parameters, or values derived from parameters, which point to / provide information about / describe the state of a phenomenon / environment / area with significance extending beyond that directly associated with a parameter value' (OECD, 1993).

OECD (1993, 1999) defines agri-environmental indicators (AEIs) as attributes of land units, which are:

Figure 2.3 The EEA information strategy 'from national monitoring to European reporting' (MDIAR framework)

Source: EEA, 2001b.



- policy relevant and have utility for users; i.e. the AEIs should:
  - provide a representative picture of environmental conditions, pressures on the environment or society's responses;
  - be simple, easy to interpret and able to show trends over time;
  - be responsive to changes in the environment and related human activities;
  - provide a basis for international comparisons;
  - be either national in scope or applicable to regional environmental issues of national significance;
  - have a threshold or reference value against which to compare them so that users are able to assess the significance of the values associated with them;

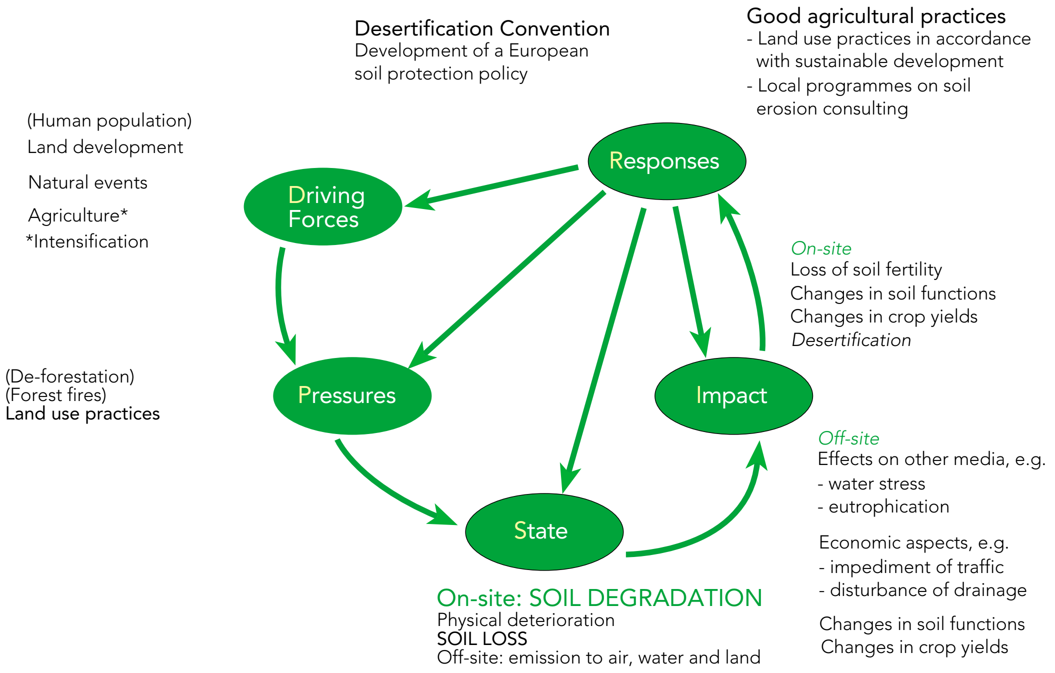
- analytically sound; i.e. the AEIs should:
  - be theoretically well founded in technical and scientific terms;
  - be based on international standards and international consensus about their validity;
  - lend themselves to being linked to economic models, forecasting and information systems;

- measurable; i.e. the data required to support the AEIs should be:
  - readily available or made available at a reasonable cost / benefit ratio;
  - adequately documented and of known quality;
  - updated at regular intervals in accordance with reliable procedures.

In addition to the above criteria, the EEA selects indicators having in mind the target audience, together with the most suitable level of aggregation and the availability of data needed to compile them (Gentile, 1999a). An overview of the situation is provided by indicators with a high level of aggregation, so-called headline indicators (Gentile, 1999a), while detailed indicators are needed to better understand underlying trends or existing links between policy measures and their effects. The challenge is finding an appropriate balance between simplification and completeness.

The EEA together with its EIONET partners, including the European Topic Centres (ETCs), are facilitating the process from national monitoring to European reporting (Figure 2.3). The MDIAR framework consists of monitoring, data collection, information, assessment and reporting. The set up of a European soil-monitoring network harmonises national networks and enables data comparability. Data flow and management entails organisation and storage in databases. Data are integrated into indicators and assessed using the DPSIR and MF / MI approaches. Reporting enables communication of the results obtained. The MDIAR chain concentrates on matching the best available environmental information with the best needed environmental and economic information.

The DPSIR assessment framework applied to soil erosion Figure 2.4



Source: EEA-ETC/S, 1999.

2.2. The DPSIR assessment framework applied to soil erosion

Figure 2.4 presents the DPSIR assessment framework applied to soil erosion as proposed by EEA-ETC/S (1999). Possible driving forces can be grouped according to human activity and physical phenomena, which in turn result in potential pressures on the land. An important driving force related to soil erosion is the intensification of agriculture. Intensification of agriculture encourages unsustainable land use practices and deforestation, which in turn enhance the risk of soil erosion. These pressures may change the state of the soil resources, and result in soil loss. Soil loss is recognised to have both direct and indirect impacts on the environment, expressed in terms of on-site and off-site effects, respectively (Figure 3.4).

The responses at the European level include CAP reform, soil conservation measures and land use practices in accordance with sustainable development. However, a European policy framework on soil protection, similar to those already in place for air and water, does not exist. Moreover, there is no reporting mechanism in place to assess whether existing measures are leading to improvement of soil conditions or to gauge the level of implementation of existing legislation (EEA, 2000) ([4]).

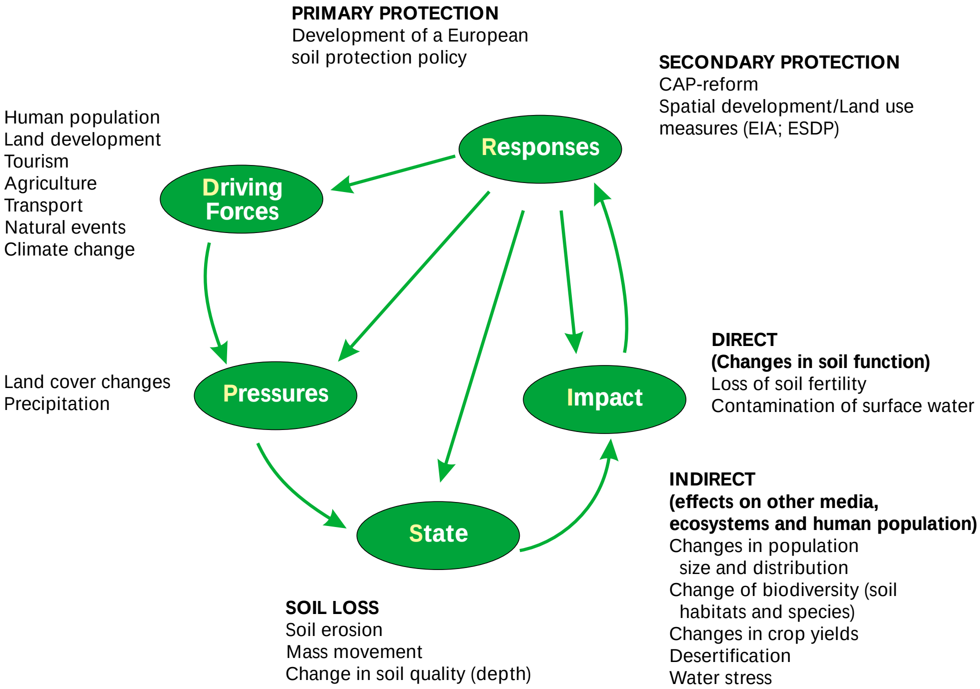
The assessment carried out through the DPSIR assessment framework does not aim at understanding or analysing soil erosion as a process, but provides information to support policy-makers' actions so that the necessary measures can be defined and the effect of current measures can be assessed.

2.3. Is the proposed DPSIR assessment framework adequate to comprehend soil erosion?

The result of the application of the DPSIR and MF/MI assessment tools to soil erosion is the identification of a set of policy-relevant indicators. However, it has to be recognised that there is a huge difference between actual and potential soil erosion, which is not adequately reflected in the present framework (EEA-ETC/S, 1999). Indicators describing the driving forces and pressures may affect the risk of soil erosion, but they may not affect soil erosion in itself, which also depends on physical parameters such as climate and relief. A mechanism is therefore needed to jointly estimate the potential and actual risk, based on links between the identified driving force and pressure

(4) In April 2002, the Commission adopted a communication on soil protection, later endorsed by the Council of Ministers in June 2002. The communication considers soil erosion as one of the major threats to Europe's soil and a priority for action (European Commission 2002; see also Section 1.4).

Figure 2.5 The DPSIR assessment framework applied to soil erosion modified from EEA, 2000, and EEA-ETC/S, 1999



indicators, and on an estimation or measurement of what is actually happening.

Agricultural intensification is seen as the most important driving force (EEA-ETC/S, 1999; EEA, 2000). However, tourism and transport could be added to the list of driving forces. The effect they have in common is that they change the land cover, which is the major pressure indicator for soil erosion. This would lead to a revised scheme for soil erosion within the DPSIR assessment framework, presented in Figure 2.5.

The DPSIR assessment framework lends itself to systems analysis and as such is very useful in describing the relationships between the origins and consequences of environmental problems. Obviously, the real world is more complex than can be expressed in simple causal relationships. Linkages between the different types of indicators are explored through the DPSIR chain. However, the linkages deserve further attention, not least to capture the dynamics of the system. Moreover, linkages within one type of indicators (e.g. pressures) are not explored, despite their repeatedly reported importance.

The emphasis of the DPSIR assessment framework is on socioeconomic related indicators, while physical indicators of pressure are not fully explored, nor explicitly mentioned. Climate change is considered as a driving force but only in the sense that it relates to human activities. Important physical factors that influence soil erosion are topography, soil type, soil vulnerability and climatic factors (particularly rainfall). These factors cannot be separated from the identified pressure indicators. On the other hand, they are implicitly incorporated into indicators of state.

A major problem with soil erosion is the temporal and spatial scale of reporting and the spatial extent to which the phenomenon occurs. Although problems of both spatial and temporal patchiness are well recognised in the various reports (EEA, 2000; EEA, 2001a), a more integrated approach of reporting seems recommendable. One solution could be to develop a regional model that allows for estimating the potential soil erosion risk, combined with periodical monitoring of actual soil erosion in selected test areas. The regional soil erosion model should express the links between the different biophysical and socioeconomic factors, i.e. be process-based; establish various spatial and temporal resolution linkages; and provide a nested strategy of focusing on environmentally sensitive areas which may require remedial measures to be taken. Sections 3 and 5 provide more details on the requirements for future regional soil erosion reporting in order to develop sound indicators of state.

In the different reports made by the EEA, it is recognised that a distinction ought to be made between on-site and off-site impacts of soil erosion. This distinction, however, already applies at an earlier stage in the DPSIR chain, namely at the stage of state indicators. Soil erosion can be measured in terms of actual sediment loss per unit area (on site) or in terms of sediment delivery into streams or rivers (off site).

The current level of detail chosen for the application of the DPSIR assessment framework to soil erosion implicitly enables the identification of broad groups of actors related to the perceived environmental problem. However, the full identification of the several actors involved requires a more detailed stakeholder analysis. Environmental problems can be identified and discussed by each group of stakeholders using participatory methods for eliciting the various aspects of the perceived problem. A general stakeholder analysis ultimately helps formulating policies for remediation and mitigation strategies.

In conclusion, the DPSIR assessment framework is an excellent tool onto which further extensions and strategies of reporting can be built. The framework sets a good basis for identifying the different factors influencing soil erosion, and should be coupled with a detailed stakeholder analysis in order to identify the full range of actors in the DPSIR chain.

2.4. EEA typology of indicators applied to soil erosion

The EEA identifies four different types of indicators (EEA, 1999b):

- descriptive indicators, describing the actual situation in the DPSIR assessment framework;
- performance indicators, comparing the actual situation with a specific set of desirable conditions in terms of a ‘distance to target’ assessment;
- efficiency indicators, expressing the relation between separate elements of the causal chain such as between environmental pressures and human activities;
- total welfare indicators, measuring ‘sustainability’ in the form of an index (‘Green GDP’ or index of sustainable economic welfare), currently not within the EEA’s mandate.

Efforts related to soil erosion have concentrated on descriptive indicators within the DPSIR philosophy. Without a European policy framework on soil protection, however, little progress can be expected on the other three types of indicators. Sound advice on how to develop performance indicators on soil protection will be one of the challenges of the European Topic Centre on Terrestrial Environment.

Indicators of soil erosion and data availability

2.5. Introduction

The development of policy-relevant indicators for soil was one of the main activities of the European Topic Centre on Soil (ETC/S). The EEA has proposed and discussed a set of indicators for soil erosion (EEA-ETC/S, 1999). ETC/S work aimed to identify policy-relevant indicators for soil erosion and to update the existing databases by means of data collection requests. Further recommendations were made to assess data needs and availability, and to set up monitoring activities. Since climate, soil and relief are fairly static variables, the ETC/S recommended ground cover measurements to be closely monitored. The EEA have drawn up a list of policy-relevant indicators for soil (Gentile, 1999b), which was presented at the EIONET workshop in October 1999 and at the first Soil Forum held in Berlin in November 1999 (Table 2.1) (EEA, 2001a, b).

2.6. Review

Indicators for soil erosion should incorporate the following characteristics.

- The indicators will be a measure of soil loss due to erosion as a result of climate, topography, soil properties, land cover and land management.
- The extent and severity of both potential and actual soil erosion risk will have to be quantified and related to land cover changes.
- The nature of soil erosion has to be assessed in order to evaluate the on-site loss and the possible off-site impacts.

Table 2.1 **EEA draft list of policy-relevant indicators for soil**

Source: EEA-ETC/S, 1999; Gentile, 1999b.

Issue / question	Indicator	Units	DPSIR	Soil degradation pattern	Short-term core indicators	Comment
Intensity of agriculture:			D	Not applicable	Yes	Index of output vs. input
Degree of agricultural land use (ALU)? To what extent does ALU intensify during a specified time within a given country?	Consumption of fertilisers per defined region (e.g. Member State) (and its increase)	t/ha	P	Soil erosion	No	Available in Eurostat and OECD
	Average farm size per defined region (e.g. Member State) (and its increase)	Euro/ha	D/P	Soil erosion	No	Low priority
	Average field sizes (and its increase)	Euro/ha	D/P	Soil erosion	No	Low priority
	Average crop yield per area (and its increase)	t/ha	D/P	Soil erosion	No	Desirable but not key
	Average net profit per area	Euro/ha yr	D	Soil erosion	No	Low priority
	Number of grazing animals	No/ha	P	Soil erosion	No	Desirable but not key
To what extent is the area of member countries affected by soil erosion (both wind and water erosion)?	Short term: rough estimations by the countries: percentage of area affected by soil erosion per defined region (e.g. Member State)	%	S	Soil erosion	No	Desirable but difficult to obtain
To what extent is the total area of Europe affected by soil erosion (both wind and water erosion)?	Depending on the progress of validation of the ISRIC map	km^2	S	Soil erosion	No	Also outlooks
What is the extent of total soil loss by soil erosion (water erosion)?	Short term: rough estimations: estimation of the total gross erosion of defined areas based on the sediment delivery ratio of selected rivers (in dependence of the watershed area)	t	S	Soil erosion	Yes	Also outlooks
What is being done to remove off-site damages by soil erosion?	Expenditures for removals of sediment deposits in built-up areas (traffic routes, houses)	Euro	I/R	Soil erosion	Yes	Desirable but not key
How much is spent on sustainable farming?	Local agricultural programmes to enforce sustainable farming management systems (incl. terminated set-aside of arable land)	Euro	R	Soil erosion/ Diffuse contamination	No	Desirable but not key
How much is spent on erosion prevention?	Expenditures for special soil erosion prevention programs, forest fire protection	Euro	R	Soil erosion	No	Desirable but not key
To what extent is the erosion risk area of member countries protected from soil erosion (both wind and water erosion)?	Portion of actual erosion risk area under erosion control management (set-aside arable land, strip cropping, contour ploughing, crop changing, balanced grazing, reforested), on total area of actual erosion risk	%	R	Soil erosion	No	Key but difficult

Note: Priority indicators are marked in bold.

Table 2.2 EEA indicators for soil erosion tested according to the OECD criteria

EEA Indicator	Policy relevant	Utility		Analytical soundness		Measurability		Effect	Comments
	Represen-tative	Easy to interpret	Com-parable	Scientific/ Techni-cally	Data available	Documen-ted	Updated		
Fertiliser use and trend	Yes	No	Probably	???	Eurostat, OECD	Yes	Yes	Complex	Economic criterion, link variable
Farm size and trend	Yes	Yes	Sometimes	Probably	Nationally	Yes	Periodi-cally	Complex	Not linked directly
Field size and trend	Yes	In part	Yes	Probably	National/ regional	Yes	Yes	Complex	Data partially available
Crop yield and trend	Yes	No	Yes	Yes	National/ EU	Yes	Yes	Complex	Data for actual and estimated (CGMS) yields
Net profit and trend	Yes	No	Yes	Probably	National	Yes	Yes	Not relevant	
Stocking rate and trend	Yes	No	Yes	No	National/ EU	Yes	Yes	Complex	Dichotomy between intensive indoor and outdoor stocking
Actual soil erosion	Yes	No	???	Yes	Rarely available	In part	No	Direct	Extent not known, expensive to measure
Delivery of sediment	Yes	No	???	Yes	Difficult to measure	In part	No	Direct	Measurement difficult, source difficult to establish
Removal of sediment	No	No	No	No	???	No	No	Direct	Comprehensive measurements not possible
Prevention (agriculture)	Yes	No	Yes	Yes	Probably not	In part	No	Direct	Usually piecemeal
Prevention (forest, natural)	Yes	No	Yes	Yes	No	In part	No	Direct	Usually piecemeal
Erosion control	Yes	Yes	Yes	Yes	Rarely available	In part	No	Direct	Usually piecemeal

As accelerated erosion is a complex process, it is necessary to develop indicators that identify the causes. Physical factors that influence erosion rates include topography, soils, climate and land cover. Land cover is in turn influenced by the socioeconomic environment and as such by anthropogenic activities, notably land use and management.

Table 2.2 lists the EEA indicators for soil erosion with brief comments on the OECD criteria listed in Section 2.1. The first six indicators relate to pressures as a result of agricultural intensification. These pressure indicators all have in common that they are complex and not directly linked to the phenomenon of soil erosion. The identified indicators of state and impact are difficult or expensive to measure and the data are usually not readily available. Indicators of response are prevention and control measures, which are rarely in existence at present. A more comprehensive discussion follows in the next sections.

2.6.1. Indicators of driving forces and pressures

According to the EEA (EEA-ETC/S, 1999), the main driving force on soil that causes erosion in regions with potential and actual soil erosion risks is the intensification of agriculture. This is a complex indicator and it is related to different pressure indicators. The corresponding pressures are cost-effective but unsustainable land use practices, the use of machinery for the cultivation of enlarged fields, the overgrazing and other instruments of intensive land use practices (EEA-ETC/S, 1999). Average field sizes (and increase of field sizes), combined with average farm size per region as well as the consumption of fertilisers and the number of grazing animals, give an indication of the intensification of agriculture.

The intensification of agriculture is not necessarily directly related to soil erosion. The higher the degree of intensity of agricultural land use the higher may be the soil loss by water and wind erosion in potentially high erosion risk areas, but the reverse could equally be true. For example an intensive farming system employing soil conservation measures, such as terracing and cover crops, may result in less soil erosion than a more extensive system that does not involve conservation techniques. Intensive land use can be combined with efficient soil conservation measures.

Section 4 concentrates on other aspects related to pressure indicators. One major remark is that the intensity of agriculture should never be evaluated alone in relation to erosion. Soil loss due to erosion is a result of climate, topography, soil properties, land cover and land management. Land cover also includes the natural vegetation.

2.6.1.1. Consumption of fertilisers

The proposed indicator is 'the consumption of fertilisers per defined region (e.g. Member State)', measured in tonnes/ha. The consumption of fertilisers can give an indication of the intensification of agriculture (EEA-ETC/S, 1999). Another positive aspect is that data on estimated consumption of fertilisers are available at national level from the European Fertiliser Manufacturer's Association (EFMA) or via Eurostat/OECD.

The reliability of the data used to calculate this indicator may be seriously questioned. The main source of information on fertilisers in Europe is EFMA (see http://www.efma.org/). The data from EFMA are the production of fertiliser from the associated members. Then the EFMA uses data on imports and exports to calculate fertiliser use or consumption at the national level. For example, the current approach is:

(Fertiliser consumption {in a Member State}) = (production) — (exports) + (imports) (2.1)

To determine the actual fertiliser use by equation (2.1), certain adjustments should be applied to take account of losses (e.g. 10–15 %) and use outside general agriculture, for example in market and domestic gardens (e.g. 10 %). However, fertiliser applications vary for different crops so it is not possible to predict the consumption of fertilisers using this approach without knowing precisely the spatial distribution of crops and local agricultural practices.

The main conclusion is the higher the degree of intensity of agricultural land use, the higher the likely loss of soil through water and wind erosion in potentially high erosion risk areas (EEA-ETC/S, 1999). However, fertiliser consumption data cannot be determined accurately enough to be used as an indicator for soil erosion at the scale required. Moreover, fertiliser applications may increase when using soil conservation measures so that soil erosion decreases.

Together with consumption of fertilisers, average farm size (per defined region (e.g. Member State) and its increase), average field size (and its increase), average crop yield (per area and its increase), average net profit (per area) and number of grazing animals give an indication of the intensification of agriculture (EEA-ETC/S, 1999). This does not necessarily imply an increase in soil erosion. The factors that relate directly to erosion are soil type, topography, crop cover and precipitation. However, knowing the contribution of the agro-economic sectors to soil erosion is essential for the policy-makers to be able to take the requisite measures and monitor their implementation, but the lack of good quality data hinders the development of suitable indicators in the short term.

2.6.1.2. Average farm and field size

The proposed indicators are 'average farm size per defined region (e.g. Member State) (and its increase)' and 'average field size (and its increase)', both measured in ha. Data on farm and field size are available at national and European level. These data are periodically updated, with full farm surveys every 10 years and sample surveys of farm structure every two to four years. However, these data are only averages on a large area basis, e.g. Member State, and there is no demonstrable direct link between actual soil erosion and either farm or field size.

As stated above, average farm size and average field size can give an indication of the intensification of agriculture. Furthermore, monitoring an increase in farm and field size would infer increased intensification of agricultural practices. However, only in areas of medium and high erosion risk would increased soil loss be likely to result directly from an intensification of agriculture. As indicators of soil erosion, these parameters cannot be used independently.

2.6.1.3. Crop yields and animal numbers

The proposed indicators are 'average crop yield per area and its increase', measured in tonnes per ha and 'number of grazing animals' in numbers per ha. Data on crop yields and stock numbers are updated annually at national and European level. Where there are difficulties in obtaining crop yield data, forecasts are available from simulation modelling, for example the crop growth monitoring system (CGMS) that underpins the MARS project. However, these data are usually only averages on a large area basis (e.g. national level). Moreover, there is no demonstrable direct link between actual soil erosion and either crop yields or animal numbers. Crop types and the extent of the area devoted to each crop type also influence soil erosion. Interpreting the data on grazing animals is confounded by the type of land use system (for example, livestock fed by fodder or outdoor grazing).

As stated above for average farm size and average field size, crop yields and animal numbers can only give an indication of the state of intensification of agriculture. Monitoring increases in yields and/or stocking densities would infer increased intensification of agricultural practices. However, the potentially adverse effects might only occur in areas of medium and high erosion risk and could be mitigated by the adoption of conservation techniques. Therefore, as indicators of soil erosion, these parameters cannot be used independently.

2.6.2. Indicators of state

In the absence of direct measurements, soil erosion state indicators should be able to provide a picture of both the extent and the severity of the potential/actual soil erosion risk (EEA-ETC/S, 1999). The potential risk calculations should take into account climatic, topographic and edaphic conditions, whereas the actual risk should take into account both vegetation cover and actual land use. The comparison of the potential with actual soil erosion risk could be considered as a risk due to land use changes and practices.

The indicators of state should also provide information on the rate of the actual soil loss under the existing soil management and erosion control practices and on the rate of soil loss tolerance.

2.6.2.1. Area affected by soil erosion

Two indicators are proposed as measures of the 'area affected by erosion': 'percentage of area affected by soil erosion per defined region (e.g. rough estimations by the Member States)' and 'extent (km^2) to which the total area is affected by soil erosion (both wind and water erosion)'.

The area affected by erosion is an important indicator for soil erosion. Trends in soil erosion could be established from periodic estimates. A number of national databases are available for making estimates at national level. However, national databases are not available for all EU countries. Estimates of the area actually affected by soil erosion at regional and national levels are not readily available. This is because measurements of actual erosion are difficult and usually expensive to make or erosion is not a problem at all. Soil erosion often takes place surreptitiously and over long periods before the true extent is appreciated. Accurate data are therefore scarce.

An alternative to the direct measurements and actual erosion estimates would be the use of models to estimate the risk of erosion, potential and actual (see Section 3.3).

Some estimates of actual erosion risk have already been made: e.g. Corine and recent work by the European Soil Bureau (Van der Knijff et al., 1999, 2000; Kirkby and King, 1998). The European Soil Database, the MARS meteorological database, digital elevation data (DTM/DEM), Corine land cover are available for making estimates at European level.

This is one of the key indicators for soil erosion that should be adopted by the EEA. Estimates from Member States, based on national data sets, could be compared with estimates derived from European data sets (e.g. the European Soil Database). Although, there are difficulties in making measurements, existing data should be compiled and stored centrally for comparison with model estimates. Erosion models offer a mechanism whereby the area affected by erosion can be estimated. An appropriate model should be identified and used in conjunction with standard data sets to provide standardised estimates of the areas at risk from soil. The result would be to provide an appropriate state indicator including time series for use by policy-makers (5).

2.6.2.2. Actual versus potential soil loss

The proposed indicator is the 'extent of total soil loss by soil erosion due to water', measured in tonnes per ha per annum. EEA-ETC/S (1999) propose the USLE equation or preferably other recent regional quantitative models to estimate on-site soil erosion. The comparison between the potential and actual soil erosion risk can be considered as a risk indicator for land use changes.

On a medium timescale soil erosion maps could be prepared on the basis of the 'Soil geographical database of Europe' (soil data), the 'Soil regions of Europe' map (topographic data), land cover data (Corine or better, more recent remote sensing images) and climatic data. The Pesera methodology is based on the use of these data and will be able to result in a pan-European soil erosion risk map (see Annex III — Workshop paper by Gobin and Kirkby). A regional model that allows for estimating the potential soil erosion risk should be combined with periodical monitoring of actual soil erosion in selected test areas.

2.6.2.3. Transport of sediments

In order to quantify actual soil losses, the gross erosion in defined watersheds of selected rivers could be estimated from the 'sediment delivery ratio', in t per m^3 per year.

Data on sediment transfer are proposed as a proxy indicator of actual soil loss (EEA-ETC/S, 1999). However, the sediment source remains highly uncertain and can rarely be traced back to surrounding land, riverbanks or channel. A digital database to define catchment boundaries in Europe (scale 1: 1 000 000) is under development at the Space Applications Institute, JRC, in coordination with the EEA. Data on sediment concentrations and annual suspended sediment yields should always be related to the catchment area. However, the data may not be readily available at present. The EEA has established a European freshwater monitoring network (EuroWaterNet), which could be a possible source for data on river sediments.

A difficulty to consider is that data on sediment transport for selected rivers do not relate to the exact source of the sediment. The sediment loads in rivers can only give an indication of the erosion taking place over large areas. As an indicator for soil erosion, sediment delivery data are rarely accurate enough to be an independent indicator. EEA-ETC/S (1999), in fact, consider the transport of sediments as an indicator of impact.

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(5) The Pesera project, funded by the European Commission under the 5th Framework Programme for Research, aims to provide and finalise such a model within the next year and could possibly provide better estimates (Gobin and Govers, 2001). See Annex III workshop paper by Gobin and Kirkby.

2.6.3. Indicators of impact

Indicators of impact could be divided into on-site and off-site impacts. On-site impacts in terms of loss of soil fertility are mostly compensated for by technical advances. On the other hand, off-site impacts are more easily measured and could be expressed in economic terms.

2.6.3.1. Removal of sediment deposits

The proposed indicator relates to 'expenditures for removals of sediment deposits in built-up areas (traffic routes, houses)'. Data on remedial measures are rarely available at the national level, let alone at the European level. However, there are subsidies provided by the EU for remedial works via the CAP. Remedial measures usually follow major floods and should be linked to flood forecasting systems.

2.6.4. Indicators of response

The comparison of soil erosion rates with, yet to be defined, soil loss tolerances for different regions would provide estimates of the impacts and the required response.

2.6.4.1. Conservation practices

An important indicator of response is the expenditure for 'local agricultural programmes to enforce sustainable farming management systems (including the set-aside of arable land)'. These practices include contouring, terracing, strip cultivation, and subsurface drainage (Renard et al., 1997). Other measures involve adoption of minimum tillage systems, planting cover crops (to reduce the duration of bare ground), and changing fundamentally the land use system (for example, conversion from arable to pasture).

Conservation practices have been demonstrated to considerably reduce soil loss through erosion in other parts of the world. Many of these practices increase plant cover and therefore directly reduce erosion. Many are also recognised as 'good agricultural practice'. However, data and information on conservation practices are rarely collected systematically and stored centrally in Europe.

Conservation practices are important in reducing or eliminating soil erosion but they are usually only adopted after soil erosion has been identified as a significant problem.

2.6.4.2. Mitigation strategies

The indicator proposed is the 'expenditures for special soil erosion prevention programmes, including forest fire protection'.

Measures involve implementation of fire prevention systems and building of holding reservoirs. Conservation practices are important in reducing or eliminating soil erosion but they are usually only adopted after soil erosion has been identified as a significant problem. Data and information on conservation practices are rarely collected systematically and stored centrally in Europe.

2.7. Options for the future: determining the risk of soil erosion

From the review of the current indicators for soil selected by the EEA, it is concluded that, from a scientific and technical standpoint, the most appropriate state indicator is the area affected by erosion. However, because there is a serious lack of direct measurements of soil loss, by water and by wind, a surrogate parameter or indicator is needed.

Conventional wisdom suggests that the area actually affected by erosion should be directly related to the area at risk from erosion, provided that the area at risk has been determined using an appropriate model of soil erosion, together with the necessary spatial data sets. Soil erosion takes place at the field scale, and the main problem is that the digital data sets used to quantify the factors causing erosion are usually too coarse (in terms of spatial resolution) to enable accurate estimation of soil losses at this scale.

An important surrogate indicator of actual erosion is its risk. A risk is the chance that some undesirable event may occur. Risk assessment involves the identification of the risk, and the measurement of the exposure to that risk. The response to risk assessment may be to initiate categorisation of the risk and/or to introduce measures to manage the risk. In some cases, the risk may simply be accepted. In other cases, the priority will be to adopt a mitigation strategy. Such risk management, traditionally a significant activity in the commercial sector (e.g. the insurance industry) has now been adopted in the environmental protection field.

Various approaches can be adopted for assessing soil erosion risk. A distinction can be made here between expert-based and model-based approaches.

2.7.1. Expert-based methods

An example of an expert-based approach is the soil erosion risk map of western Europe by De Ploey (1989). The map was produced by various experts who delineated areas where, according to their judgment, erosion processes are important. A limitation of this approach is that the author does not give a clear-cut definition of the criteria according to which areas were delineated (Yassoglou et al., 1998).

Factorial scoring is another approach that can be used to assess erosion risk (Morgan, 1995). The Corine soil erosion methodology produced soil erosion risk maps with a resolution of 1 km² for southern Europe (Corine, 1992), excluding northern Europe. A relative ranking of soil erosion risk per area was obtained through the summation of individual erosion risk scores for each of the following parameters: rainfall, soil susceptibility, slope angle, slope distance, land use and prevention measures. The Corine approach relies heavily on risk assessment by experts, and it remains difficult to assess the effect of changes in land use and / or climate on the erosion risk as no quantitative estimate of soil erosion is made. For the same reasons, it is not feasible to incorporate more detailed data, nor is it possible to evaluate the accuracy of the final result. More details are provided in Section 6.3.

Montier et al. (1998) developed an expert-based method for the whole of France. As with Corine, the method is based on scores that are assigned to factors related to land cover (nine classes), the soil's susceptibility to surface crusting (four classes), slope angle (eight classes) and erodibility (three classes). An interesting feature of their method is that it takes into account the different types of erosion that occur on cultivated areas, vineyards, mountainous areas and the Mediterranean. This way, the interaction between soil, vegetation, slope and climate is accounted for to some extent.

A problem with most methods based on scoring is that the results are affected by the way the scores are defined. In addition to this, classifying the source data in, for example, slope classes results in information loss, and the results of the analyses may depend strongly on the class limits and the number of classes used. Moreover, unless some kind of weighting is used each factor is given equal weight, which is not realistic. If one decides to use some weighting, choosing realistic values for the weights may be difficult. The way in which the various factors are combined into classes that are functional with respect to erosion risk (addition, multiplication) may also pose problems (Morgan, 1995). Finally, as factorial scoring produces qualitative erosion classes, the interpretation of these classes can be difficult.

2.7.2. Model-based methods

A wide variety of models are available for assessing soil erosion risk. Erosion models can be classified in a number of ways. One may make a subdivision based on the timescale for which a model can be used: some models are designed to predict long-term annual soil losses, while others predict single storm losses (event-based). Alternatively, a distinction can be made between lumped models that predict erosion at a single point, and spatially distributed models. Another useful division is the one between empirical and physical-based models. The choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money.

Jäger (1994) used the empirical universal soil loss equation (USLE) to assess soil erosion risk in Baden-Württemberg (Germany). De Jong (1994) used the Morgan, Morgan and Finney model (Morgan et al., 1984) as a basis for his Semmed model. Input variables are derived from standard meteorological data, soil maps, multi-temporal satellite imagery, digital elevation models and a limited amount of field data. This way, erosion risk can be assessed over large, spatially diverse areas without the need for extensive field surveys. So far, the Semmed model has been used to produce regional erosion risk maps of parts of the Ardêche region and the Peyne catchment in southern France (De Jong, 1994; De Jong et al., 1998).

Kirkby and King (1998) assessed soil erosion risk for the whole of France using a model-based approach. Their model provides a simplified representation of erosion in an individual storm. The model contains terms for soil erodibility, topography and climate. All storm rainfall above a critical threshold (whose value depends on soil properties and land cover) is assumed to contribute to runoff, and erosion is assumed to be proportional to runoff. Monthly and annual erosion estimates are obtained by integrating over the frequency distribution of rainstorms.

Several problems arise when applying quantitative models at regional or smaller scale. First, most erosion models were developed on a plot or field scale, which means that they are designed to provide point estimates of soil loss. When these models are applied over large areas the model output has to be interpreted carefully. One cannot expect that a model that was designed to predict soil loss on a single agricultural field produces accurate erosion estimates when applied to the regional scale on a grid of say 50 km pixels or coarser. One should also be aware of which processes are actually being modelled. For example, the well-known universal soil loss equation (USLE) was developed to predict rill- and interrill erosion only. Therefore, one cannot expect this model to perform well in areas where gully erosion is the dominant erosion type, let alone mass movements like landslides and rockfalls.

Also, at the regional scale it is usually impossible to determine the model's input data (like soil and vegetation parameters) directly in the field. Usually, the model parameters are approximated by assigning values to mapping units on a soil or vegetation map, or through regression equations between, for example, vegetation cover and some satellite-derived spectral index. In general, however, this will yield parameter values that are far less accurate than the results of a field survey. Because of all this, the relative soil loss values produced by models at this scale are generally more reliable than the absolute values.

This is not necessarily a problem, as long as the user is aware that the model results give a broad overview of the general pattern of the relative differences, rather than providing accurate absolute erosion rates. Because of this, the availability of input data is probably the most important consideration when selecting an erosion model at the regional/ national scale. It would not make sense to use a sophisticated model if sufficient input data are not available. In the latter case, the only way to run the model would be to assume certain variables and model parameters to be constant. However, the results would probably be less reliable than the results that would have been obtained with a simpler model that requires less input data (De Roo, 1993). Also, uncertainties in the model's input propagate throughout the model, so one should be careful not to use an 'over-parameterised' model when the quality of the input data is poor.

Perhaps the biggest problem with erosion modelling is the difficulty of validating the estimates produced. At the regional and larger scale, virtually no reliable data exist for comparing estimates with actual soil losses. King et al. (1999) attempted to validate an erosion risk assessment for France by correlating soil loss with the occurrence of mudflows. However, other processes are involved here and such comparisons do not substitute for 'real' measurements.

2.8. General conclusions of review

The proposed indicators for soil erosion are evaluated according to the OECD criteria listed in Section 2.1. The six pressure indicators, average farm size, average field size, consumption of fertiliser, number of grazing animals, crop yield and net profit, relate to agricultural intensification. These pressure indicators all have in common that they are complex and not directly linked to the phenomenon of soil erosion. The identified indicators of state and impact are difficult or expensive to measure and the data are usually not readily available. Indicators of response are prevention and control measures, which are rarely in existence at present or are not recorded. One major conclusion is that the intensity of agriculture should never be evaluated alone in relation to erosion. Soil loss due to erosion is a result of climate, topography, soil properties, land cover and land management. Land cover also includes the natural vegetation.

3. Driving force, pressure and state indicators related to land use

Accelerated soil erosion, in excess of natural geological rates, is caused by anthropogenic activity. Human activity is a major factor in shaping the landscape, whereas the physical structure of a landscape often constrains its use. Land use and management are the result of these human activities and as such are the most important factors that influence soil erosion. This chapter focuses on the link between soil erosion and land use, and how this link is and/or should be reflected in the proposed indicators.

3.1. Soil erosion indicators and land use

Driving forces related to soil erosion have been defined on the basis of intensification of agriculture in which the risk for insufficient sustainable land use practices increases. The proposed indicators aim to describe the intensification of agriculture and its increase. As indicators for driving forces/pressures related to the intensity of agriculture have been proposed: (a) consumption of fertilisers per region, (b) average farm size per region, (c) average field sizes, (d) average crop yield per area, (e) average net profit per area, and (f) number of grazing animals. The intensity of agricultural production or the trend toward intensification has been considered as one of the main causes for soil degradation by erosion. Furthermore, tourism has been considered as an important driving force causing pressures on soil resources. Tourism has direct impacts in both soil sealing and soil erosion.

State indicators proposed by the EEA aim to provide information on the extent of the area affected by soil erosion. These indicators represent the short-term approach to soil erosion assessment. Data for the short-term approach are mainly derived from questionnaires from statistical institutions (Eurostat) and the EEA. Since in most European countries there are no data available on soil erosion, such indicators have limited application.

As an alternative, indicators providing information on the area under potential and actual soil erosion risk are proposed. Risk indicators aim to provide a picture of the extent and the severity of the potential soil erosion risk (taking into account climatic, topographic and soil conditions) and the actual soil erosion risk (taking into account the vegetation cover and the actual land use).

The comparison of the potential with the actual soil erosion risk is a measure for the impact of land use changes on soil erosion risk. The information can cover the area of a member country or the total area in Europe and provides estimates of the area at risk.

EEA-ETC/S proposed that the long-term approach to soil erosion assessment should take into consideration the ground cover due to vegetation and other protection measures (e.g. mulching), in areas of a high potential soil erosion risk.

The long-term indicator approach for soil erosion is based on data used in the universal soil loss equation (USLE), such as climate, soil, relief, vegetation and protection measures. Problems of such a methodology are the high variability in space and time of data such as ground cover, type of land use, and protection measures.

The Corine soil erosion project has identified land use and vegetation cover as a major input in defining actual soil erosion risk. Land use and vegetation maps are normally highly generalised from one area to another, and are quickly out of date. Remote sensing products provide temporal information and are proposed here as an important source of information for vegetation cover. The normalised difference vegetation index (NVDI) is often used as an indicator of vegetation growth determined by optical sensors. This index when compared during different periods of the year can indicate the vegetation cover change during the growing period of crops and natural vegetation. However, the introduction of the NDVI will only make sense if it is combined with regularly updated land use data, such as established in the Corine land use map.

3.2. Review of the proposed indicators in relation to land use intensity

The proposed indicators in relation to land use and intensity of land use partially satisfy the needs for assessing the soil erosion risk across different agro-ecological regions. As mentioned in the EEA-ETC/S working report (EEA-ETC/S, 1999), data on soil erosion made available by the EU countries are highly variable. Furthermore, the application of the universal soil loss equation has the disadvantage of requiring data such as vegetation cover at a high temporal and spatial resolution.

The proposed indicators of intensification of agriculture can be considered as a good basis for assessing soil erosion risk but they require further expansion with other factors such as other human activities that affect land cover, existing policies for the protection of soils and the degree of enforcement of such policies.

It has to be considered that in hilly cultivated areas tillage erosion is usually much more important than wind and water erosion. In the last decades there is an increasing awareness that the erosion processes which are primarily responsible for the severe degradation occurring in topographically complex landscapes cannot be attributed to wind or water erosion only, but are caused mainly by tillage erosion. Tillage erosion is a progressively downslope translocation of soil caused mechanically by tillage implements, and it is considered as a main cause of land degradation and land abandonment in hilly cultivated areas throughout the EU countries. Areas that have been introduced to cultivation during this century are being abandoned at an increasing rate in the last decades due to a dramatic decrease of the land productivity resulting mainly from tillage erosion. The availability of heavy powerful machinery has favoured deep soil ploughing with high speeds, and in directions usually perpendicular to the contour lines, causing displacement of huge amounts of soil from upper landscape positions and deposition to lower landscape positions. Tillage erosion exposes subsoil, which may be highly erodible by wind or water, and fills in ephemeral flow areas, acting as a delivery mechanism for water erosion. Data from various sources show that tillage erosion can account for up to 70 % of the total loss in cultivated areas (Van Muysen et al., 1999).

3.3. Options for the future on relating land use and land use intensity to soil erosion

The rate of soil degradation is dependent upon the rate of land cover degradation, which in turn is influenced by both adverse climatic conditions and land use management changes. Vegetation cover, type of land use, and intensity of land use are clearly important factors controlling the intensity and the frequency of overland flow and surface wash erosion. Vegetation cover may be altered radically by man within a short time, but physical and biological changes within the soil, affecting erosion rates, may take longer periods. Type of land use and land use intensity is affected by various environmental and socioeconomic factors, therefore indicators for soil erosion risk assessment should be related to these factors.

3.3.1. Climate characteristics affecting vegetation

The characteristics of the climate of an area that can affect vegetation growth and vegetation cover and therefore soil erosion are rainfall, both amount and intensity, and aridity. These climate characteristics are easily available for all regions of the EU.

Erosion data collected in various sites along the Mediterranean region show that the amount of rainfall has a crucial effect on soil erosion. Generally, there is a tendency of increasing runoff and sediment loss with decreasing rainfall in hilly Mediterranean shrublands, especially in the region where rainfall is greater than 300 mm/year. Below the 300 mm annual rainfall limit, runoff and sediment loss decrease with decreasing rainfall. Rainfall amount and distribution are the major determinants of biomass production on hilly lands. Decreasing amounts of rainfall combined with high rates of evapotranspiration drastically reduce the soil moisture content available for plant growth. In areas with annual precipitation of less than 300 mm and high evapotranspiration rates, the soil water available to the plants is reduced drastically. The soil remains relatively bare favouring overland water flow whenever rainfall events happen.

Aridity is a critical environmental factor in determining the evolution of natural vegetation by considering the water stress, which may occur and cause reduced vegetation cover. In the Mediterranean region, vegetation presents a great capacity of adaptation and resistance to dry conditions, and many species can survive many months through prolonged droughts with soil moisture content below the theoretical wilting point. Aridity can greatly affect plant growth and vegetation cover, particularly annual plants. Under dry climatic conditions in areas cultivated with rain-fed cereals, the soil remains bare favouring high erosion rates under heavy rainfalls following a long dry period.

Closely related to climatic characteristics is the topographic attribute, slope aspect. Slope aspect is considered an important factor for land degradation processes. Aspect affects the microclimate by regulating the angle and the duration at which sunrays strike the surface of the soil. In the Mediterranean region slopes with southern and western facing aspects are warmer, and have higher evaporation rates and lower water storage capacity than northern and eastern aspects. Therefore, a slower recovery of vegetation and higher erosion rates are expected in southern and western aspects than in northern and eastern aspects. As a consequence, southern exposed slopes usually have a persistently lower vegetation cover than northern exposed slopes. The degree of erosion measured along south-facing hill slopes is usually much higher (even twice higher) than in the north-facing slopes under various types of vegetation cover.

3.3.2. Vegetation characteristics affecting soil erosion

Indicators of soil erosion related to the existing vegetation can be considered in relation to: (a) fire risk and ability to recover, (b) erosion protection offered to the soil, and (c) percentage plant cover. Forest fires are one of the most important causes of land degradation in hilly areas of the Mediterranean region. Fires have become very frequent especially in the pine-dominated forests during the last decades with dramatic consequences in soil erosion rates and biodiversity losses. The frequency of fire occurrence is lower in grasslands and mixed Mediterranean macchia with evergreen forests. Also, Mediterranean pastures are frequently subjected to man-induced fires in order to renew the biomass production. The Mediterranean vegetation type is highly inflammable and combustible due to the existence of species with a high content of resins or essential oils. Conversely, it is known that vegetation has a high ability to recover after fire and the environmental problems related to fire normally last for only a limited number of years after the fire occurred.

There are several factors that affect the process of the recovery, apart from the fire and site characteristics, which can be both natural and anthropogenic. Years of unusual drought or sites that cannot be affected from the moist sea winds during summer show a slower rate of recovery. Human interference, such as livestock grazing or change in the land use pattern, may damage irreversibly the recovering vegetation. Particularly important are the time intervals between subsequent fires. The ability of the ecosystems to recover is not unlimited and a fire frequency beyond a certain threshold can also lead to a permanently degraded state. This can be due both to the nutrient and seed bank depletion and to increased erosion. These processes have already led to severe degradation of extensive hilly areas in the Mediterranean region.

Vegetation and land use are clearly important factors controlling the intensity and the frequency of overland flow and surface wash erosion. Extensive areas cultivated with rain-fed crops such as cereals, vines, almonds and olives are mainly confined to hilly lands with shallow soils which are very sensitive to erosion. These areas become vulnerable to soil erosion because of the decreased protection by vegetation cover in reducing effective rainfall intensity at the ground surface. Almonds and vines require frequent removal of perennial vegetation using herbicides or by tillage. In fact, soils under these crops remain almost bare during the whole year, creating favourable conditions for overland flow and soil erosion.

Erosion data measured along the northern Mediterranean region and the Atlantic coastline located in Portugal, Spain, France, Italy and Greece in a variety of landscapes and under a number of land uses representative of the Mediterranean region (rain-fed cereals, vines, olives, *Eucalyptus* plantation, shrubland) showed that the greatest rates of runoff and sediment loss were measured in hilly areas under vines.

Areas cultivated with wheat are sensitive to erosion, especially during winter, generating intermediate amounts of runoff and sediment loss especially under rainfalls higher than 380 mm per year. Olives grown under semi-natural conditions, particularly where there is an understorey of annual plants greatly restrict soil loss to negligible values. Erosion in shrublands increased with decreasing annual rainfall to values in the range of 280–300 mm, and then decreased as rainfall decreased further.

Several hilly areas under natural forests around the Mediterranean region have been reforested with exotic species such as *Eucalyptus*. Such soils are undergoing intense erosion as compared with soils left under natural vegetation. However, the measured rates of erosion under *Eucalyptus* are relatively lower than those measured under vines, almonds and cereals.

Soil erosion data measured from various types of vegetation and certain physiographic conditions showed that the best protection from erosion was measured in areas with a dominant vegetation of evergreen oaks, pines and olive trees under semi-natural condition. Pines have a lower ability to protect the soils in southern aspects due to the higher rate of litter decomposition and the restricted growth of understorey vegetation. Deciduous oak trees offered relatively low protection from erosion in cases where the falling leaves did not cover the whole soil surface.

The main factors affecting the evolution of the Mediterranean vegetation, in the long term, are related to the irregular and often inadequate supply of water, the long length of the dry season, and in some cases fire and overgrazing. According to the types of leaf generation, the following two major groups of vegetation can be distinguished: (a) deciduous: drought avoiding with a large photosynthetic capacity but no resistance to desiccation; and (b) evergreen (sclerophyllous): drought enduring with low rates of photosynthesis. The main response of the plants to increased aridity is the reduction in leaf area index. Severe droughts that cause a reduction in leaf area index may be beneficial in the short term as plant respiration is reduced, but such drought will increase the probability of enhanced soil erosion when rain eventually falls, as protective vegetation cover is reduced.

The various ecosystems present in the Mediterranean region have a great capacity of adaptation and resistance to aridity, which most of the species, existing under Mediterranean climatic conditions, have to survive. Plants may have to endure soil moisture contents below the theoretical wilting point for many months. Most probably the expected changes in the vegetation performance, resulting from a gradual precipitation decrease, would only be noticed after a critical minimum number of years.

Among the prevailing perennial agricultural crops in the Mediterranean, olive trees present a particularly high adaptation and resistance to long-term droughts and support a remarkable diversity of flora and fauna in the undergrowth. This undergrowth is even higher than for some natural ecosystems. Under these conditions, annual vegetation and plant residues form a satisfactory soil surface cover, preventing surface sealing and minimising the velocity of the overland water. In the case where the land is intensively cultivated, higher erosion rates are expected.

Many studies have shown that the variation in runoff and sediment yields in drainage basins can be attributed to the vegetation cover and land use management changes. Many authors have demonstrated that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases. A value of 40 % vegetative cover is considered critical below which accelerated erosion dominates in a sloping landscape. This threshold may be modified for different types of vegetation, rain intensity and land attributes. It shows, however, that degradation begins only when a substantial portion of the land's surface is denuded; then it proceeds with an accelerated mode that cannot be arrested by land resistance alone. Deep soils on unconsolidated parent materials show slow rates of degradation and loss of their biomass production potential. In contrast, shallow soils with lithic contact on steep slopes have low productivity, and low erosion tolerance if they are not protected by vegetation.

3.3.3. Management quality and human-induced factors

The definition of soil erosion risk of an area requires both key indicators related to the physical environment and to the human-induced stress. A piece of land, irrespective of its size, is characterised by a particular use. This use is associated with a given type of management, which is dictated mainly by climate and changes under the influence of environmental, social, economic, technological and political factors. Depending on the particular type of management, land resources are subject to a given degree of stress. Moreover, the existence of environmental policies, which apply to a certain area, moderates the anticipated impacts of a given land use type compared to the situation where no such policies are in effect.

The extensive deforestation of hilly areas and intensive cultivation with rain-fed cereals has already led to accelerated erosion and degradation in the last century. The erosion risk is especially high in areas cultivated with rain-fed cereals. For one or two months after sowing winter cereals the land remains almost bare, and the erosion risk is high considering that rains of high intensity and occasionally long duration usually occur during that period. The sloping lands of the Thessaly plain, the largest lowland of Greece, were for centuries under grazing especially in winter by migratory flocks and herds. The rapid increase in population due to immigration in the early 1920s resulted in the sharp increase of the areas, which were brought under wheat cultivation. Erosion experiments and estimations from the exposure of tree roots demonstrated that erosion on these areas had proceeded at rates of 1.2–1.7 cm soil per year since the introduction of wheat.

Many hilly areas have experienced abandonment at an increasing rate due to low productivity. Land abandonment may lead to the deterioration or replenishment phase of soils, depending on the particular land and climatic conditions of the area. Hilly areas that can support sufficient plant cover may improve with time by accumulating organic materials, increasing floral and faunal activity, improving soil structure, increasing in infiltration capacity and, therefore, causing a decrease in the erosion potential. In cases of poor plant cover, the erosion processes may be very active and the degeneration of these lands may be irreversible. In cases of land partially covered by annual or perennial vegetation, the remaining bare land with soils of low permeability (clays) creates favourable conditions for overland flow, soil erosion and land degradation.

In the last few decades, favourable soil and climatic conditions and the availability of ground or surface water have resulted in intensive farming of the lowlands of the Mediterranean region. The development of high input agriculture in the plains provided much higher net outputs than those obtained from terracing agriculture. Furthermore, recently the value of such terraces has markedly declined because of the low accessibility by tractors. At present, most of these areas have been abandoned, and the terraces have collapsed causing a rapid removal of the soil by runoff water, apart from where the stonewalls are protected by the roots of fast-growing shrubs and trees. Maintaining such terraces appears a very expensive practice compared to most other alternatives for soil erosion control.

Wheat production in hilly Mediterranean areas has drastically declined during the last few decades and the intensity of grazing has increased at the same time. Shepherds often damage the natural vegetation by deliberately setting fires to eradicate the vegetation and encourage the growth of new grass, which the livestock then overgraze. Once the land is bare of its vegetative cover and the soil is loosened, the torrential rains of autumn and winter begin to wash away the topsoil.

The process of land degradation can be greatly accelerated by high densities of livestock which lead to vegetation degradation and, in turn, to soil compaction. An obvious consequence of overgrazing is the increase in soil erosion, since the gradual denudation of the landscape exposes the soil to water and wind erosion. Under such management conditions and hot and dry climatic conditions, soils of these areas cannot economically support a sufficient vegetative cover to avoid degradation. Overgrazing of these climatically and topographically marginal areas, accompanied by fires, constitutes a degradation-promoting land use, further depleting the existing land resources.

The recent number and the extent of forest fires occurring in the Mediterranean region are amongst the most serious environmental problems. In addition to the loss of vegetation, forest fires induce changes in physico-chemical properties of soils, such as water repellence, loss in nutrients and increased runoff and erosion. They also destroy wildlife habitat, cause loss of human life and damage infrastructure. The loss of vegetation after fire and the progressive inability of soils to regenerate adequate vegetation cover due to erosion have already led to severe degradation of hilly areas in the Mediterranean region.

Fires have become frequent in pine-dominated forests during the last 50 years. Most of the fires can be attributed to the carelessness of people. The majority of fires occur in areas with high xerothermic indices and moisture deficits. Soil dryness and wind speed are the principal factors of fire evolution. The areas affected by forest fires are increasing dramatically throughout the Mediterranean basin. In the period from 1960 to 1975, the average rate of burning was 200 000 ha/year, from 1975 to 1980 470 000 ha/year, and 660 000 ha/year from 1981 to 1985.

Erosion rates seem to be enhanced after fires. The increased erosion rates are only partly due to the removal of vegetation. More important seems to be the forming of an impermeable subsurface layer, which decreases infiltration rates, while causing a quick saturation of the upper layers leading to overland flow and erosion. In contrast aggregate stability increases after fire and that increase is more pronounced after severe burns.

The management quality can be related to the intensity of land use and to the applied measurements for environmental protection related to certain policies. Land use can be classified according to several criteria leading to hierarchies of land use types. The number of criteria employed is dictated by the level of detail desired as well as by the availability of the proper data. The principal classification criterion is the main purpose for which land is used. Based on this criterion, the land use types can be distinguished as following:

- agricultural land (cropland, pasture or rangeland),
- natural areas (forests, shrubland, bare land),
- mining land (quarries, mines, etc.),
- recreation areas (parks, compact tourism development, tourist areas, etc.),
- infrastructure facilities (roads, dams, etc.).

Using the above classification of land use on land parcels allows the intensity of land use and the enforcement of policy on environmental protection to be assessed. The intensity of land use of a cropland can be evaluated on the basis of the frequency of irrigation, degree of mechanisation of cultivation, application of fertilisers and agrochemicals, types of plant varieties used, etc. In the degree of mechanisation, the following characteristics should be included: type of tillage instrument, plough depth, wheel speed of the tractor, direction of tillage operation, etc.

The intensity of land use of a pastureland can be defined by estimating the sustainable stocking rate (SSR) and the actual stocking rate (ASR) for the various land parcels under grazing. The ratio of ASR/SSR can be used to assess the intensity of land use.

In natural areas such as forests, shrubland, etc., the intensity of land use can be defined by assessing the actual (A) and sustainable yield (A/S). Then the intensity of land use can be classified based on the ratio A/S.

The intensity of land use for areas with mining activities can be defined by evaluating the measurements undertaken for soil erosion control such as terracing, vegetation cover, etc. Then the intensity of land use can be classified based on the evaluated degree of land protection from erosion.

In areas undergoing active recreational use such as skiing, motor rallies, etc., the intensity of land use can be evaluated by defining the actual and the permitted number of visitors per year (A/P). Then the land use intensity can be classified based on the ratio A/P.

Particular attention must be given to the policies related to soil protection such as policies supporting terracing, policies favouring extensive agriculture, etc. Of course their effectiveness depends on the degree to which they are enforced. Therefore, rating of policies can be based on the degree to which they are enforced. Hence, the information must be collected on the existing policies and their implementation /enforcement.

3.4. Conclusions of review of indicators in relation to land use

Many of the soil erosion indicators proposed by the EEA relate to land use and land use intensity. Land use and vegetation cover, in general, are the major input in defining actual soil erosion risk. It is therefore advocated to use regularly updated land cover data, such as established in the Corine land use map, in combination with remotely sensed products such as the normalised difference vegetation index (NDVI) in order to capture seasonal variations in land cover.

The proposed indicators of intensification of agriculture can be considered as a good basis for assessing soil erosion risk but they require further expansion with other factors that affect land cover, existing policies for the protection of soils and the degree of enforcement of such policies. Other human activities that affect land use and determine land use intensity include infrastructure, recreation, mining activities or forest management.

Land cover is affected by different environmental and socioeconomic factors, such as precipitation, vegetation type and management quality, which require monitoring in order to understand the complex relationship with soil erosion. Concerning management, tillage erosion is a prime example of human-induced erosion.

4. Regional assessment of the extent of soil erosion by water

A regional soil erosion assessment, providing an estimate of the area affected by soil erosion and the expected magnitude, is needed in order to make objective comparisons that may provide a basis for further environmental analysis, economic statements or policy development. Suitable assessment methods need to be developed to this purpose.

This section deals primarily with assessing the extent of soil erosion by water as this is the most important form of soil erosion in Europe. Four alternative methods for carrying out regional assessment are compared. The Glasod maps and hot-spot map can be classified as methods based on distributed point data, while the RIVM and Corine maps can be classified as factor- or indicator-based maps. A description of the processes of soil erosion, crucial to an understanding of the following sections, can be found in Annex V.

4.1. Alternative assessment methods

Assessments of soil erosion on a European scale are required for a number of reasons:

1. to make objective comparisons of the soil resource, taking account of past erosional degradation;

2. to estimate the average rate of erosion to estimate the rate of loss of soil resource and its economic cost;

3. to estimate the probability and distribution of severe erosion events, to evaluate the implications for loss of production and off-site deposition;

4. to provide an objective basis for allocation of resources for remediation, mitigation or more detailed research and assessment;

5. to assess the impact on the soil resource of future climate and / or land use change, due to global warming, possible policy changes and economic conditions.

Assessment of soil erosion may be based on a range of methodologies. Some of these are based on the collection of distributed field observations, others on an assessment of factors, and combinations of factors, which influence erosion rates, and others primarily on a modelling approach. All of these methods require calibration and validation, although the type of validation needed is different for each category. There are also differences in the extent to which the assessment methods identify past erosion and an already degraded soil resource, as opposed to risks of future erosion, under either present climate and land use, or under scenarios of global change.

4.1.1. Distributed point data

One important form of erosion assessment is from direct field observations of erosion features and soil profile truncation. Erosion features consist of rills and gullies, some of these ephemeral, and associated deposition in swales and small valleys. Soil profiles may show local loss of upper horizons, or burial by deposition from up-slope. Deposited material may provide dateable material, which can indicate when erosion occurred, but much of this evidence is cumulative over the period since cultivation began, or in some cases over the whole of the Holocene. Data may be collected from regional experts in soils or soil erosion. They may also be collated from field or remote (air photo) surveys of erosion features. Higher satellite resolution (e.g. Ikonos) may, in the near future, also allow this method to be applied from space platforms. Some quantitative data are also available from erosion plot sites.

These methods require validation to standardise differences in the intensity of study of different areas and in the clarity of suitable features on different soil types. There are also differences in methods and traditions between scientists in different areas of Europe. On their own these methods cannot provide a complete picture except for small sample areas, and require the use of other methods to interpolate between areas.

The main advantage of distributed observations of erosion is that data are unambiguous where they exist, and give a good indication of the current state of degradation of the soil resource, and other methods lack this certainty. The main disadvantage of these methods is that they provide little or no information about when erosion occurred, unless there are supporting data on this point. Many areas of the Mediterranean are thought to have suffered anthropogenic acceleration of erosion since early classical times, and many hills are now denuded of their former natural soil cover. Although of great historical interest, this has little bearing on current or prospective erosion hazards.

4.1.2. Factor or indicator mapping

Since many of the processes and factors which influence the rate of erosion are well known, as outlined above, it is possible to rank individual factors for susceptibility to erosion, providing a series of erosion indicators. For example, climatic indices may be based on the frequency of high intensity precipitation, and on the extent of aridity or rainfall seasonality. Soil indicators may reflect the tendency to crusting and the experimental erodibility of soil particles or aggregates. Similar rank indicators may be developed for parent materials, topographic gradient and other factors. Clearly a high susceptibility for all factors indicates a high erosion risk, and a low susceptibility for all factors indicates a low erosion risk.

Individual indicators may be mapped separately, but it is more problematic to combine the factors into a single scale, by adding or multiplying suitably weighted indicators for each individual factor. There are difficulties both about the individual weightings and about the assumed linearity and statistical independence of the separate factors. The method should therefore be most effective for identifying the extremes of high and low erosion, but less satisfactory in identifying the gradation between the extremes.

Despite these theoretical limitations, factor or indicator mapping has the considerable advantage that it can be widely applied using data which are available in Europe-wide GIS for topography and soils at 1 km resolution, and for climate at 50 km resolution. Kosmas et al. (1999) provide one example of this approach, applied on a regional scale to areas in Greece, Italy and Portugal.

4.1.3. Process modelling

There is a continuous spectrum between mapping based on ranked indicators and process models with a more explicit physical or empirical basis. Nevertheless it is fruitful to consider, as a third approach towards Europe-wide soil erosion assessment, the application of a process model. Although, at first sight, this approach appears to be the most generally applicable, there are major problems of validation, and in particular in relating coarse scale forecasts to available erosion rate data, much of which is for small erosion plots. Many of the most successful process models require more detailed distributed parameter and rainfall intensity data than are currently available on a European scale, so that they cannot be applied without radical simplification. One important aspect of this problem is the need to develop a model that can be used for validation at fine scales, and for Europe-wide forecasting on a coarse scale, so that cross-scale reconciliation must be as explicit as possible. Nevertheless this approach has the potential to provide a rational physical basis to combine factors that can be derived from coarse scale GIS, and that overcome the difficulties about weighting and inter-correlation that are encountered in purely factor-based assessments.

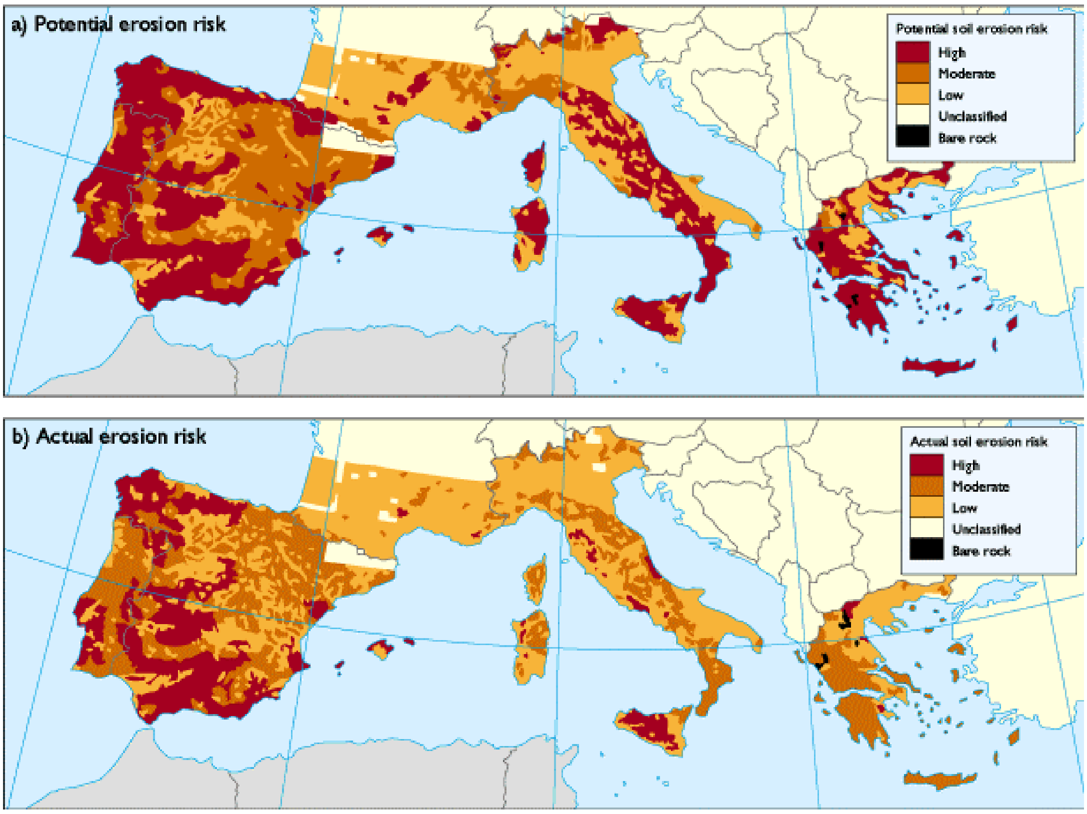
Process models have the potential to respond explicitly and rationally to changes in climate or land use, and so have great promise for developing scenarios of change, and what-if analyses of policy or economic options. Set against this advantage, process models generally make no assessment of degradation up to the present time, and can only incorporate the impact of past erosion where this is recorded in other data, such as soil databases. Models also generally simplify the set of processes operating, so that they may not be appropriate under particular local circumstances. Although the USLE has been the most widely applied model in Europe (e.g. Van der Knijff et al., 2000), it is now widely considered to be conceptually flawed. Other models are now emerging, based on runoff thresholds (e.g. Kirkby et al., 2000) or the MIR (minimum information requirement) approach (Brazier et al., 2001) applied to the more complex USDA WEPP model (Nearing et al., 1989).

4.2. The Corine approach

The Corine programme was established in 1985:

1. to help guide and implement Community environment policy, and to help incorporate an environmental

Potential versus actual erosion risk as estimated by the Corine methodology — Figure 4.1



Source: Corine, 1992.

dimension into other policies, by providing information on priority topics;

2. to help ensure optimum use of financial and human resources by organising, influencing and encouraging initiatives by international organisations, national governments or regions to obtain environmental information;

3. to develop the methodological base needed to obtain environmental data which are comparable at a community level.

The Corine soil erosion risk maps (Figure 4.1) are the result of an overlay analysis by a geographical information system, enabling the evaluation of the soil erosion risk category. The main source of information used was the soil map of the European Communities (CEC, 1985). Potential soil erosion risk was defined as the inherent risk of erosion, irrespective of current land use or vegetation cover (Corine, 1992). The map of potential erosion risk (Figure 4.1) therefore represents the worst possible situation. The area of land in this region with a high erosion risk totals 229 000 km^2 (about 10 % of the rural land surface). The largest area is found in Spain, mainly in the southern and western parts. In Portugal, areas of high erosion risk cover almost one third of the country. About 20 % of the land surface in Greece, 10 % in Italy and 1 % in France is subject to high erosion risk. The difference between the areas of potential and actual erosion risk (compare maps in Figure 4.1) reflects the protective influence provided by present land cover, and the dangers inherent in changes in land use practices.

4.2.1. Methodology

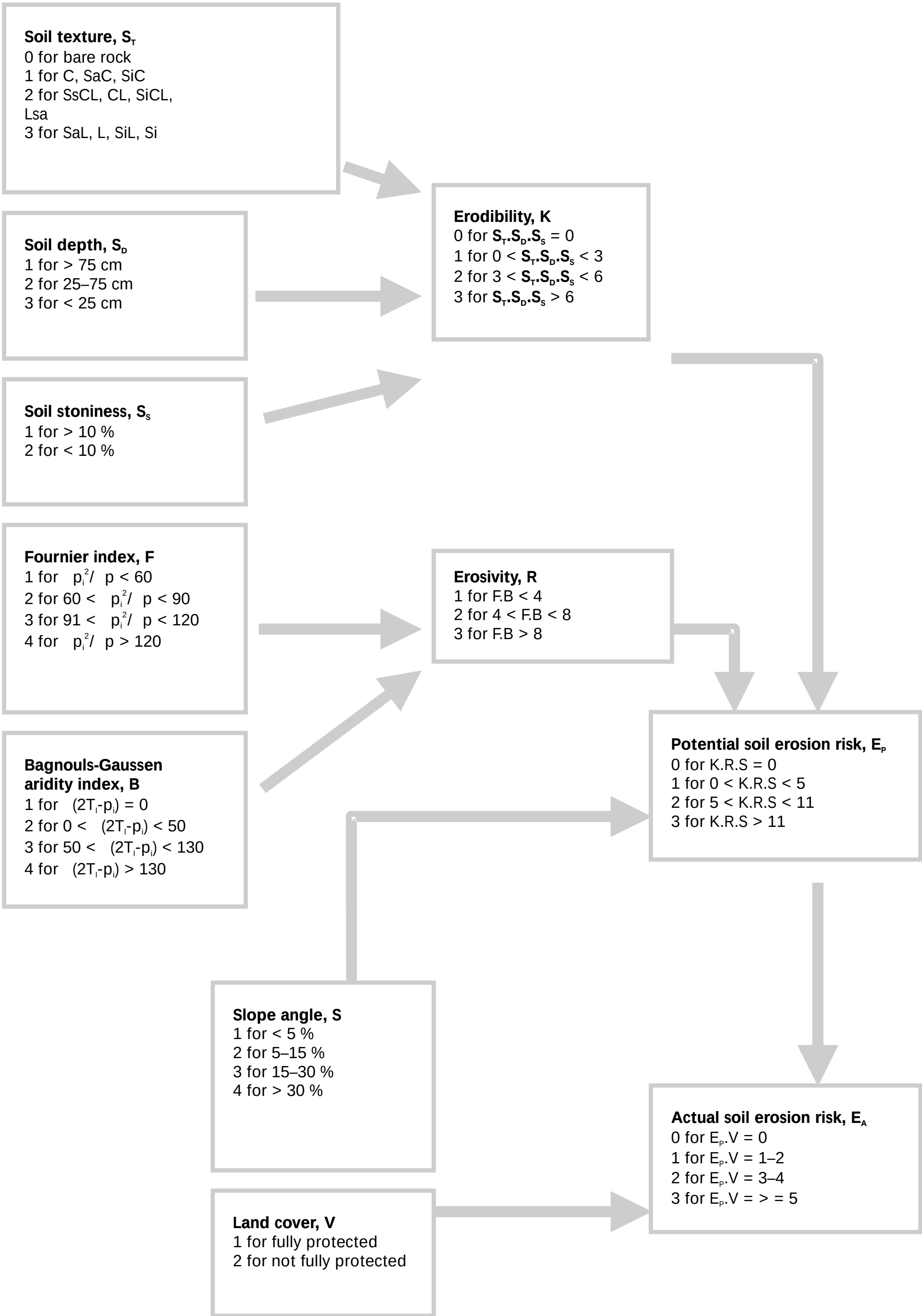
For one of these priority topics, soil erosion, a new methodology was developed, which provides a factor-based assessment of risk (Figure 4.2). It was recognised that there was no suitable Europe-wide map of erosion, and that existing maps differed widely in methodology and scales of assessment. The methodology used was based on a simplification of the universal soil loss equation (USLE), a regression-based model, for which there is a massive database for US conditions, but little systematic data for Europe.

$$E = K\,R\,S\,P\,V \qquad (4.1)$$

Where E is the annual soil loss,
K is soil erodibility,
R is rainfall erosivity,
S is the slope length factor,
P is the crop management practice factor,
and V is the vegetation cover factor.

Figure 4.2 **Methodology for Corine soil erosion assessment**

Source: Corine, 1992.



The USLE (equation (4.1)) is intended to provide an estimate of average annual erosion loss in tonnes per unit area. The Corine soil erosion methodology is a considerable simplification of the USLE (Corine, 1992; Briggs and Giordano, 1995). Erodibility is estimated from soil texture, depth and stoniness. Erosivity is estimated from the Fournier and Bagnouls-Gaussen climatic indices. Slope gradient is included, but without a slope length correction, and vegetation and crop management are collapsed into two categories of protected and not fully protected, using data from the associated Corine land cover database. These factors are combined to estimate three categories of potential and actual soil erosion risk. Potential risk excludes vegetation factors, and so identifies land at risk, while actual risk includes the vegetation factor to indicate whether the potential is being realised. A map showing the assessment for southern Europe is provided in Figure 4.1 and the overall scheme is summarised in Figure 4.2.

4.2.2. Advantages and limitations

The Corine soil erosion assessment has the great advantage of simplicity, in that it provides a clear forecast, on an objective basis, for the whole of the area studied. The method is based, at least in principle, on a well-established technology, the universal soil loss equation, which has been very widely used, both in America and worldwide. Being based on a factor method within a 1 km GIS base, the method can be applied at a resolution that allows discrimination within regional areas. The method correctly identifies the areas of the Mediterranean that have the highest risk of erosion. As a product of its time, it has considerable merit, and could be improved with the more detailed land cover classification now available, providing refinement in the USLE land cover and crop management factors.

However, the USLE, although still widely used on account of its simple structure, is now widely regarded as a post-mature technology, and cannot therefore be recommended as the best basis for estimation of erosion risk. Furthermore, mapping of USLE forecasts on national scales, for example for Italy (Van der Knijff et al., 2000) shows wide discrepancies between Corine and USLE forecasts, so that Corine may not even correctly represent the USLE factors. The Corine report concedes (p. 92) that 'future development of this work would allow more sophisticated models of soil erosion to be used. Particularly on improving the factors used in the procedure, notably in the calculation of erosivity and soil erodibility, and in the classification of land cover' (Corine, 1992). On a qualitative basis, comparison of the erosion maps of southern Europe appear to show too great a dependence on the climatic factors in determining erosion risk, with relatively less weight given to important factors of erodibility and land cover. For use in the future, the Corine assessment also has the limitation that it is restricted to southern Europe, whereas present needs for erosion data apply to the whole of the European area.

4.3. The 'hot-spot' approach

An analysis and mapping of soil problem areas ('hot spots') in Europe was published in the EEA-UNEP joint message on soil (EEA, 2000) ([6]). This addresses a number of soil problems, and only soil erosion aspects are reviewed in this section. The purpose of the study was to support the joint message on the need for a pan-European policy on soil, identifying 'hot spots' of degradation in Europe and examining environmental impacts leading to change and particularly degradation of soil function. The work involved compilation and analysis of data available at the EEA, together with additional data from the scientific literature. These data were incorporated into a GIS (ArcView) for manipulation and display.

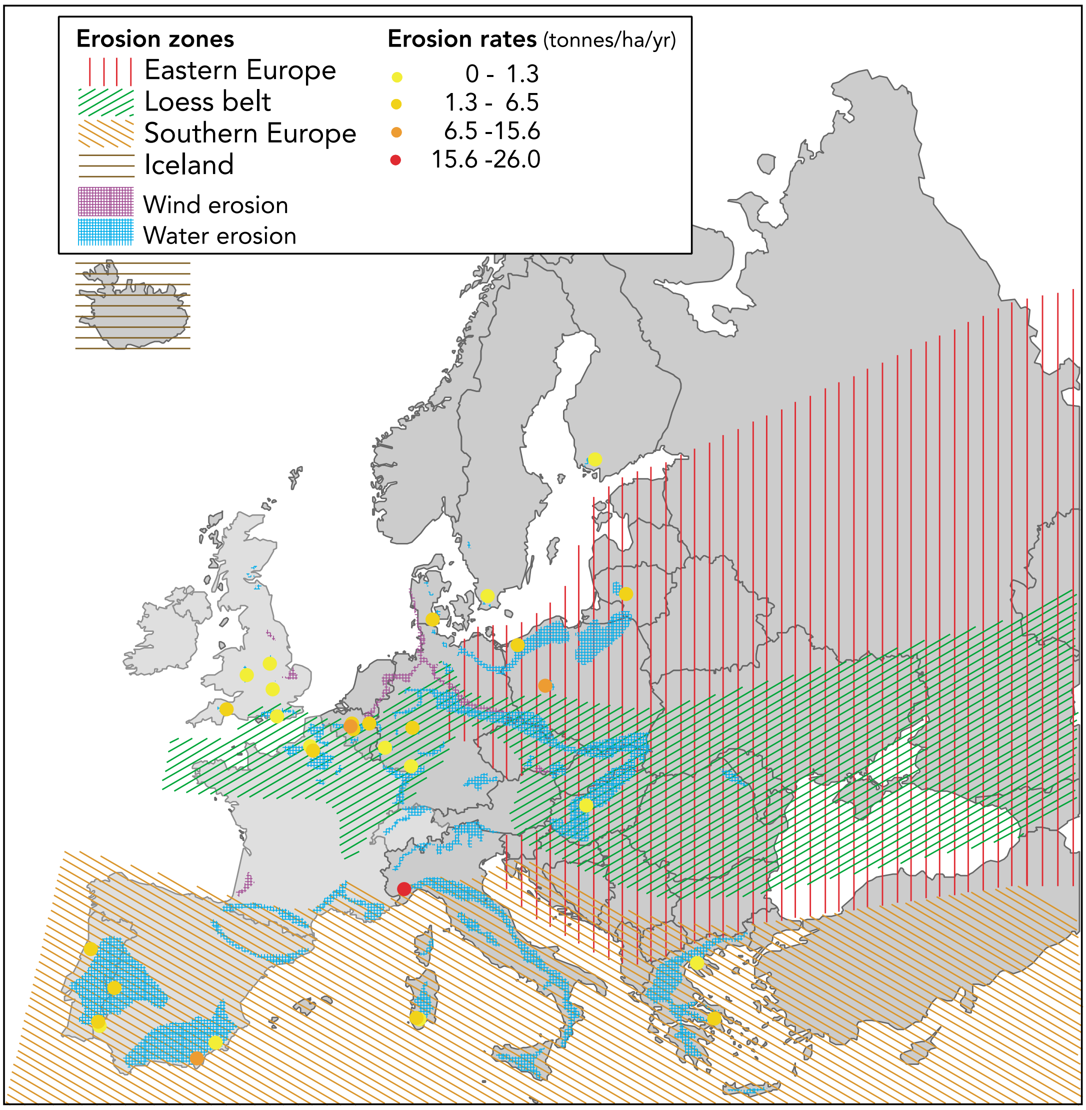
The hot-spot map aims to present a kind of 'spatial indicator' that would enable the identification of priorities of intervention and the visualisation of data gaps.

4.3.1. Methodology

For soil erosion, it is recognised that, because of its patchy distribution in time and space, and the uneven density and quality of local measurements, a simple mapping of hot spots is futile. The map produced has been developed from earlier maps (Favis-Mortlock and Boardman, 1999; De Ploey, 1989), based on local empirical data, as opposed to Corine or other estimates based on erosion models, which are considered unsuitable for application at coarse scales (EEA, 2001a) (see Figure 4.3). In the hot-spot approach, broad zones are first identified for which the erosion processes are broadly similar. Hot spots are then highlighted within each zone and associated with the best estimates, from the literature, for rates of erosion in these hot-spot areas. The intention is to identify areas of current erosion risk, under present land use and climate, as opposed to either evidence of past erosion, or of the potential for erosion under some hypothetical conditions.

(6) An EIONET review of the 'hot-spot' analysis and maps was undertaken in 2001. The results are discussed in EEA, 2002b.

Figure 4.3 Probable problem areas of soil erosion in Europe



Source: EEA, 2000; EEA, 2001.

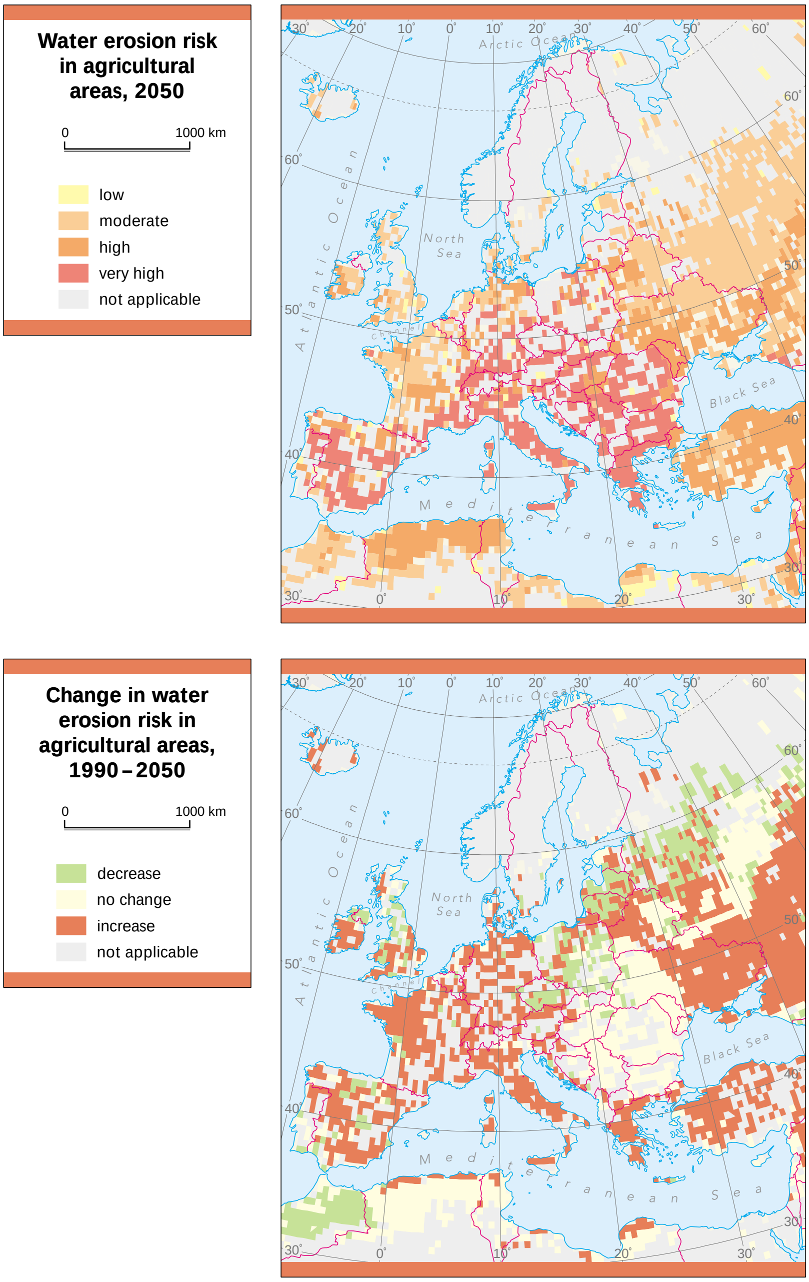
In detail, the data provide general or particular information about water erosion for approximately 60 sites or small regions across Europe, with measured erosion rates, which could be placed on the map at 35 sites. Measurements are taken from erosion plots, fields and small catchments. The data are then grouped into three broad groups, for eastern Europe, the Loess belt and southern Europe, which primarily represent different land use history, parent materials and climate respectively. The problems associated with erosion hot spots are identified as primarily off-site in the short term, with siltation and pollution by agricultural chemicals. In the longer term, loss of soil productivity is seen as increasingly important.

4.3.2. Advantages and limitations

Although there are advantages in concentrating on measured empirical data where these are abundant, and interpolation can be meaningful, the sporadic distribution and episodic occurrence of soil erosion makes it very ill-suited to this approach. There is, however, scope for combining data from the literature with ongoing measurements and estimates from some factorial or modelling approaches as a means of rational interpolation. In its present form the most important information contained in these maps lies in the considerable experience of their compilers, which it is hard to document or quantify.

Within the area of overlap with the Corine map in southern Europe, the hot-spot map inherits from the De Ploey map a greater concentration on parent material as a key factor in localising significant erosion. It is also clear that sites of high erosion identified on this map are definitely areas of high impact, but that there is no reliable way to extrapolate these local results, even to their surrounding area.

Water erosion vulnerability for 2050, according to the baseline scenario (7) by RIVM Figure 4.4



Source: EEA, 1999a.

4.4. The RIVM approach

As part of a major report on strategies for the European environment, a baseline assessment of water erosion was prepared for 1990 (RIVM, 1992). This assessment of current risk was combined with climate and economic projections within the framework of the IMAGE 2 model to generate scenario projections for 2010 and 2050. This approach has the advantage of making explicit scenario projections, a feature lacking in other approaches, but is currently only available at 50 km resolution, so that it cannot readily be interpreted at sub-national scales. This approach also has the advantage of combining physical and economic elements within a single framework. However, the value of this integration must be judged on the reliability of all components, of which only the soil erosion assessment is addressed here. The results of this assessment are shown in Figure 4.4.

(7) In the last EEA state of environment report (EEA 1999a) an increase in the risk of water erosion was expected by the year 2050 in about 80 % of EU agricultural areas, as an impact of climate change. The increase would mainly affect the areas where soil erosion is currently severe. These results were produced jointly with the Commission, based on 'business-as-usual' socioeconomic and energy developments which did not assume that the Kyoto targets would be met (pre-Kyoto EC energy scenarios).

4.4.1. Methodology

IMAGE 2 is primarily a global model composed of 13 sub-regions (Alcamo, 1994). OECD-Europe and eastern Europe are two of these regions. IMAGE 2 is an integrated model designed to simulate the dynamics of the global society-biosphere-climate system. It consists of three fully linked sub-models: energy–industry that computes emissions of greenhouse gases (GHGs) as a function of energy consumption and industrial production; terrestrial environment that simulates changes in global land cover and the flux from biospheric GHGs into the atmosphere; and atmosphere–ocean that computes average global and regional temperature and precipitation patterns. IMAGE 2 is linked to the MIDAS model for CO_2 emissions and energy demand and supply; to GEM-3 for population and GDP by country and by sector; and to WorldScan for EU-15 GDP.

Water erosion represents a module of the IMAGE model adapted from the water erosion model of Batjes (1996) on a ½° x ½° (approximately 50 km) grid. The water erosion impact module generates a water erosion risk index based on three main parameters: terrain erodibility, rainfall erosivity, and land use pressure.

The methodology is described below and summarised in Figure 4.5.

1. Terrain erodibility is based on soil type and landform, which are regarded as constant parameters. Land form is classified into general types (flat, undulated, mountainous, etc.) by using the difference between minimum and maximum altitudes for each grid cell, using the 10 minute grid elevation data set of the Fleet Numerical Oceanography Centre (FNOC) which provides 9 points per 50 km grid cell. Soil type is derived from the FAO 'Soil map of the world' and is composed of soil depth, soil texture, and bulk density. General averages for these characteristics are supplied by the WISE soil profile data set.

2. Rainfall erosivity is represented by the month with the maximum rainfall per rain-day. This is considered to be indicative of rainfall erosion potential. Data on precipitation and number of wet days are derived from the IIASA climate database for mean monthly measured climate variables from an array of weather stations for the period 1931 to 1960. Precipitation is considered a dynamic variable, while the number of wet days is assumed to remain constant.

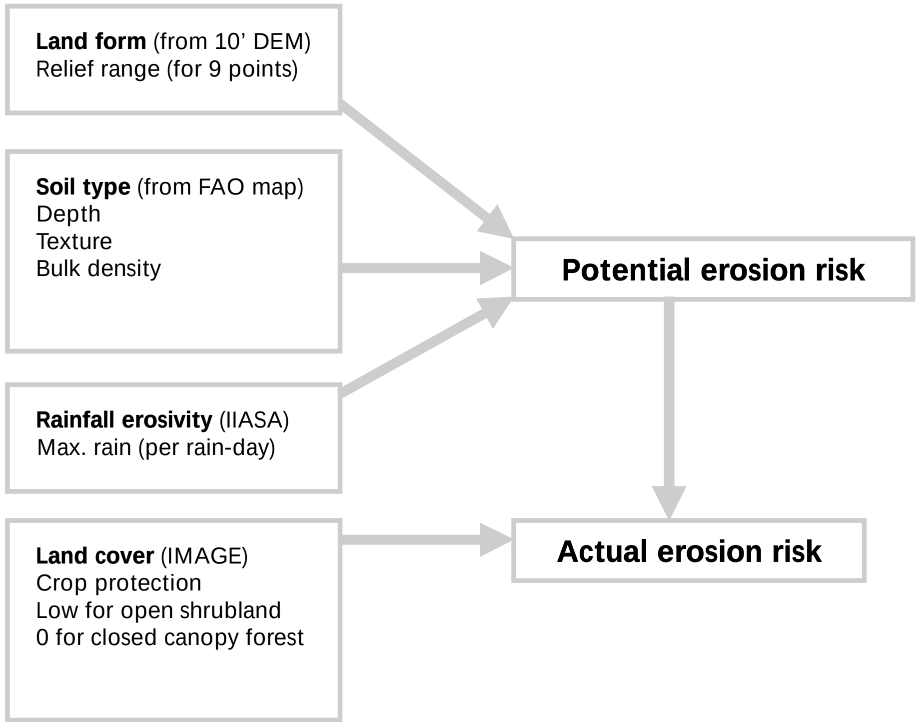
3. The potential erosion risk derived from these two factors is then converted to actual erosion risk by a land cover factor, representing the degree of protection afforded by various land covers (agricultural crops) from land cover maps. Natural vegetation with a closed canopy (e.g. forests) is assumed to provide optimal protection (no risk) and natural vegetation with a more open structure (e.g. shrubs) is assumed to provide sub-optimal protection (low risk). Land cover maps for the IMAGE model are derived from several sources including Olson's land cover database and statistical information from FAO.

4.4.2. Advantages and limitations

The main advantage of the RIVM approach lies in its potential for integration with other environmental factors within an integrated model of the physical and economic environments, and the IMAGE model used is not evaluated here. Nevertheless these advantages cannot be fully realised unless the underlying model modules are themselves of an acceptable standard.

The RIVM soil erosion model is a factor model, like Corine, but, although initiated six to eight years later, is in many ways a still more simplified approximation to the imperfect USLE model. If Figure 4.5 is compared with Figure 4.2, the similarities and differences are immediately evident. It may be seen that the soil erodibility takes a similar form to Corine or USLE, with components for soil type, and a simplified gradient and index. The rainfall erosivity component is seen as an inadequate representation, which contains neither the theoretical basis underlying USLE nor the fair empirical alternatives provided in Corine. Only land use provides an improvement on Corine, due to the availability of better land cover data than were available early in the Corine project. The RIVM method exploits the potential, inherent in any physically based or factor-based assessment, of providing scenario analysis, through the inclusion of two dynamic components, the monthly rainfall totals (affecting erosivity) and land cover (affecting the assessed actual erosion risk).

Summary of RIVM methodology for water erosion assessment — Figure 4.5



The RIVM approach is therefore seen to share some of the advantages of all methods which use distributed data sources, by providing an objective assessment across the European area. However, neither the 50 km resolution nor the implementation of the factors contributing to erosion are seen as providing a state-of-the-art assessment.

4.5. The Glasod approach

The main objective of the Glasod project was to strengthen the awareness of decision-makers on the risks resulting from inappropriate land and soil management to the global well-being. To achieve this, the United Nations environment programme (UNEP) commissioned the International Soil Reference and Information Centre (ISRIC) in 1988 to coordinate a worldwide programme in cooperation with a large number of soil scientists throughout the world to produce, on the basis of incomplete existing knowledge, a scientifically credible global assessment of the status of human-induced soil degradation within the shortest possible time frame. The task was subcontracted to correlators in 21 regions to prepare, in close cooperation with national soil scientists, regional soil degradation status maps. These regional maps were correlated to provide the Glasod world map of soil degradation.

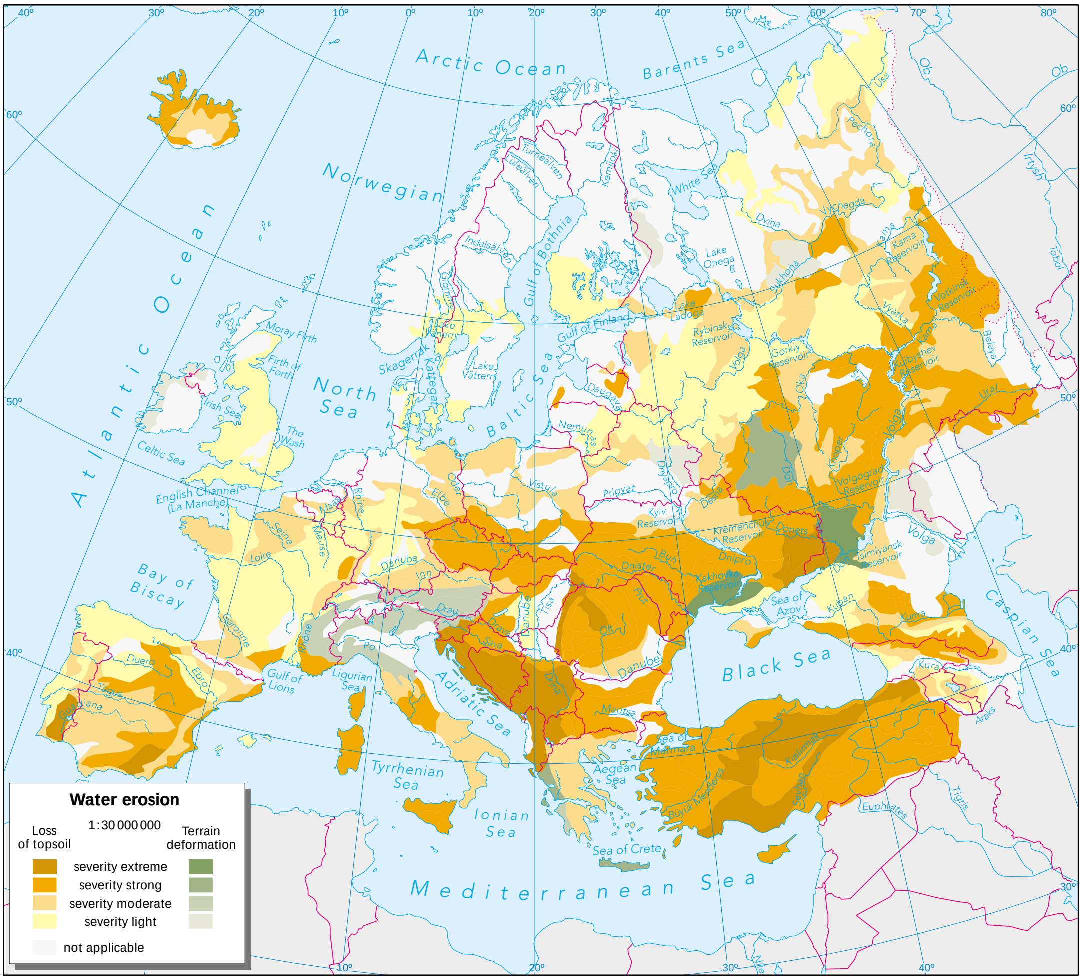
It is important to recognise the limited aims of the project, and to observe that Glasod is the only approach which has, to date, been applied on a worldwide scale. It is based on responses to a questionnaire sent to recognised experts in all countries (Oldeman et al., 1991). It thus shares with the hot-spot approach dependence on a set of expert judgments, but can provide very little control or objectivity in comparing the standards applied by different experts for different areas.

The information and data on erosion and physical degradation in the Dobris assessment (EEA, 1995) are based on an updated version of the European part of the global assessment of soil degradation (Glasod) map. For this update (Van Lynden, 1995), questionnaires were sent to scientific teams in each European country for comments and additions on the Glasod map. Not all countries completed and returned the questionnaires and the degree of detail of the information received varies greatly. It must also be noted that the scale of the maps (1: 10 000 000) limits the detail that can be shown, providing a minimum resolution of approximately 10 km. The results are shown in Figure 4.6.

The Glasod map identifies areas with a subjectively similar severity of erosion, irrespective of the conditions which

Figure 4.6 **Water erosion of soils in Europe according to the Glasod approach**

Source: EEA, 1998 modified from Van Lynden, 1994.



produced this erosion. For water erosion, areas are grouped together primarily on the basis of the severity of topsoil loss. It is clear from comparison with other maps that there are substantial differences between the objective standards applied in different regions, although parts of southern Spain, Sicily and Sardinia are described as areas of high erosion risk in all assessments.

4.5.1. Methodology

The stages in the production of the Glasod global map were as follows (Van Lynden, personal communication, 2001).

- In close collaboration with ISSS, Staring Centre, FAO and ITC, 300 soil scientists worldwide were contacted and correlators for 21 designated regions identified.
- These collaborators were provided with guidelines for the assessment of the status of human-induced soil degradation (1988) and with a base map (Mercator project;1:10 million average) with loosely defined physiographic units (polygons).
- The assessment consisted of an expert judgment (following the general guidelines prepared) of degradation status (type, extent, degree, rate and cause) for individual polygons on a national / sub-national level.
- This information was compiled by the regional correlators.
- Final map compilation and publication of the global map at ISRIC / Staring Centre in 1990.
- The resulting map was digitised afterwards with an attribute database and supplementary statistics on the extent and degree of degradation.
- Thematic maps, derived from the Glasod database, were prepared by UNEP / GRID for inclusion in the World Atlas of Desertification. The Glasod map and complementary statistics have been used and cited in numerous scientific journals and policy documents of the World Resources Institute, the International Food Policy Research Institute, the Food and Agriculture Organisation of the United Nations, the United Nations environment programme, and many others.

Detailed information on the global extent of human-induced soil degradation, derived from Glasod, is included in Greenland and Szabolcs (1994). Results indicate that water erosion is the dominant degradation process in Europe, and that less than 10 % is considered to be strongly or severely degraded.

4.5.2. Advantages and limitations

The Glasod map is still widely used and quoted, although its authors and critics alike recognise the need for a more detailed and more quantitative assessment. Its virtue was that it was produced quickly in response to a demand, and was never intended as more than an interim assessment. Nevertheless, the impossibility of making truly objective comparisons between, and often within areas, is a major difficulty in interpreting the results. No expert knows all the erosion sites within his or her own area with equal confidence, and scales within each area tend to be from best to worst, without absolute scales for objective comparison. Some of these problems are being partially addressed in new assessments from ISRIC, which make use of physiographic units defined by the SOTER methodology, but the whole questionnaire approach is fundamentally flawed by a lack of detailed knowledge and the impossibility of objective comparisons.

Given that there are now improved methodologies, based on more quantitative analysis of particular problems, such as soil erosion, it is unquestionably timely to abandon this approach, whilst not rejecting the data from local erosion sites to calibrate more quantitative models. However, it was the first comprehensive global overview on soil degradation that created awareness and highlighted the need for a more objective approach and for validation. Updates for specific regions have been made under the Soveur and ASSOD programmes (see Annex III, workshop paper by Van Lynden).

4.6. Comparative assessment of the four methodologies

None of the four approaches reviewed here achieves state-of-the-art forecasting for soil erosion risk assessment across Europe (NB: an interpolation with a colour for a region where no observation was made is also a forecast). Because soil erosion events are associated with the incidence of storms, which are patchy in both time and space, site data must be widespread and long-continued to allow effective interpolation between available sites. Thus methods based on questionnaire surveys (Glasod) or erosion measurement sites (hot spots) are likely to be inadequate on their own. In addition, differences between expert assessments and measurement methods reduce the comparability between the limited data available.

Methods based on factors or indicators have the immediate benefit of accessing distributed data sources that are available on a European scale in electronic form (GIS). These include climate data, DEMs and soil maps. All of the mapping methods appear to use implicit or explicit reference to at least some indicators, particularly to soil classifications, but only Corine makes explicit use of an adequate range of relevant indicators. However, Corine is an implementation which is imperfect for historical reasons of data availability, of a model (USLE) which is now no longer considered as state of the art. For these reasons, although it perhaps gives the best indication of the Europe-wide distribution of soil erosion of the four methods surveyed, it is now in need of replacement, and appears not to represent expert opinion of variations in erosion rate within each national region.

4.7. Options for the future

It is clear that the widespread availability of GIS data for key controlling variables strongly favours a factorial or modelling base for future assessments of soil erosion. The difficulties associated with a modelling approach should not, however, be underestimated. It is essential that a suitable model should:

1. represent the state of the art in current understanding of soil erosion;

2. combine sufficient simplicity for application on a European scale with a proper incorporation of the most important processes;

3. have the potential for downscaling to field or plot scales where explicit validation can be made with field monitoring data, to make full use of experimental sites available.

Current thinking on modelling (COST623 2001) recognises the importance of runoff forecasting as a critical control on erosion loss. Simple runoff models are based on a runoff threshold or infiltration equation approach, and vary in complexity from the RDI model (Kirkby et al., 2000) to the USDA WEPP (Nearing et al., 1989) model. There is a trade-off between a simple model, which can be applied across a continuous range of parameters, for each cell within a European grid (as in the EC Pesera project), and a more complex model, applied for a finite number of parameter steps, the permutations of which are then repeated at many sites across a region (the MIR approach proposed by Brazier et al., 2001). In either case, there is then the additional need to ensure that there is adequate investment in validation against existing field data, although recognising their variations in quality and methodology.

Present-day soil erosion models have substantially aided insight into erosion processes, but are designed to assess soil erosion risk at small spatial units. In addition, these localised studies may not be representative of the continental and regional scales required by policy-makers to set up an adequate soil conservation strategy. Moreover, it is often technically and financially unfeasible to acquire the necessary input data to run detailed soil erosion models for decision-making at regional, national or pan-national level. For application on a broad regional scale, current models are severely limited by their high data demand and, in many cases, by a focus on individual events rather than on long-term averages or cumulative impact. This prevents the application of the best American models, such as WEPP (Nearing et al., 1989) and Kineros (Woolhiser et al., 1990) or other EU-funded models, such as the Eurosem, Eurowise and Medalus (Medrush) models. The Corine and USLE-derived models (RUSLE, etc.) are more appropriate in their data needs, but all are now recognised as lacking a physical basis which can be linked, more or less explicitly, with current concepts and research in soil erosion, and which offer the possibility of direct provision of physical and socioeconomic scenarios.

The fifth framework project 'Pan-European soil erosion risk assessment' (Pesera) will produce a regional model with a physical basis that can be applied to larger areas and can be used for scenario analysis and impact assessment. Earth observation techniques and the increased use of geographic information systems have greatly improved the availability and methods to process and analyse spatial data. In concert with the improved understanding of soil erosion processes, the development of a spatially distributed process-based model to assess soil erosion risk over large areas is therefore the next challenge. In the face of an inevitable uncertainty, the concern will be to safeguard the model's robustness based on a well-developed strategy of sensitivity analysis. Measured soil erosion data will play a crucial role in evaluating the model through quality assurance in the absence of any measurements. The model to be developed will produce quantitative results with a known reliability, and can be continuously upgraded with more accurate or detailed data upon their availability. The latter will evoke the somewhat underestimated challenge of reconciling the model with high-volume data sets. More details on the Pesera project can be found in Annex III (Ann Gobin's and Mike Kirkby's presentation).

4.8. Conclusions and recommendations on implementation of regional assessments

A number of recommendations can be made from the assessment of existing methods in this section. The most immediate is that there is scope and need for an improved assessment method, since all show serious shortcomings, and only a moderate level of agreement about the areas most seriously affected by soil erosion in Europe. The scope for a new assessment is based on the emergence of better models at appropriate scales, which can build on the data and expertise developed through the Corine project, to develop a physically based forecast for the distribution of water erosion across Europe. The need for a new assessment is based on the large variation between current maps, which show no clear consensus on the areas most at risk.

Additional recommendations relate to the specification of erosion risk, which is defined in significantly different ways for the various assessment methods. It is suggested that evidence of historical erosion should be used to modify soil databases, and as a gross qualitative indicator that an area is susceptible to erosion under certain circumstances (which may no longer apply). All of this information should be included in an assessment of the existing soil resource, and this is considered to be separate from an assessment of soil erosion risk.

Soil erosion risk refers to the expectation of future loss, under both present conditions and under different climate (due to global change) and land use (due to economic circumstances, global change or policy implementation). This can most usefully be expressed in two ways. First as an estimate of long-term average rates of soil loss, and second as the loss expected in an extreme event (for example with 100 years average recurrence interval). These assessments can then be directly related to the long-term loss of soil resources in relation to present soil depths, and to the likely costs of locally severe off-site deposition and pollution.

Part II — Workshop conclusions

The soil erosion workshop was held at the European Environment Agency (Copenhagen) on 27 and 28 March 2001. It was attended by about 15 people: EEA staff, national experts and representatives of the Commission (Environment DG, JRC).

The workshop was organised to facilitate the expert review of EEA work on soil erosion and to make recommendations for the further development of the work, in particular to be carried out by the new ETC on Terrestrial Environment.

The focus of the workshop was on assessment and reporting of soil erosion indicators across Europe. This entailed a review of the European Environment Agency's work, which specifically concentrated on soil erosion indicators, including the hot-spot maps in comparison with other regional assessment methods (see Part I).

The EEA presented the objective of the workshop and the state of play of EEA work on soil, with particular reference to indicators on soil erosion. A selected number of experts presented work related to the assessment of soil erosion and the development of indicators (see Annex I). A short discussion followed after each presentation.

The presentations were divided under three major headings: soil erosion indicators and assessment framework, regional and spatial assessment methods of soil erosion (indicators of state), and data availability for soil erosion indicators. A specific discussion was held immediately after each session, guided by the questions formulated in Annex I. During the general discussions emphasis was placed on indicators of state and impact for assessing soil erosion.

This part of the report presents an overview of workshop discussions and recommendations, organised by theme and presentation. A separate section deals with the general discussions. The programme of the workshop is included in Annex II. The papers presented are included in Annex III.

5. Soil erosion indicators and assessment framework

5.1. Operational framework

As soil erosion has impacts on several media, in particular on water quality, working links should be developed with other ETCs and specifically with the ETC on Water. The Water Framework Directive recognises the relevance of agriculture as a major source of water pollution.

Moreover, it was recommended that working links with groups of experts contributing to the development of international initiatives — such as the COST Action 623 'Soil erosion and global change', the European Society for Soil Conservation and IGBP-GCTE Focus 3 'Soil erosion network' (COST623 2001) — should be maintained.

5.2. Soil erosion indicator work at ETC/Soil

The soil erosion indicator work at the former ETC/Soil is described in detail in the working report by EEA-ETC/S (1999) prepared by Düwel and Utermann. For soil erosion indicator development, use was made of existing databases, which were augmented with questionnaire obtained data. The general conclusion is that data availability is not a real problem, but the accessibility certainly is.

There is also a perceived need to provide details on type and methods of erosion data collection (metadata). This will help establish an approach to deciding which indicators of erosion are needed and how to get them, since we need indicators which tell us what is happening now (i.e. actual) and what may be happening now and in the future (i.e. potential).

A definition of soil erosion is needed. What type of erosion is described or measured? Is it current or past (geological)? Present-day erosion is what interests the policy-maker.

Sediment delivery ratios or sediment loads in rivers are not all directly related to soil erosion (part may be caused by riverbank or channel erosion). Moreover, there is a huge time lag between conservation measures and sediment measurements so that care has to be taken in the interpretation of sediment concentrations as an indicator of impact (EEA-ETC/S, 1999). Sedimentation (and the link to eutrophication) of lakes is also important and necessitates a link with water quality studies.

5.3. GISCO databases and tools to derive pressure indicators for soil erosion

The ETC/Soil proposed intensification of agriculture as a major driving force for soil erosion (EEA-ETC/S, 1999). Subsequently, indicators for agricultural intensification were drawn from available European-wide databases. The advantages are that data are readily available and serve the short-term purpose of monitoring.

An understanding of socioeconomic driving forces and soil erosion is still very limited. The links between agricultural intensification and soil erosion are not always clear. Moreover, agricultural intensification and soil conservation are not mutually exclusive. The mechanisms of intensification are also poorly understood. For example, in the Belgian Loess belt, land under steep slopes has been taken out of production while the agriculture in general has intensified. However, in the United Kingdom, the more intensive kinds of agriculture are generally driving erosion, such as enlargement of fields, continuous arable, switch to winter cereals, more irrigation, more crops grown under plastic, more grazing animals, and more pigs reared out of doors. Land is only taken out of cultivation if farmers are paid to do that, e.g. set-aside, or if they are paid to reduce grazing intensities. All the evidence suggests that there was very little erosion prior to the late 1940s.

A major critique is that indicators of pressure related to agriculture should take account of crop types, cropping calendars and management and crop growth in a spatial context. The MARS project uses this type of information for running the crop growth monitoring system (CGMS) across Europe. Changes in areas under the various crop types are available every two years from the farm structure survey, but only at NUTS 2 level. The NUTS 3 level agricultural census data are available at 10 yearly intervals for the EU, but individual EU Member States collect this level of information more regularly.

The knowledge that crop types are changing can help evaluate whether erosion is likely to get more widespread, or not. Provided that within individual countries it is not too expensive nor too difficult to get data on cropping the changes in erosion risk can be assessed and passed on to the EEA. This may circumvent the lack of European-wide detailed information on cropping from year to year.

5.4. Discussion on questions

What is soil erosion? It was recommended to concentrate on present-day soil erosion for policy purposes. Because of erosion's patchiness, rates are only meaningful for very small areas. Policy-makers are interested in a European-wide assessment of the problem at present and in the future. This requires a regional assessment in terms of soil erosion risk.

Mapping actual erosion will be a very time-consuming and costly operation. Moreover, the recognised patchiness in time and space will always call for continuous updates. A risk assessment will enable a transparent and objective comparison between regions. The underlying model in a risk assessment translates what experts use into mathematical algorithms. However, a mapping instruction to map out actual erosion features on a detailed scale could be an option where more details are required on the actual state of the problem and where funds are available to undertake this expensive operation.

One very important remark is that a programme to monitor soil erosion across different agro-ecological regions and under different land uses should underpin both mapping exercises and regional soil erosion risk assessment methods. Only then a sound approach is ensured of estimations and mapping features that are directly validated and compared with measurements. Moreover, measuring campaigns may lead to new insights and therefore to better mapping and risk assessments.

Indicators of state and impact are the most important. However, factors underlying the causes of soil erosion such as pressure indicators should be clarified and communicated to the policy-maker. It is important to link each indicator to the general policy framework. Headline indicators and sub-indicators should be identified and prioritised. A major concern is the link between different indicators of one category (e.g. driving forces) that is not expressed nor explored within the DPSIR assessment framework.

Agriculture in general is a very important driving force for soil erosion. An example for some of the less-favoured areas in the Mediterranean showed that with increasing subsidies stocking rates increased and resulted in overgrazing and subsequently more erosion. A similar scenario is foreseeable if farmers are compensated for soil erosion. In a situation of financial compensation for soil eroded land, incentives for farmers to practise soil conservation will be lacking. Care should be taken in formulating the necessary remedial measures and encourage farmers in practising soil conservation techniques.

6. Regional and spatial assessment methods of soil erosion and data availability

6.1. The Glasod map

The Glasod map produced by ISRIC was the first effort to produce a global assessment of human-induced soil degradation on the basis of incomplete expert knowledge within the shortest possible time frame. This approach provides an overview on a global scale of human-induced soil degradation, and can be used to identify hot spots and awareness raising for international policy-makers. Major critiques regarding the map relate to the methodology and are reflected in a strong correlation between country boundaries and erosion risk. The Glasod approach has been further developed by other programmes such as ASSOD (Assessment of soil degradation in south and south-eastern Asia, Van Lynden and Oldeman, 1997) and Soveur (Assessment of soil degradation in central and eastern Europe, Batjes, 2000) that are linked to GIS and database technologies. But Glasod reliance on qualitative data means that the approach should not be adopted in isolation.

Another suggested approach is to use the 1:1 million scale soil map of Europe as a base for a rapid Glasod-type assessment of erosion, i.e. what is the type of erosion and its extent within a soil map unit and what are the causes of that erosion. A major disadvantage of expert mapping is that the policy-maker does not know what the underlying criteria were to produce the map (did the expert use soils, land use or a combination, etc.).

6.2. The hot-spot map

The hot-spot map (EEA, 2001a) is an empirical approach using measured data and expert opinion. This approach was adopted in view of the difficulty modelling approaches have in dealing with erosion's spatial and temporal variability, and the generally poor job these models make of modelling gully erosion. Three categories are presented: zones (expert opinion); hot-spot areas (based on the De Ploey map); and locations (published erosion rates). An obvious disadvantage is that there is a lack of reliable data to give an adequate picture of erosion hot-spot locations across the whole EU. Additionally, because of erosion's spatial patchiness, it is problematic to link erosion rates measured at specific locations with the severity of erosion in the hot-spot areas. Moreover, spatial links between the different hot-spot areas are difficult to establish. Therefore the usefulness of the hot-spot map to policy-makers was questioned.

The problem with the hot-spot map is not its aim, i.e. to bring out where erosion is, or is most likely to occur, but its scale. Small areas, e.g. soil landscape units cannot be brought out at this scale. However, a framework such as a 1:1 million, or preferably a 1:250 000, soil/land use map could form the basis for assessing erosion on which hot spots could be portrayed, i.e. very often erosion will equate with particular soil/land use associations. Such a map could be similar to the 'actual' and 'potential' erosion maps produced for England and Wales which classify soil/land use associations from very low, low, medium, high to very high risk. It would bring together both expert views as well as quantitative work. Such an approach would bring together both the Glasod and hot-spot methodologies.

An evaluation of the hot-spot map was carried out by EIONET in spring 2001. The results of the evaluation are published in EEA, 2002b.

6.3. Regional assessment of the extent of soil erosion by water

A comparison of existing maps for soil erosion assessment on a European scale was made. Four specific approaches — Glasod, hot spots, RIVM and Corine, used by the EEA to obtain a European-wide assessment of soil erosion, were related to two assessment methods (distributed point data and factor or indicator mapping). Regional process modelling (RDI model and Pesera model) was presented as a suitable alternative for future regional erosion risk assessment. A description of the RDI and Pesera model is given in Annex III (regional soil erosion risk assessment by Anne Gobin and Mike Kirkby).

It was pointed out that the four approaches used by the EEA each served specific but different purposes. For instance, the hot-spot map was aimed at locating soil erosion problem areas, whereas the RIVM map illustrated the impacts of global change on soil erosion. However, the common objective of all these specific approaches (including regional process modelling) is a regional assessment of soil erosion. Some of them consider soil erosion risk (RIVM, Corine), while others consider actual erosion (Glasod, hot-spot map).

The process modelling method has the advantage of producing an indicator of state with the possibility for analysing different scenarios and assessing impacts (i.e. estimate what may happen in the future). The major objective of scenario analysis is to reduce soil erosion through policy-making. Clearly, the policy-maker has a major impact on land cover and land management through various land use policies. Any changes in these two factors affect soil erosion. The focus remains on indicators that are relevant to human activities.

Modelling efforts should be thoroughly validated against erosion measurements, and a clear distinction should be made between modelled erosion risk and present-day erosion rates. Rainfall intensity is a crucial input to any soil erosion model and is incorporated in the Pesera model through rain distribution as a surrogate (Kirkby et al., 2000).

All current erosion modelling approaches have severe limitations in capturing erosion's spatial variability. Moreover, any model based on the USLE will not include gully erosion, which, as Poesen et al. (1996a, 1998) have shown, can be a major contributor to total erosion in (at least some parts of) Europe. The Pesera model was presented as a potential solution to future regional erosion risk assessment.

Three different views were adopted among the workshop participants concerning regional erosion assessment: (1) representation of real measurements, (2) expert judgment and (3) modelling approaches (whether factorial or physically based). The first two groups represent anti-modelling views. There was a general consensus, however, that both measurements and expert judgment remain a vital part in factorial or process modelling of regional erosion. It was the role or weight that is given to the different components in the process of regional assessments that remained a point of discussion.

6.4. General discussion on regional/ spatial soil erosion indicators

For policy purposes, there is a need to define a method which could be used to assess the present state of soil erosion but also to predict future responses. This calls for the definition of an indicator and a calculation procedure.

The use of expert-based maps versus indicator or model-based maps was discussed in detail. Experts could judge the severity of soil erosion and have considerable knowledge of the detail. However, an indicator reflecting the extent (area) affected by soil erosion requires some kind of interpolation. Moreover, in expert judgments, the methodology is seldom repeatable and hence it does not provide a sound basis for comparing subsequent future judgments. Expert judgments could be too biased for policy decisions to be based on. On the other hand, for a process as complex as soil erosion, experts have a crucial role to play in validation and evaluation of the end product.

Generally, it was agreed that the indicators to be developed should have the following properties and adhere to the following principles:

1. quantitative,
2. objectively calculated,
3. validated against measurements,
4. evaluated by experts.

It needs to be clearly pointed out that validation of the model/indicator is essential, and that this validation needs to be planned and resourced in the same way as the model/indicator development itself. Since only limited measured data are available for the EU (and the measurements are of rates on small areas), databases of measurements need to be combined with expert opinion in the model/indicator validation. An input in validation could include radionuclide measurements to determine current erosion.

Whenever possible, the use of maps should be accompanied with an accuracy evaluation. Well-defined, unambiguous class definition and the analysis of errors may improve the statistical use of the maps. The mixture of land use and land cover, like in the Corine legend, can determine loss of information and may pose difficulties in the calculation of indicators. For example, the urban green area is a category of land use and for the cover it can be a lawn, a wood area and part of it could be covered by artificial infrastructures. The integration of map production and field statistical survey can be an important tool providing synergy to improve the characteristics of the respective products. The integration of the LUCAS Eurostat project and Corine land cover offers scope for validating future erosion modelling efforts, considering that LUCAS could make available field data on soil erosion phenomena all over Europe.

The array of indicator characteristics would offer a standardised approach that can be repeated as data sets become more accurate or more readily available. A method based on both runoff and land cover would be commendable, since both are measurable and both significantly affect soil erosion. USLE-based methods do not recognise the physical rationale behind the erosion process, and the relative importance of the different factors is not always satisfactory. However, the development of runoff based indicators will require more time. Therefore factor-based methods similar to the USLE approach will have to be adopted in the interim to produce a first workable solution. Runoff and cover changes should be viewed in conjunction with management practices.

Policy-makers may also prefer compatibility with an international framework such as that established within the OECD framework. It is of no use to invent indicators that would wrongly direct subsidies. Focus should be on encouraging soil conservation strategies.

7. General discussion on indicators

7.1. Data availability for soil erosion indicators

An overview of existing databases available at the JRC for the calculation of a soil erosion indicator of state was given. The European soil profile database (SPADE), containing data on 355 soil profiles across western Europe, should provide the necessary information for assessing soil vulnerability to erosion. Examples of pedotransfer rules for soil erodibility and soil crusting show the importance of incorporating baseline soil data into soil erosion risk assessments. However, it is suggested that erosion risk assessment should be based on catchment areas and not on soil polygons. The 500 to 1000 km² European catchment geographical database (scale 1:1 000 000) should suit the purpose.

7.2. Indicators of state

An indicator of state to be developed in the short term should be based on topography, soil type and land cover. There is a perceived shortcoming of high-resolution digital elevation data on the European scale. Slope classes derived from the European soil database will therefore be the basic topographic input. Pedotransfer rules for soil crusting and erodibility were developed by INRA-Orléans (Le Bissonnais and Daroussin, 2001) based on soil type, texture and parent material. A second pedotransfer rule will have to be derived for stoniness. The Corine land use map should then be overlaid with the slope classes, soil crustability and stoniness maps in order to produce a first soil erosion indicator of state. However, care should be taken with the mixed nature of cover and use in the Corine legend. There is a need to have an agreement on the operational procedure for state indicators (and other indicators), for Member States to follow.

The most challenging part will be the development of the scoring system to the different factors. Experts should regularly upgrade the scoring system and explore its various alternatives. Metadata should be included on the confidence level of the estimation.

In the longer term, improvements should include climatic factors and regular updates in land cover. Land cover updates should make use of vegetation indices derived from optical earth observation. The availability of higher resolution DEMs across the EU is a matter of urgency — the current 1x1 km² is not adequate for erosion state indicators

The time aspects of more physically based soil erosion indicators should be explored in more detail.

7.3. Indicators of impact

A distinction ought to be made between off-site and on-site impacts.

Off-site indicators of impact deal with sediment loads in rivers and freshwater bodies. In the short term, agro-chemical application at NUTS level 3 should be overlaid with the erosion score developed in the previous section. In the long term, data on costs of sediment removal (from rivers, canals, lakes and ditches) should be collected. Another indicator to be developed in the long term is water quality, whereby distance and connectivity to freshwater bodies will have to be considered in the off-site effects of soil erosion. However, care has to be taken with the interpretation of off-site indicators of impact (see Section 5.2).

Meaningful on-site indicators are more difficult to develop. Crop productivity springs to mind as a clear on-site effect. However, relating actual yield to soil loss is extremely difficult in European high-input agricultural systems. Moreover, it will have to be monitored over a long time period. In Mediterranean regions, productivity should be confronted with the available water capacity calculated over soil depth. Loss of soil fertility or soil quality could be considered, but are difficult to measure. Particularly for wind erosion, costs of re-seeding could be estimated.

Data on land management changes (e.g. tillage practices) and in particular conservation practices should be collected in a systematic manner. This could be realised in conjunction with the IACS system. This type of indicator accentuates the response rather than the impact of soil erosion.

Part III — Recommendations for further work

8. Recommendations to the EEA

All recommendations are related to accelerated soil erosion (i.e. where the natural soil erosion rate has been significantly increased by human activities that cause changes in land cover and management). In a first instance, the EEA should focus on soil erosion by water and add soil erosion by wind or tillage erosion in a later phase.

The set of recommendations follow the main chapters of the report. They relate to the following categories: general, DPSIR assessment framework, proposed indicators, land use and soil erosion indicators, and regional erosion assessment.

8.1. General recommendations

The following general recommendations are related to the general reporting and networking activities.

1. Since soil erosion has impacts on several media, in particular on water quality, working links should be developed with other ETCs and specifically with the ETC on Water. The Water Framework Directive recognises the relevance of agriculture as a major source of water pollution.

2. Working links with groups of experts contributing to the development of international initiatives — such as the COST Action 623 on 'Soil erosion and global change', the European Society for Soil Conservation, IGBP-GCTE Focus 3 'Soil erosion network' (COST623 2001), the Eurostat projects IRENA and LUCAS — should be maintained.

3. Institutional links with data providers should be strengthened if the EEA is to provide policy-makers and the general public with information on the state of the environment. A general complaint was that data, and particularly statistical data, exist but are often not accessible.

8.2. Recommendations related to the DPSIR assessment framework

The DPSIR assessment framework is an excellent approach onto which further extensions and strategies of reporting on soil erosion can be built. The following recommendations are made to the EEA in an attempt to extend the framework.

1. Although a policy-relevant integrated assessment of soil erosion should not aim at understanding or analysing soil erosion as a process, the full range of underlying factors that influence soil erosion should be considered. These factors include topography, soil, climate, land cover (including vegetation), land use and land management.

2. Particularly physical indicators should be fully explored in the application of the DPSIR assessment framework to soil erosion and explicitly mentioned in the resulting DPSIR scheme. Climate change is considered as a driving force but only in the sense that it relates to human activities. Important physical factors that influence soil erosion are topography, soil type, soil vulnerability and climatic factors (particularly rainfall). These factors should not be separated from the identified pressure indicators. At the same time, headline indicators and sub-indicators should be identified and prioritised.

3. All factors that change land cover, land use and land management should be included as driving forces. At present, only agricultural intensification is seen as the most important driving force (EEA-ETC/S, 1999; EEA, 2000). A revised DPSIR scheme, presented in Figure 2.5, has therefore been proposed, but could certainly be elaborated further upon. Examples of driving forces to be included are human population, land development, tourism, transport, natural events and climate change.

4. The revised DPSIR scheme (Figure 2.5) presents land cover change and precipitation as the most important pressure indicators of soil erosion, as they are seen to be directly influencing the degree of soil erosion.

5. The DPSIR assessment framework lends itself to systems analysis and as such is very useful in describing the relationships between the origins and consequences of environmental problems. Obviously, the real world is more complex than can be expressed in simple causal relationships. Linkages between the different types of indicators are explored through the DPSIR chain. However, the linkages deserve further attention, not least to capture the dynamics of the system. Moreover, linkages within one type of indicators (e.g. pressures) are not explored, despite their repeatedly reported importance.

6. There is a huge difference between measured erosion, actual erosion risk and potential erosion risk. Indicators describing the driving forces and pressures may affect the risk of soil erosion, but they may not affect soil erosion in itself at present, which also depends on underlying physical factors such as soil vulnerability and climatic conditions. A mechanism is therefore needed to jointly estimate the potential and actual risk, based on links between the identified driving force and pressure indicators, and on an estimation or measurement of what is actually happening.

7. In the different reports made by the EEA, it is recognised that a distinction ought to be made between on-site and off-site impacts of soil erosion. This distinction, however, already applies at an earlier stage in the DPSIR chain, namely at the stage of state indicators. Soil erosion can be measured in terms of actual sediment loss per unit area (on-site) or in terms of sediment delivery into streams or rivers (off-site).

8. At present, there is no reporting mechanism in place to assess whether existing measures are leading to improvement of soil conditions or to gauge the level of implementation of existing legislation. This could be a focal point of action.

9. The current level of detail chosen for the application of the DPSIR assessment framework to soil erosion implicitly enables the identification of broad groups of actors related to the perceived environmental problem. However, the full identification of the several actors involved requires a more detailed stakeholder analysis, which ultimately would help formulate sound policies for remediation and mitigation strategies.

8.3. General recommendations related to the proposed indicators

Recommendations related to the indicators proposed by EEA-ETC/S (1999, 2000) (see also Table 2.1) are presented below. A separate section is devoted to the indicators of state (Section 8.5). A number of recommendations are also provided that are related to land use issues in the indicators for soil erosion (see Section 8.4).

1. Driving forces, other than agricultural intensification, should be included (see above).

2. Driving forces or pressures should never be evaluated alone in relation to erosion. In order to understand the complexity of accelerated erosion, it is necessary that at least some of the indicators identify the causes of soil erosion. Physical factors that influence erosion rates are topography, soils, climate and land cover. Land cover is in turn influenced by the socioeconomic environment and as such by anthropogenic activities, notably land use and management. Physical factors should be explicitly mentioned and linked to the existing indicators.

3. The six proposed pressure indicators relate to agricultural intensification. It should be made explicit that all are complex and not directly linked to the phenomenon of soil erosion. Moreover, the indicators are usually only averages on a large area basis and should therefore be carefully interpreted.

4. GISCO databases, such as NUTS and Corine land cover, can be used together with farm structure survey (FSS) data from Eurostat to derive the proposed indicators of agricultural intensification. However, a concise effort should be made to spatialise or disaggregate the

agricultural statistical data to the maximum possible.

5. The lack of good quality data on actual fertiliser use makes it a weak indicator at present.

6. In addition to crop yield, crop type, crop rotations, crop management and area devoted to a particular crop should be considered as indicator of pressure.

7. The nature of soil erosion has to be assessed in order to evaluate the on-site loss and the possible off-site impacts. The identified indicators of state and impact are difficult or expensive to measure and the data are usually not readily available. An effort should be made to compile and centralise existing data.

8. The area affected by erosion is the key indicator for soil erosion, and should be augmented with an indication of the magnitude of erosion in a particular area. A separate section is devoted to this set of state indicators.

9. Indicators of state have to be a measure of soil loss, and should explicitly relate to climate, topography, soil properties, land cover and land management.

10. The extent and severity of soil erosion will have to be quantified and related to land cover changes.

11. Sediment delivery ratio or sediment loads in rivers are not all directly related to soil erosion (part may be caused by riverbank or channel erosion). There may be a time lag between conservation measures and sediment measurements so that care has to be taken in the interpretation of sediment concentrations as an indicator of impact. Sedimentation (and the link to eutrophication) of lakes is also important and necessitates a link with water quality studies.

12. Indicators of response are conservation practices and mitigation strategies, which are rarely in existence at present. However, a concise effort should be made to monitor prevention and control measures.

8.4. Recommendations related to land use and soil erosion indicators

Land use and management are the result of human activities and as such are the most important factors that influence and control accelerated soil erosion. Land cover may be radically altered within a short time, but physical and biological changes within the soil, affecting erosion rates, may take longer periods. The following recommendations relate to the importance of considering land use issues in the development of soil erosion indicators.

1. As stated above, driving forces and pressures should be expanded to all factors that influence land cover.

2. A risk analysis is recommended in order to highlight the risk that is specifically related to the type of land cover. This involves a distinction between actual and potential soil erosion risk (see recommendations for indicator of state).

3. Land cover type and change are the best pressure indicators for soil erosion, as they directly control the intensity and frequency of overland flow and soil erosion. Land cover type and changes, including forest fires and deforestation, can be detected by combining the reference land cover database, Corine land cover, with vegetation changes indices from NOAA-AVHRR, SPOT Vegetation or other earth observation derived indices.

4. Precipitation regimes directly and indirectly, through their influence on land cover, influence soil erosion and should therefore be included as important pressure indicators. These regimes can be detected using the GISCO climate coverages and the monitoring agriculture by remote sensing (MARS) meteorological database. The combination of precipitation regimes with other physical factors such as topography (e.g. aspect) should also be considered.

5. Depending on the particular type of land use and management, including intensity, land resources are subject to a given degree of stress. Land use and management should therefore be monitored as an important factor that

influences soil erosion. Tillage erosion is a prime example of human-induced erosion.

6. Indicators should be developed for monitoring the effectiveness and level of enforcement of soil protection policies.

8.5. Recommendations related to regional erosion assessment (indicators of state)

The area affected by erosion is an important indicator of state for soil erosion. Ultimately, it is the area that is affected by soil erosion and an estimate of the expected magnitude in a particular area that policy-makers would need to know in order to formulate a sound soil protection policy. Regional soil erosion assessment is therefore needed in order to make objective comparisons that may provide a basis for further environmental analysis, economic statements or policy development.

Two important forms of erosion assessment that reflect the current state of degradation are measurements and field observations. Apart from the time and expenses related to collecting these types of distributed point data, spatial interpolation is not justified due to the sporadic distribution and episodic occurrence of soil erosion. Regional soil erosion assessment therefore requires other techniques to be used taking care not to neglect measurements and field observations.

1. Effective monitoring and reporting on soil erosion can only take place when the following concepts related to soil erosion are understood: (a) the fundamental processes of soil erosion and in particular of soil erosion by water as this is the most important form of soil erosion, (b) accelerated soil erosion and (c) the underlying bio-physical and socioeconomic factors that influence soil erosion.

2. Indicators for soil erosion should be developed according to the following properties and procedures: quantitative, objectively calculated, validated against measurements and evaluated by experts.

3. Actual soil erosion measurements, such as collected for the hot-spot map, should continue to be compiled.

4. Field observations are invaluable as soil erosion indicators of state. However, the impossibility of making truly objective comparisons between and often within areas calls for a standardised approach to record and particularly map the observations.

5. In conjunction with soil erosion measurements and observations, data on climate, topography, soil and land use should be carefully documented for each observation or measurement. The erosion type, scale of measurement/observation, study period should be well documented. This requires the set-up of a comprehensive database, including metadata.

6. A Europe-wide monitoring network for soil such as proposed by the EEA (2001b) should include soil erosion, covering the most affected areas (hot spots). A standardised approach to record soil erosion should be defined.

7. Questionnaire-based mapping approaches provide quick results for creating awareness, but should be avoided in the future whilst not rejecting field observations and measurements.

8. The temporal and spatial patchiness of soil erosion favours a risk analysis approach in order to make comparisons between regions and to complement field measurements and observations. The underlying model in a risk assessment should ideally translate experts' knowledge into mathematical algorithms. The widespread availability of GIS data for key controlling variables strongly favours a factorial or modelling base for assessments of soil erosion.

9. Factorial models are useful for identifying the extremes of low and high erosion, but less satisfactory in identifying the gradation between the extremes. There are difficulties about combining different factor ratings into a single scale, about the individual weightings and about the assumed linearity and statistical independence of the separate factors. A process modelling approach is therefore recommended in case the full spectrum of soil erosion has to be assessed.

10. The difficulties associated with a process modelling approach should not be underestimated and a suitable model should (a) represent the state of the art in current understanding of soil erosion, (b) respond explicitly and rationally to changes in climate and land use, (c) combine sufficient simplicity for application on a regional scale and (d) relate coarse scale forecasts to measured erosion rate data so that explicit validation can be made with field monitoring data, to make full use of experimental sites. The process modelling method has the advantage of producing an indicator of state with the possibility for analysing different scenarios, which in turn enables the formulation of soil conservation policies. The Pesera project has adopted this modelling approach.

11. Modelling efforts should be thoroughly validated against erosion measurements, and a clear distinction should be made between modelled erosion risk and present-day erosion rates.

12. A programme to monitor soil erosion across different agro-ecological regions and under different land uses should underpin both mapping exercises and regional soil erosion risk assessment methods. Only then a sound approach is ensured of estimations and mapping features that are directly validated and compared with measurements. Moreover, measuring campaigns may lead to new insights and therefore to both better mapping and risk assessments.

13. Erosion literature commonly identifies 'tolerable' rates of soil erosion, but these rates usually exceed the rates that can be balanced by weathering of new soil from parent materials, and can only be considered acceptable from an economic viewpoint. Tolerable soil loss rates should be developed but at the same time carefully evaluated by experts.

9. Conclusions

The DPSIR assessment framework is an excellent tool onto which further extensions and strategies of reporting can be built. A revised scheme for erosion within the framework presents changes in land cover and precipitation as the most important pressure indicators of soil erosion. The DPSIR assessment framework sets a good basis for identifying the different factors influencing soil erosion, but, at the current level of detail, the resulting scheme for soil erosion does not explicitly allow for the full identification of actors in the DPSIR chain.

Driving forces and related pressure indicators other than 'agricultural intensification' should be included. However, their relationship with soil erosion is complex. Physical factors that cause erosion should be included, i.e. topography, soils, climate and land cover, and their interaction with pressures should be analysed. The identified indicators of state and impact are difficult or expensive to measure and the data are usually not readily available. Indicators of response are prevention and control measures, which are rarely in place at present.

Generally, it was concluded that the indicators should be developed according to the following properties and procedures: quantitative, objectively calculated, validated against measurements and evaluated by experts.

Land cover type and change, land management and land use are the best pressure indicators for soil erosion. Land cover type and change can be monitored by combining Corine land cover data with earth observation derived indices. In addition, land use and management information can be derived from Eurostat, together with the farm structure survey data. The statistical data should be spatialised and disaggregated to the maximum possible.

A regional assessment using a combination of modelling, expert estimates and other methods should be developed in order to provide a general view and identify the hot-spot areas where to undertake a detailed soil erosion monitoring programme.

Regional soil erosion assessments enable estimates of the area that is affected by soil erosion and the expected magnitude in a particular area, both of which are required to formulate sound soil protection policies. Indicators of state should reflect all four strategies of regional soil erosion assessment, i.e. distributed point data, expert mapping, factor mapping and process modelling. The four different methods described in this report are not mutually exclusive and each provides a different emphasis. Erosion rate measurements and field observations provide an unambiguous measure of actual erosion, where they exist. However, apart from the time and expenses involved, spatial interpolation is not justified due to the sporadic distribution and episodic occurrence of soil erosion. Factorial approaches provide a measure of erosion risk and can only be recommended for identifying the extremes of low and high erosion, but not for the gradation between the extremes.

A process modelling method is recommended for modelling soil erosion risk in relation to climate and land use changes. Field campaigns are necessary and databases should be made with erosion measurements, field observations, data on underlying factors influencing erosion (climate, topography, soils and land use) and related metadata (period of record, erosion type, etc.).

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Annexes
Annex I — List of participants

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Annex II — Agenda

Tuesday 27/3/2001

Convenor: Gerard Govers

Time	Speaker	Subject
Soil erosion indicator framework		
14.00–14.30	Anna Rita Gentile	General introduction and European framework applied to soil erosion
14.30–15.00	Olaf Düwel	Soil erosion indicator work at the former ETC/Soil
15.00–15.30	Paul Campling and Costas Kosmas	GISCO databases and tools to derive pressure indicators for soil erosion
15.30–17.00	Chair: Gerard Govers	Discussion on indicator framework

Wednesday 28/3/2001

Convenor: Gerard Govers

Time	Speaker	Subject
Regional / Spatial indicators		
10.00–10.30	Godert Van Lynden	The Glasod map
10.30–11.00	Dave Favis-Mortlock	The hot-spot map
11.00–11.30	Anne Gobin and Mike Kirkby	Regional assessment of the impact of soil erosion by water
11.30–13.00	Chair: Gerard Govers	Discussion on regional/spatial soil erosion indicators
13.00–14.00	*Lunch*	
Data availability		
14.00–14.30	Robert Jones	Data availability for soil erosion indicators at the European level
14.30–15.30	Chair: Gerard Govers	Discussion on data availability, data gaps and needs
General discussion		
15.30–16.30	Chair: Gerard Govers	General conclusions and recommendations
16.30–17.00	Anna Rita Gentile	Concluding remarks

Questions to guide the discussions
In the evaluation and discussions during the workshop, the following questions were used to guide the review.

1. What is soil erosion?

2. What information does a policy-maker need to assess soil erosion and its current impacts, and to formulate remedial measures in Europe?

3. Is the conceptual framework (DPSIR; MF-MI approach) adequate to describe soil erosion in Europe (its state, impacts on the soil resource and on other media, the causes and measures)?

4. Is the list of proposed indicators for soil erosion adequate? How many and which type of indicators should be advocated? (ideas for change). For each indicator in the list:
   - Is the indicator adequate?
   - Are the data used adequate?
   - Are the conclusions and is the assessment correct?
   - What else should be taken into account?

5. What are the driving forces of soil erosion? (with specific attention to agriculture)

6. Are the drivers of soil erosion sufficiently known and how do they link to the phenomenon?

7. Are there other quantifiable indicators of impact apart from the proposed indicator 'removal of sediment deposits'?

8. Is the assessment of soil erosion in Europe correct? Are the methods used scientifically sound?

9. What are the recommendations for further work?

A specific point of discussion was the indicator of state for soil erosion. Soil erosion is recognised to be highly variable in both space and time. The following questions were used as guidelines to discuss the assessment of soil erosion.

1. Which erosion types should be considered? (wind, water, gully, mass movements, active versus non-active erosion (old gullies)

2. How can or should tillage erosion be incorporated in the framework?

3. Can thresholds be derived for policy purposes? How should these be set?

4. What should be the preferred scale for assessing soil erosion taking into account its use for policy-makers? (nested strategies at multiple scales, etc.)

5. How should the extent of the erosion problem be mapped in relation to the severity or frequency?

6. What are good indicators of state and impact?

Annex III — Background papers presented at the workshop

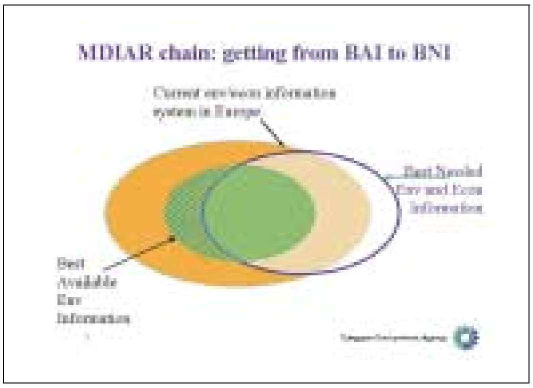
State of play of EEA work on soil erosion indicators

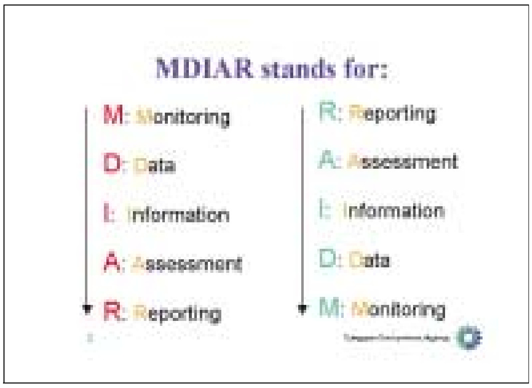
Anna Rita Gentile
Project Manager for soil and contaminated sites
European Environment Agency

This first presentation provided some background information and focused on the objectives of the EEA work programme on soil and a description of the European soil monitoring and assessment framework. The state-of-play of EEA work on indicators for soil erosion and EEA expectations from the workshop were also discussed.

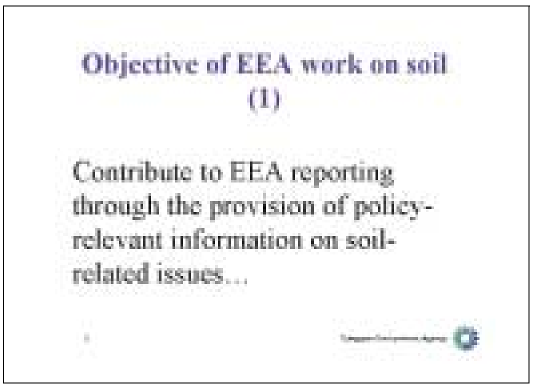
In particular, the EEA organised the workshop with the aim to take stock of the work done, get expert advice on how to proceed with the work on soil erosion, connect with other relevant initiatives on soil erosion at the European and national level and help to define the work plan of the new European Topic Centre on Terrestrial Environment.

A selection of overheads is included below.





So far, the EEA has collected information based on the 'best available' data. However, this approach, although allowing for the provision of timely information, has shown some limitations. For example, it may not help rationalise ongoing data collection and monitoring activities at the national and European levels, possibly covering subjects that are not needed, while resources should be better employed to fill data gaps in other priority areas (BTG, 1998). In order to help streamline monitoring, assessment and reporting activities, a broader approach is required. In the long term, the objective is to focus on the 'best needed' data. This shift should be obtained by building stronger links to EU policy needs, by focusing on the assessment of the environmental impacts of soil degradation and by undertaking a more detailed analysis in hot-spot areas.



How is the work organised?

Conceptual and operational framework for the assessment and the monitoring of soil in Europe based on the general EEA "monitoring to reporting framework"

European framework for the assessment and the monitoring of soil (1)

The framework is both:

- Conceptual (DPSIR, MF/MI)
- Operative

European framework for the assessment and the monitoring of soil (2)

based on:

- EEA 'from monitoring to reporting framework' (MDIAR)
- political framework (definition of priority issues; based on needs)
- Identification of relevant indicators through use of analytical tools (e.g. DPSIR,MF/MI)

Implementation

- European Topic Centre on Soil (1996-1999)
- Working groups on soil indicators (2000)
- European Topic Centre on Terrestrial Environment (2001-2003)

European Topic Centre on Soil

- Contribution to EEA reporting
- Identification and development of selected policy-relevant indicators
- Proposal for an assessment and monitoring framework
- Implementation of an assessment framework for contaminated sites

Objectives of current work

- Fill the gap between ETC/S and ETC/TE
- Proceed on the work on soil contamination (indicators + EIONET workshop)
- Review the work on soil erosion and soil sealing (2 expert workshops)
- Review the work on hot spots (EIONET consultation)
- Provide input to the work of new ETC/TE

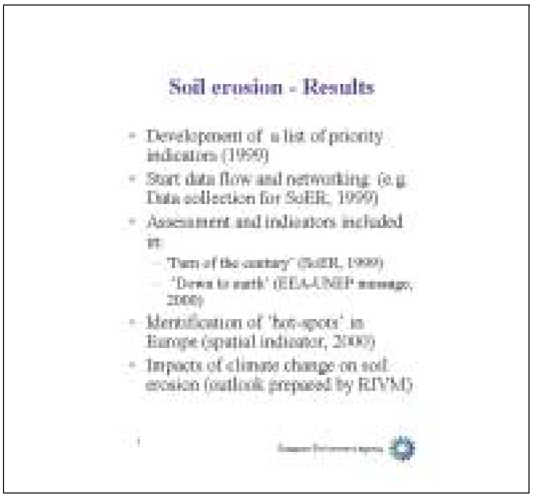
Further work (ETC/TE)

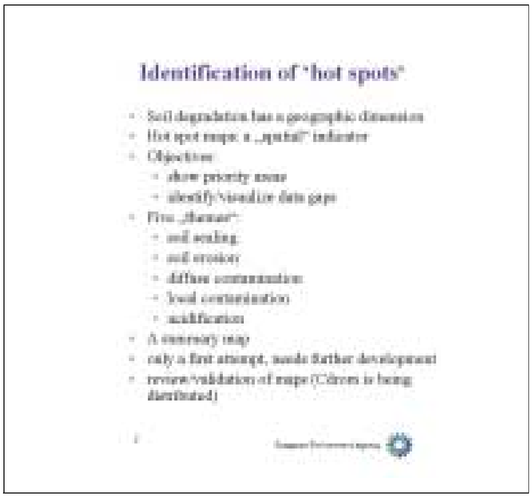
- Further development of indicators on soil
- Extend the work to new EEA countries (Enlargement - Central and Eastern Europe)
- Main outputs:
  - Contribution to EEA „big" reports
  - Assessment of soil degradation in Europe (update of current assessment/soil message)

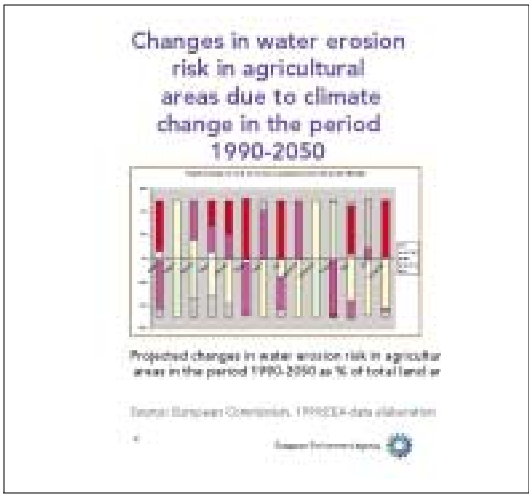
Next EEA "big" reports

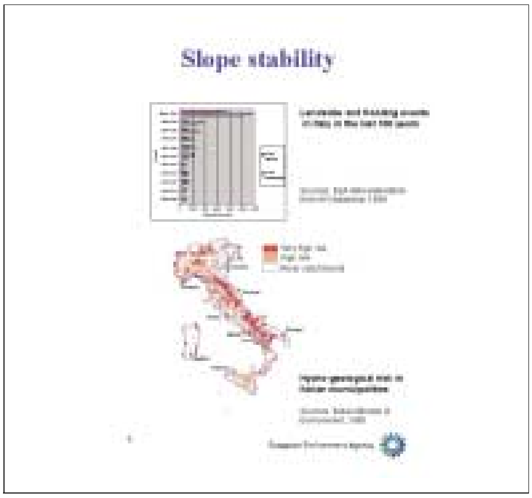
- **May 2001**: for the EU reporting cycle on integration for Göteborg meeting (June 2001) → Environmental Signals 2001 with extended version on sectors
- **April 2002**: for UNCED (Rio+10, Autumn 2002) → Up-dates of the 2001 indicator-fact sheets, plus essays on specific issues
- **September 2002**: Kiev Meeting (Winter 2003) → Environmental Signals 2002 for UNECE/EPE with extended geographical coverage (pan-Europe)
- **2004**: for 6th EAP review? → the 5-year State & Outlook report

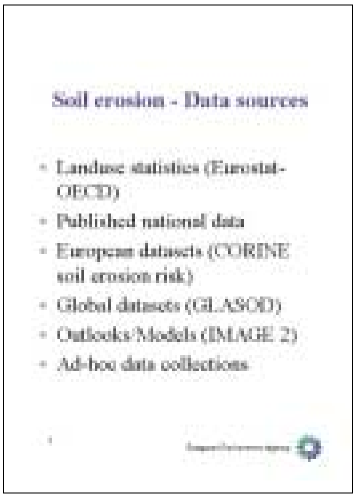
The presentation continued with the illustration of the results achieved in the development of the work on soil erosion (see also Düwel and Utermann's presentation later in this annex). Finally, the EEA needs in terms of data and expertise were discussed. These issues are described by a selection of overheads below.

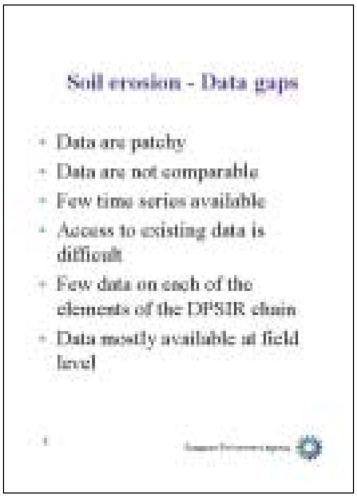












Soil erosion hot-spot map for Europe

David Favis-Mortlock
School of Geography
Queen's University Belfast

Background

The map of soil erosion hot spots for Europe (Figure 4.3 in main text: EEA, 2000; EEA, 2001) aims to identify problem areas for soil erosion by water and wind. It is based upon published observations and measurements of erosion in the field, and is a development of a map which was previously produced for the EEA (Favis-Mortlock and Boardman, 1999). An empirical approach was adopted in preference to one based upon estimates from erosion models — such as that of Corine (1992) — since current models have difficulty in dealing with erosion's spatial and temporal variability (Boardman and Favis-Mortlock, 1998. This is particularly true for estimates of erosion over large areas, such as Europe.

However, problems of over-generalisation (Boardman, 1998) can also beset empirically based studies of erosion rates over large areas (e.g. Pimentel et al., 1995). For this reason, an attempt has been made here to indicate erosion at a hierarchy of scales (Table 1). The two coarser levels of the hierarchy are purely qualitative, whereas the finest ('location') level is associated with locally measured data for erosion rates. Its empirical basis means that areas and rates on this map refer to actual erosion (i.e. erosion under present land use and climate) rather than potential (i.e. hypothetical) erosion. This is a clear advantage for the formulation of soil conservation policy.

However, relatively little reliable measured data on soil erosion exist. This is the principal disadvantage of the approach used for this map. It is probably for this reason that a majority of published maps of erosion at the national scale are partially or wholly based upon model results. This scarcity of measured data appears to be the case for both western and eastern Europe. For example, a map of erosion in Romania (Mircea, 1983) makes use of both model results and measurements (Ion Ionita, personal communication, 2000); however, to disentangle these is far from simple.

The hierarchical approach used for this map also renders it different from other empirically based large-area erosion maps such as Glasod (Oldeman et al., 1991) and Map 7.3 ('Water erosion of soils in Europe') in *Europe's environment: The Dobríš assessment* (EEA, 1995). Both these maps identify areas

Spatial units used to construct the hot-spot map Table A3.1

Unit	Description	Source of information
Zones	Broad zones where the nature of erosion is, in general, similar	Expert opinion of the map compilers
Hot-spot areas	'Hot-spot' areas, mostly within these zones	Opinion of several experts via the map of De Ploey (1989) plus that of the map compilers
Locations	Locations, mostly within these hot-spot areas, for which there are measurements of erosion rates	Published literature (see References)

with a subjectively similar severity of erosion, irrespective of the conditions which produced this erosion, and irrespective of its wider impacts. By contrast, the approach used here allows:

- hot-spot areas to be grouped or differentiated according to which zone(s) they are in, i.e. on the differences or similarities in erosional conditions;
- quantification of erosion rates for points within the hot-spot area (where data permit).

Thus the reader can pick out broad similarities and differences — in terms of both causes and impacts — for those regions of Europe which suffer from an erosion problem; and can link these broad zones with measured rates. With knowledge of the ways in which affected regions resemble and differ from each other, future European soil conservation strategies can be more efficiently targeted. For example, selection of appropriate sites for remediation might involve criteria such as:

- is currently active (i.e. does not result mainly from erosion in the past);
- gives rise to off-site effects which are significant in the short term, such as flooding and water quality problems;
- is likely (in the longer term) to experience a significant on-site drop in agricultural productivity as a result of erosion.

Data quality issues

The spatial and temporal occurrence of erosion

Erosion is patchy in both space and time (cf. Figure 1). Loss of soil can be highly variable even in areas of severe erosion. For water erosion for example, the vagaries of topography concentrate erosive flows so that severe erosion in one field can be found side by side with almost untouched areas. Similarly, several years can pass between major erosion events (water or wind) even in erosion-prone regions. Long time series of measurements of erosion are therefore required to adequately estimate erosion rates. Temporal distributions of erosion are highly skewed, so that calculation of long-term average values for erosion is statistically dubious (use of the median is preferable, but uncommon).

Precise delineation of erosion hot spots is therefore futile. Additionally, even within an area which is designated as a hot spot it may well be that only a minority of fields will show obvious erosion at any time. Also since almost all erosion monitoring studies operate for only a relatively short period, any assessment of erosion rates for these hot-spot areas is fraught with uncertainty.

Spatial considerations regarding data collection

To a large extent (8), erosion is independent of national boundaries. However, field measurements of soil erosion may be obtained during a study which is funded or sponsored by a particular country, or by a scientist who works within well-defined regional boundaries. The emphasis placed upon erosion studies also varies markedly from country to country. As a result, the availability of data on European erosion varies strongly from region to region. There is thus some risk both of spurious 'hot spots' being generated simply by the presence of abundant data for an area, and also of the inverse problem: lack of data resulting in under-emphasis of an area's erosion problems. Any Europe-wide study of erosion must therefore exercise discrimination in the face of possibly artefactual positive or negative hot spots.

Techniques of data collection

Techniques of data collection are an issue with respect to the erosion rates quoted here. Even for the same location, erosion rates obtained by different methods (9) are likely to vary. This study has — unavoidably — had to draw upon data for erosion rates which were obtained by a range of methods. While in some cases it is possible to reconcile such methodological variations, in general the result is to increase the uncertainty associated with rates assigned to mapped hot spots. Soil loss rates calculated from plot-sized areas (the most common among the studies reported here) can be up to one or two orders of magnitude higher than sediment yields calculated from catchments. However, results from small areas such as plots do not include the contribution which talweg (valley-bottom) gullying can make to total erosion: this may be over 40 % in north Europe and over 80 % in south Europe (Poesen et al., 1996a). Due to erosion's temporal variability, soil loss rates from single events are generally not reported here,

(8) Except where trans-border land use is strongly influenced by differing national policies.
(9) For example, by field survey of rill depths, collection of sediment lost from a plot, or aerial photography.

except where measured data are scarce, e.g. eastern Europe.

Other issues regarding data

Most of the source publications for this map are in English. This is a definite limitation, although ameliorated to some extent by the use of English publications which summarise earlier non-English work.

The design and use of this map

As described previously, this map shows erosion on a three-level spatial hierarchy. For proper use of this map it is vital to remember the following caveats:

- hot-spot boundaries are rather arbitrary;
- even within a hot-spot area, erosion occurs patchily;
- there is a considerable variability and uncertainty associated with all cited rates of erosion;
- expert judgment has played a major role in the methodology used here. This is unavoidable, given the complex nature of erosion's occurrence and the limitations of currently available data. Thus it is important to note that, just because erosion is not indicated at a particular location on this map, this *does not imply that no erosion occurs there*. For example, erosion occurs regularly in Denmark (Hasholt, 1988, 1998) but does not appear to be a major problem there.

Boundaries for water and wind erosion hot-spot areas in western and southern Europe are in most cases modified from De Ploey (1989), while others have been deduced from the publications cited. Those for eastern Europe are also derived from individual publications, interpolated as necessary.

Interpretation of the map

General

There are three broad zones of erosion in pan-Europe: a southern zone, a northern Loess zone, and an eastern zone ([10]). In the southern zone, severe water erosion results from intense seasonal rainfall. This is often associated with overgrazing or a move away from traditional crops. Erosion here may be of considerable age. The principal impact is on-site: soil productivity decreases as a result of thinning. The northern zone has moderate rates of water erosion. This mostly results from less intense rainfalls falling on saturated, easily erodible soils. There is also local wind erosion of light soils. Impacts here are mainly off-site, as agricultural chemicals from the north's more intensive farming systems are moved into water bodies along with eroded sediment. Partially overlapping these two zones is the eastern zone, where former large state-controlled farms produced considerable erosion problems. Eroded sediments here may also be contaminated from former industrial operations. Other, relatively minor, areas of erosion occur outside these zones. Within all three zones, there are 'hot-spot areas' where erosion is more serious. The coverage of reliable measurements of erosion is very patchy, and to an extent reflects the activities of particular workers rather than the severity of the problem.

Rates of erosion

As noted in the methodology, regional rates inferred from this map must be very tentative. None the less there is some indication that average rates of soil loss are higher in southern and eastern Europe than in the north-west. This is conventional wisdom; however, rates for the south appear to be generally much lower than (for example) the 27 t $ha^{-1}yr^{-1}$ for the whole of Spain which was quoted in *Europe's environment: The Dobríš assessment* (EEA, 1995, p. 155).

Erosion's impacts across Europe Table A3.2

Zone	Short term (i.e. decades)	Long term (i.e. centuries)
North-west Europe	Off-site: water pollution from agricultural chemicals	On-site: loss of soil productivity
Southern Europe	On-site: mainly loss of soil productivity	On-site: loss of soil productivity
Eastern Europe	On-site: loss of soil productivity Off-site: water pollution from former industrial waste, as well as agricultural chemicals	On-site: loss of soil productivity

(10) Iceland was not included in the original study.

Impacts of erosion
The impacts of erosion are not a simple function of erosion rate. These impacts can be categorised as 'on-site' and 'off-site'. Off-site problems of water pollution from agricultural chemicals can result even from very low rates of soil loss (Harrod, 1994).

Erosion's impacts across Europe can be very generally summarised as described in Table 2.

Policy implications
EU recognition of the impacts of soil erosion has to date largely been confined to the south of Europe e.g. the Corine ([11]) and Medalus ([12]) studies (Stanners and Bourdeau, 1995). This is principally due to a focus only on on-site effects. However, if off-site impacts are also considered, then there is a need for greater EU acknowledgement of erosion problems elsewhere in Europe. At a national level, there has been some progress in this direction.

Along with need for EU recognition of the Europe-wide nature of erosion's impacts is a need for coordinated scientific endeavour to tackle it. An immediate need is for an improved European map of erosion problems. As far as is possible, this should be based (for the reasons given above) upon measured data.

Future work
Soil erosion is a serious problem in Europe, yet the availability of measured data is very poor. Thus, effort should be put into:

- the establishment of appropriate monitoring schemes to assess current rates of erosion (cf. Poesen et al., 1996b; Burt, 1994);
- the creation of schemes to bring together existing measured data, including information regarding collection methodologies;
- the production of an improved map based upon these data.

There has some been some recent progress on the second point. The establishment of international groups such as the IGBP-GCTE soil erosion network (Ingram et al., 1996) and EU COST Action 623 'Soil erosion and global change' (see http://www.cost623.leeds.ac.uk/cost623/) has enabled erosion researchers to begin to establish the dialogues which will eventually lead to a better-harmonised and more freely available pool of data on erosion. A first product is GCTE (1997).

Qualitative small-scale soil degradation assessment databases — The Glasod map

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In this paper a standardised and internationally endorsed methodology for qualitative — and mostly small-scale — assessment of soil degradation will be described. The methodology was first used for the global assessment of the current status of human-induced soil degradation (Glasod) in 1990 and subsequently in a slightly modified format for other assessments (see Figures 1 and 4.6 in the main text).

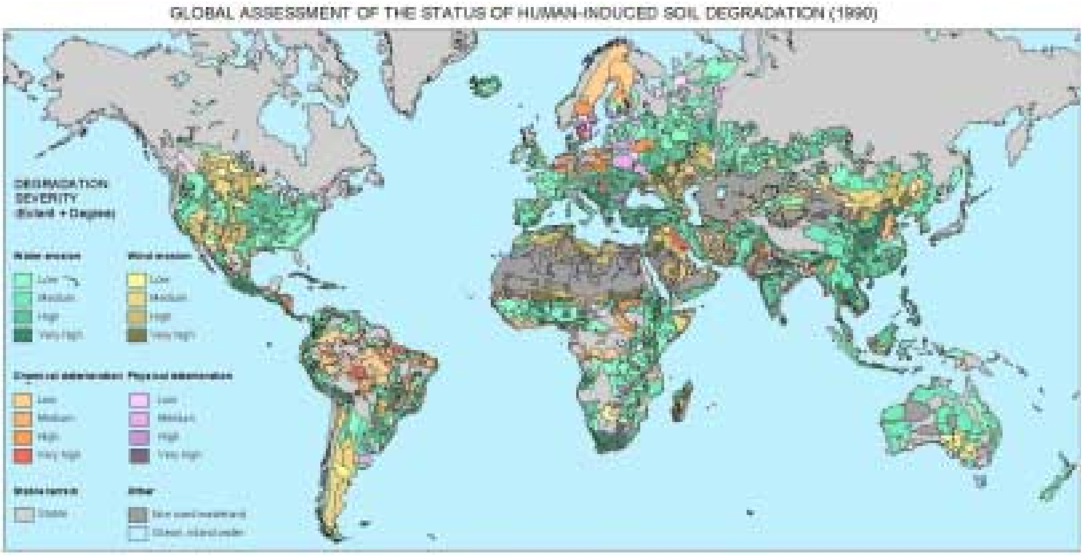
The Glasod map (1990)
Introduction
Recognising the need to obtain a better overview of the geographical distribution and the severity of human-induced soil degradation, the United Nations environment programme (UNEP) commissioned the International Soil Reference and Information Centre (ISRIC) in 1988 to coordinate a worldwide programme in cooperation with a large number of soil scientists throughout the world to produce, on the basis of incomplete existing knowledge, a scientifically credible global assessment of the status of human-induced soil degradation within the shortest possible time frame.

Activities included:

- the preparation of general guidelines;
- subcontracting correlators in 21 regions to prepare, in close cooperation with national soil scientists, regional soil degradation status maps;
- correlation of the regional maps into a world map of soil degradation; and
- publishing 5 000 copies of the Glasod map.

(11) See Corine (1992).
(12) For example, Mairota et al. (1997).

The Glasod map Figure A3.2



Publication
The Glasod map was officially released at the 14th International Congress of Soil Science in Kyoto (August 1990). Subsequently the map was digitised and a soil degradation database was created. Thematic maps, derived from the Glasod database, were prepared by UNEP / GRID for inclusion in the World Atlas of Desertification. The Glasod map and complementary statistics have been used and cited in numerous scientific journals and policy documents of the World Resources Institute, the International Food Policy Research Institute, the Food and Agriculture Organisation of the United Nations, the United Nations environment programme, and many others.

Scope of the assessment
The assessment was made on a small scale (1:10 million average) and has a global coverage. It was based on expert judgments from national institutions or individual scientists and addressed the current status of degradation rather than risk. More than 20 possible soil degradation types were considered.

Strength and impact of Glasod
Glasod was the first comprehensive soil degradation overview to be published on a global scale in a relatively rapid (three years) and cheap (around USD 300 000) manner. It raised awareness on soil degradation problems and created wide interest among scientists and the general public. It provided an overview for national and regional planning and enabled identification of 'hot spots' for further study. From the received feedback it was clear that Glasod responded to a strong apparent need for a global overview. Multiple requests were received for national breakdowns or new assessments at country level. Glasod also showed the need for an assessment of measures to control degradation, i.e. showing some 'good news'. At the same time, the need for an additional more objective / qualitative approach (especially for more detailed scales) as well as the need for data validation and updating also became obvious.

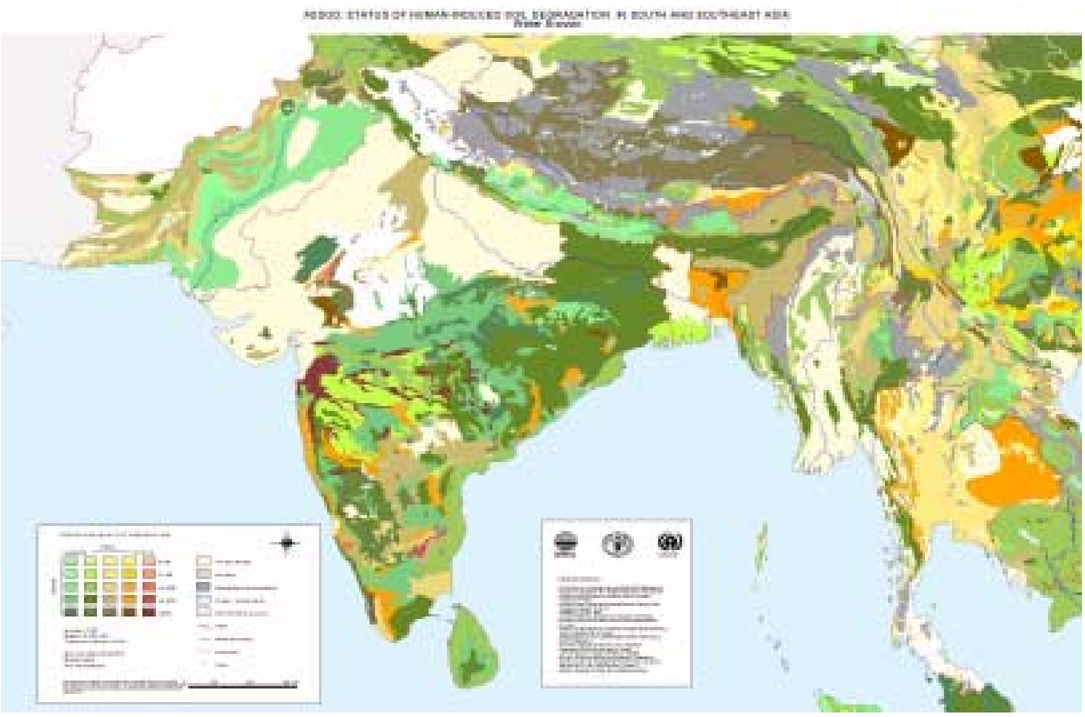
Who are the users?
Glasod has a wide range of potential and proven users, such as:

- international policy-makers and planners (e.g. UNEP, FAO, WRI),
- national policy-makers and planners,
- international conventions and programmes (CCD, Kyoto Protocol, UN-CPB, IGBP),
- researchers at national and international level (NARIs, CGIAR, universities),
- education professionals (teachers, professors, etc.) and students,
- environmental organisations (general public awareness).

Limitations and problems
As a 'quick and dirty' methodology, Glasod (and its derived successors) also has several limitations that need to be taken into consideration. Some of these limitations were overcome in subsequent assessments.

- The small scale makes Glasod less appropriate for national breakdowns;
- The expert judgment approach can lead to subjectivity;

Figure A3.3 **The ASSOD map for south and south-east Asia**



- Cartographic restrictions at the time of publication limited the number of attributes on the map;
- The representation of the map items causes a visual exaggeration: each polygon which is not 100 % stable shows a degradation colour, even if only 1 to 5 % of the polygon is actually affected;
- Extent was expressed in classes rather than percentages;
- The map has a complex legend: extent and degree (severity) are aggregated for four major degradation types (water and wind erosion, physical and chemical deterioration);
- Only the 'dominant' main type of degradation is shown in colour;
- Degradation sub-types are only shown by codes printed in each polygon;
- Glasod presented only 'bad news' (doom scenario).

Follow-up of Glasod / derived initiatives

ASSOD (1997): Assessment of the status of human-induced soil degradation in south and south-east Asia

In 1993 an expert consultation of the FAO-supported Asian network on problem soils recommended the preparation of a south and south-east Asian soil degradation status assessment (ASSOD) on a scale of 1:5 million. This study was commissioned by UNEP to ISRIC and carried out in close cooperation with FAO and national institutions in 16 countries. The project used a modified Glasod methodology, with more emphasis on the impact of degradation on productivity and on the rate of degradation and used a 1:5 million physiographic base map following criteria outlined in the global and national soil and terrain digital databases methodology (SOTER, Van Engelen and Wen, 1995). The ASSOD project finished in 1997. All information was stored in a digital database, which is linked to physiographic units through a GIS. This enables a more flexible production of outputs: thematic or regional maps, no restrictions on number of attributes per polygon, less complex legend.

Soveur (2000): Mapping of soil and terrain vulnerability in central and eastern Europe

In 1997 FAO and ISRIC initiated the project on 'Mapping of soil and terrain vulnerability in central and eastern Europe' (Soveur). There were three main activities in the project:

- development of a soils and terrain digital database, at scale of 1:2.5 million, for the countries under consideration, using the uniform methodology of SOTER;
- assessment of the status of soil degradation, with special focus on diffuse pollution, according to a modified Glasod methodology;
- providing the soil geographic and attribute data for an assessment of the vulnerability of soils to selected categories of pollutants.

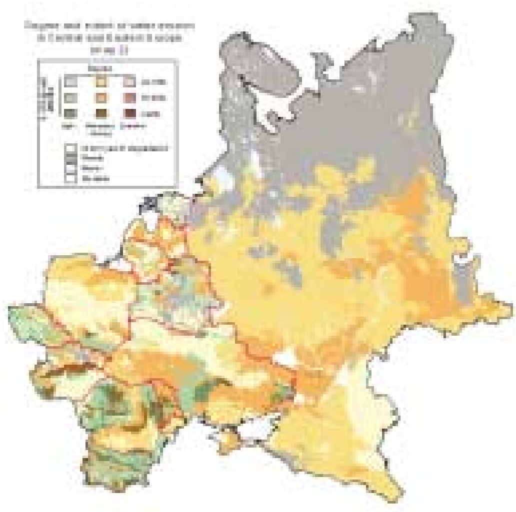
Implementation
The Soveur project has been implemented in close collaboration with specialist institutes from 13 countries: Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Belarus, Ukraine, Moldova, and (the European part of) the Russian Federation. Initial results were presented and discussed during an international workshop in October 1999. Thereafter, the assessment was finalised. In December 2000 the databases and technical documentation were released on a CD-ROM in the FAO's *Land and water media series* (No10). This CD-ROM contains information in the form of databases, maps and reports on soil, on the soil degradation status and gives a soil vulnerability assessment for 11 metals in 13 countries in central and eastern Europe.

Beneficiaries
Target beneficiaries are ministries and planning bodies in the collaborating countries who can use the definitive databases and derived maps for policy formulation at the national level, for instance by identifying areas considered most at risk. The project further contributes to strengthening the capabilities of national 'environmental' organisations in central and eastern Europe, and it can play a significant role in enhancing scientific cooperation within Europe on issues of soil degradation and pollution. Further, it is an integral part of a global programme on the development of a world soils and terrain information system, a world assessment of the status and risk of soil degradation, and studies of the potential productivity assessment of the land (cf.. UNCED, 1993).

General degradation guidelines
Based on the experiences with Glasod (Figure 1), ASSOD (Figure 2) and Soveur (Figure 3), guidelines for the qualitative assessment of soil degradation have been developed that are generally applicable, scale-independent and offer links to other standardised methodologies (SOTER, WOCAT).

WOCAT: since 1992, ongoing
In response to the 'bad news' of Glasod a new project was initiated to investigate what measures are being taken to combat degradation. A consortium of various national and international organisations, institutions and individuals, guided by a management board is undertaking an

The Soveur map for central and eastern Europe Figure A3.4



inventory of soil and water conservation (SWC) worldwide. Through the collection, analysis and dissemination of existing experiences, it is expected that mistakes and duplication of efforts can be minimised. WOCAT is using a set of comprehensive questionnaires on technologies, approaches and mapping respectively that serves as a framework for the evaluation of soil and water conservation and a methodology for data collection at the same time. This information is stored in an MS-ACCESS database with a user-friendly menu for storage, analysis and output of data. Regional and national training workshops to assist in the data collection, analysis and output production have been conducted in over 30 countries, mainly in Africa, Asia and Latin America, and further SWC evaluation programmes are ongoing in most of these.

Methodological details
Mapping
As a base map for the assessments in principle any map with uniquely delineated polygons can be used, but a (SOTER) polygon map based on physiography/soils is recommended. For the Glasod map this was not yet the case and an IGN world map on a 1:10 million average scale, Mercator projection with loosely defined physiographic units was used. The ASSOD project used a SOTER physiographic map (1:5 million), while in the Soveur project a SOTER soil and terrain map on a 1:2.5 million scale served as a basis for the assessment. For WOCAT several base maps have been used: the Glasod map for the first exercises in eastern and southern Africa (1995), the ASSOD map in Thailand and China (Fujian province), SOTER maps

Differences between various degradation assessments

Table A3.3 **Comparisons of degradation assessments**

	Glasod	ASSOD	Soveur	General
Coverage	Global	South and south-east Asia (17 countries)	Central and eastern Europe (13 countries)	General
Scale	1:10 million (average)	1:5	1:2.5	Variable
Base map	Units loosely defined (physiography, land use, etc	Physiography, according to standard SOTER methodology	Physiography and soils according to standard SOTER methodology	SOTER maps or other as appropriate
Status assessment	Degree of degradation + extent classes (severity)	Impact on productivity (for three levels of management) + extent percentages	Degree and impact + extent percentages	Degree and impact + extent percentages for major land use types
Rate of degradation	Limited data	More importance	As for ASSOD	As for ASSOD
Conservation	No conservation data	Some conservation data	No conservation data	No conservation data, but close link with WOCAT
Detail	Data not on country basis	Data available per country	Data available per country	Depends on scale
Cartographic possibilities	Maximum two types per map unit	More degradation types defined, no restrictions for number of types per map unit	As for ASSOD, but special emphasis on pollution	As for ASSOD
End product	One map showing four main types with severity	Variety of thematic maps with degree and extent shown separately	As for ASSOD	As for ASSOD
Database/GIS	Digital information derived from conventional map	Data stored in database and GIS before map production	As for ASSOD	As for ASSOD
Source	Individual experts	National institutions	National institutions	Regional, national or local institutions

(1:5 million) and larger in other places and more recently also administrative maps with districts, provinces, etc. serving as polygons. The latter has the advantage that many socioeconomic data are more readily available for administrative units. Additional soil and terrain information, as well as other bio-physical layers such as land cover and land use, can then be overlaid later on.

Data collection (degradation)
For the degradation assessment the following data are collected:

- major land use type ([13])([14]) ([15]),
- type of degradation (four main types, about 20 sub-types),
- extent of degradation: affected percentage of (land use area within) polygon,
- degree of degradation,
- impact of degradation,
- rate of degradation,
- causative factors.

In addition to these, WOCAT collects the following information on SWC practices:

- name of the technology,
- SWC category,
- extent,
- effectiveness,
- trend in effectiveness,
- period of implementation,
- reference to the corresponding technology questionnaire (describing the same technology in much higher detail),
- productivity trend,
- reason for positive or negative productivity trend.

(13) * not in GLASOD.
(14) * not in ASSOD.
(15) * not in SOVEUR .

Soveur assessment: degree and relative extent of water erosion — Table A3.4

Degree and relative extent of water erosion					
Wt	DEGREE	(% of country area)			
COUNTRY	Light	Moderate	Strong	Extreme	Total
Belarus	1.8 %	6.7 %	0.0 %	0.0 %	8.5 %
Bulgaria	21.0 %	16.6 %	2.1 %	0.0 %	39.8 %
Czech	8.9 %	5.7 %	0.5 %	0.0 %	15.1 %
Estonia	0.8 %	2.4 %	0.0 %	0.0 %	3.2 %
Hungary	2.6 %	8.5 %	10.1 %	0.0 %	21.2 %
Latvia	0.0 %	11.3 %	0.1 %	0.0 %	11.4 %
Lithuania	3.0 %	7.1 %	0.3 %	0.0 %	10.4 %
Moldova	0.3 %	6.9 %	27.6 %	0.0 %	34.8 %
Poland	0.0 %	6.4 %	0.4 %	0.0 %	6.7 %
Romania	11.0 %	7.2 %	0.0 %	0.0 %	18.2 %
Russia	0.0 %	0.0 %	4.2 %	0.0 %	4.2 %
Slovakia	0.5 %	0.8 %	4.1 %	0.0 %	5.4 %
Ukraine	2.9 %	12.1 %	0.4 %	0.0 %	15.4 %
Wd	DEGREE	(% of country area)			
COUNTRY	Light	Moderate	Strong	Extreme	Total
Belarus	0.1 %	0.0 %	0.0 %	0.0 %	0.2 %
Moldova	0.3 %	0.4 %	0.3 %	0.1 %	1.0 %
Poland	0.0 %	2.2 %	0.3 %	0.0 %	2.5 %
Romania	0.2 %	1.7 %	6.7 %	0.0 %	8.6 %
Slovakia	0.3 %	2.4 %	4.1 %	0.0 %	6.8 %
Ukraine	0.0 %	0.8 %	1.8 %	0.0 %	2.5 %
Wo	DEGREE	(% of country area)			
COUNTRY	Light	Moderate	Strong	Extreme	Total
Lithuania	0.0 %	0.4 %	0.0 %	0.0 %	0.4 %
Romania	2.5 %	1.5 %	0.0 %	0.0 %	4.0 %
Ukraine	0.2 %	1.3 %	0.9 %	0.0 %	2.5 %

Note: Wt = water erosion (terrain deformation)
Wd = water erosion (loss of topsoil)
Wo = water erosion (off-site effects)

Results of the assessment

Output production (degradation)

Whereas for Glasod, due to conventional preparation of the map, only a hard copy world map was produced (see Figure 1), the ASSOD and Soveur data can be presented in a much more flexible way: various digital and hard copy thematic maps (Figures 2 and 3) and / or regional selections; tables (Table 2) and graphs on area coverage for all or selected types, degree of degradation, impact, rate, etc.

Future developments?

- More regional and national qualitative assessments
- More specific and quantitative assessments
- Glasod revisited (new global assessment)
- Links to action plans for remediation

Indicators of soil erosion at the ETC/Soil

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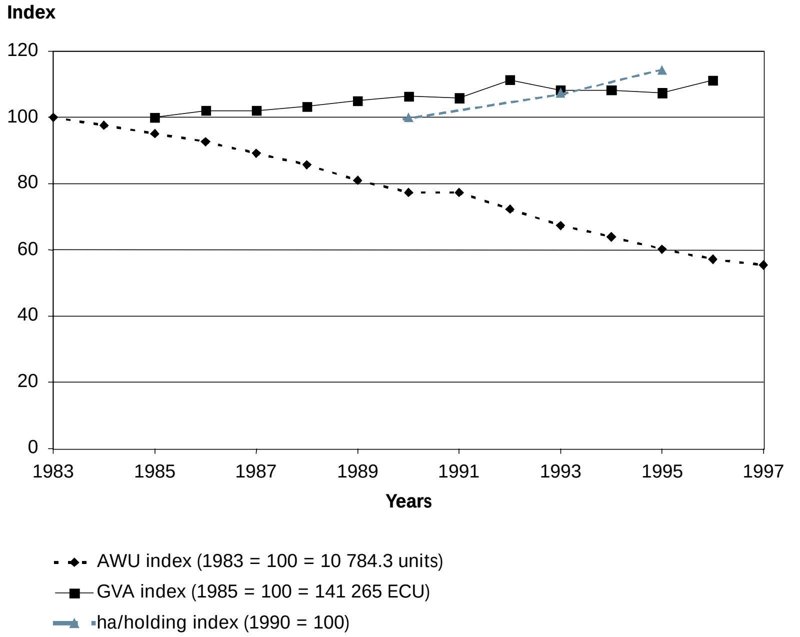
Introduction

The European Environment Agency's (EEA) main mission is to support sustainable development through the provision of relevant, reliable, targeted and timely information to policy-makers and the general public. For this purpose the EEA is establishing a monitoring and reporting system based on indicators. In the period

Figure A3.5

Intensification of agricultural productivity as a driving force (pressure) indicator — Intensification of agricultural productivity measured in terms of annual work units (AWUs) as compared to gross value added (GVA), EU-15, 1983–97

Source: Agricultural statistics (Eurostat in report of DG VI); Indicator fact sheet AG6 — Agricultural environmental efficiency; New Chronos: Data set name: Number and area of agricultural holdings including mountains



Note: Additional information about intensification can be derived from the increase of total agricultural area per agricultural holding.

1996–99 the European Topic Centre on Soil (ETC/S) supported the EEA work programme providing information and contributing to EEA reporting on environmental issues related to soil.

The main causes of soil loss and deterioration in Europe are considered to be soil sealing, soil erosion and local and diffuse contamination (EEA, 1999a). The following paper deals with the physical soil degradation patterns of soil erosion and soil sealing.

The indicator concept

In 1993, the OECD presented a core set of indicators for environmental performance reviews (OECD, 1993). Indicators were defined as 'a parameter, or a value derived from parameters, which points to / provides information about / describes the state of a phenomenon / environment / area with a significance extending beyond that directly associated with a parameter value' (OECD, 1993).

The basic OECD criteria for indicator selection have been applied by the EEA. The criteria can be summarised under three headings: policy relevance and utility for users, analytical soundness, and measurability (see Part I, Section 2.1 of the main text for a full list). When developing indicators these criteria should be taken into account.

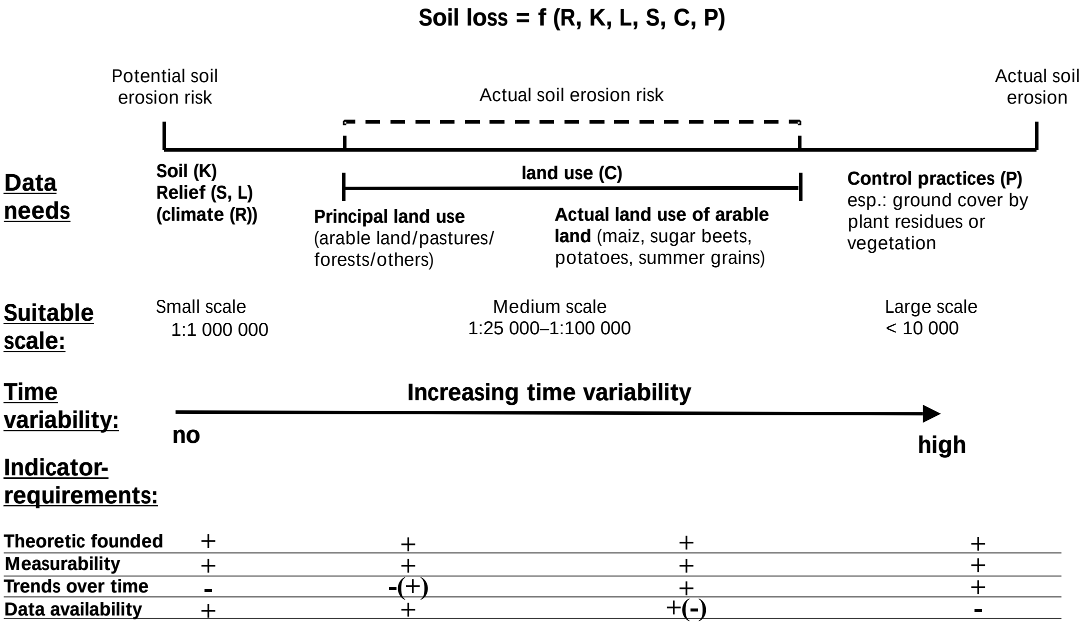
Different human activities (driving forces) exert pressures on the environment and change its quality (state). The change of environmental conditions has impacts on other environmental issues. Society responds to the changes and impacts through environmental, general economic and sectoral policies. Taking this chain of causes and effects into account the EEA has developed the DPSIR framework (driving forces, pressures, state, impact, responses) (cf. Gentile, 1999a). The development of relevant indicators for reporting makes use of this framework.

DPSIR applied to soil erosion

In a first attempt the DPSIR assessment framework has been applied to the soil degradation patterns soil erosion and soil sealing. The aim was to develop short-term indicators for actual reporting as well as a long-term approach for a periodical reporting system.

Figure 2.4 in the main text presents the DPSIR assessment framework applied to soil erosion. The intensification of agriculture increases the risk of insufficiently sustainable land use practices. Unsustainable land use practices in themselves enhance the risk of soil degradation, e.g. physical soil deterioration.

Indicator-based approach for monitoring soil erosion Figure A3.6



Possible driving forces and / or pressure indicators should aim to describe the intensification of agriculture and its increase. Figure 1 gives an example: the gross value added (GVA) reflects the efficiency of the agricultural production. The data on working hours, expressed as annual working units (AWUs) give information on the actual volume of labour devoted to farming.

An increasing GVA, produced by a decreasing number of people employed in the agricultural sector, shows the trend of intensification of the agricultural production. This trend is confirmed by the trend towards larger units of agricultural holdings. The indicator has to be seen in combination with other indicators describing the agricultural section, e.g. the trends of fertiliser and pesticide uses.

Short-term information about the current state of soil erosion is given in the report *Environment in the European Union at the turn of the century* (EEA, 1999a). The soil chapter of this report contains two tables (Tables 3.6.2 and 3.6.3) dealing with the area affected by water erosion and the total amounts of soil losses due to water erosion. The data are derived from questionnaires from statistical institutions (e.g. Eurostat) and the EEA.

Since in most European countries there are no data available on soil erosion, these tables are rather fragmentary — they only contain information from Germany, Spain, Austria and Iceland.

An attempt at a data update by the ETC / S in 1999 resulted only in few additional data and in some cases (Germany) the data previously available were withdrawn.

A long-term approach should focus on the abovementioned basic criteria for indicator selection. In order to cover all European countries, a unique methodology has to be implemented. The methodology has to enable a periodical monitoring to identify trends and effects of response measures.

Soil losses due to water erosion are a function of climate, soil, relief, vegetation and protection measures (cf. for example the universal soil loss equation (USLE) (Wischmeier and Smith, 1978).

One problem is the high variability of the data needed, both in terms of scale and time. But if it were possible to make available data related to control practices, e.g. mulching or other measures increasing the ground cover (by vegetation, plant residues or others), this would be an indicator for soil erosion that is theory based, measurable and able to show trends over time. Figure 2 summarises the proposed approach.

Following this approach the first step should be to identify areas with a high potential of soil erosion risk with regard to soil erodibility and relief. The second step is to focus on areas where there is a high risk of actual soil erosion taking into account the principal form of land use (e.g. arable land).

Table A3.5 **Calculated annual gross erosion rates on the basis of the sediment delivery ratio (selected data: minimum and maximum annual gross erosion per country)**

Source: Data collection request, 1999 (EEA-ETC/S).

	River name	Sampling periods	CA (catchment area) (km^2)	Suspended solids (t/a)	SDR	Annual sediment loads/CA (t/ha*a)	Annual gross erosion/CA (t/ha*a)
Finland	Kokemäen-joki	91–96	27 046	91 463	0.03	0.03	1.1
	Iijoki	91–96	14 191	17 192	0.04	0.01	0.3
FYROM (Macedonia)	Vardar	71–86	21 350	2 207 520	0.03	1.0	31.9
	Sataeska	78–90	351	32 483	0.1	1.0	9.3
Germany	Oder	92/97	112 950	441 000	0.02	0.04	2.2
	Donau	92/97	77 053	2 557 000	0.02	0.3	16.1

As a third step the ground cover should be monitored for example, allowing an assessment of the state of soil erosion by water. In order to be able to translate the monitored ground cover data into actual soil losses a fourth step is needed, namely the monitoring of real actual soil erosion losses in selected test areas.

Especially with regard to agricultural land this approach means: the higher the share of crops which increase the risk of soil erosion (‘row crops’, e.g. corn, sugar beet, potatoes) of total arable land in areas with a high potential soil erosion risk, the higher the actual soil losses due to soil erosion, unless accompanying protection measures are applied.

Soil, climatic and relief conditions cannot be changed by human activities, at least not in the short term. Hence ground cover measures could be used to combat soil erosion in other forms of land use as well.

Another indicator approach towards assessing the situation of soil erosion in Europe is based on the measurement of sediment loads in rivers and streams. The idea was to use the sediment delivery ratio for these estimates. The sediment delivery ratio is the fraction of the gross erosion that is expected to be delivered to the point of drainage area under consideration (Mitchell and Bubenzer, 1980). On the basis of an equation published by Wischmeier ([16]) (1975, 1976) an attempt was made to calculate annual gross erosion rates (t/ha*a). Table 1 gives selected results (minimum and maximum calculated annual gross erosion per country). The data have been obtained through the data collection request of the ETC/S this year. Data were delivered by Finland, Macedonia and Germany.

Organised in classes of < 1 t/ha*a (none to low erosion), 1–10 t/ha*a (moderate erosion), 10–20 (high erosion) and (10)–30 t/ha*a, the results show almost none to low erosion rates in Finland, moderate (northern part) to high rates (southern part) in Germany, and up to very high erosion rates in the southern European area of Macedonia.

The present approach (which is just at a conceptual level) will have to be discussed in depth. Among other things, one has to take into account that originally the sediment delivery ratio was used to determine large-scale water pollution from agricultural land (< 1:5 000).

Nevertheless data on suspended solids give information about the impact of soil erosion on other media and should at least as an impact indicator be integrated into an environmental monitoring network.

Summary

Table 2 summarises the approaches discussed in this paper to determine state indicators, both short term and long term for the soil degradation patterns of soil erosion.

Short-term state indicators for soil erosion are presented in the soil chapter of the *Turn of the century* report published by the EEA in 1999 (EEA, 1999a). They describe the area affected by erosion and total amounts of soil losses due to erosion in selected European countries based on questionnaires and data collections by different institutions (OECD, Eurostat, EEA-ETC/S). Data are only fragmentary (only few countries available), and data reliability remains to be checked.

(16) SDR $= -0.02 + 0.385 * CA^{-0.2}$; SDR = sediment delivery ratio, CA = catchment area.

Indicator approaches for soil erosion: State of the art Table A3.6

	State indicators	Data sources	Data availability	Data reliability
Short-term approach	• Area affected by erosion • Soil losses due to erosion	• Different statistical institutions • Questionnaires and data collections	(✓)	?
Long-term approach	ground cover from vegetation and other protection measures (e.g. mulching) in areas of high potential soil erosion risk	• Map of potential soil erosion risk • Periodical monitoring by remote sensing combined with ground validations in test areas	✓ (?)	✓ (?)

To handle the soil erosion problem in the long run, a special approach is proposed, which is based on a map of potential soil erosion risk combined with periodical monitoring by means of remote sensing validated by ground monitoring in selected test areas. Especially with regard to agricultural land this approach means: the higher the share of crops which increase the risk of soil erosion ('row crops', e.g. corn, sugar beet, potatoes) of total arable land in areas with a high potential soil erosion risk, the higher the actual soil losses due to soil erosion, unless accompanying protection measures are applied.

There are data needs concerning the ground cover in areas of high erosion risk. A European-wide map of potential soil erosion risk and data of ground cover due to vegetation and other protection measures (e.g. mulching) would reveal data gaps. One way of obtaining additional data would be to cooperate with other European institutions, e.g. the Space Application Institute (JRC-SAI).

Apart from agricultural land use, ground cover is a possible indicator for other land uses potential leading to soil erosion.

GISCO databases and tools to derive driving force/pressure indicators for soil erosion

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This paper provides an overview of the GISCO databases and tools which are currently available for providing information on indicators for soil erosion in general and driving force and pressure indicators for soil erosion in particular. The paper is broken down into five sections:

- Introduction to GISCO databases and tools
- Overview of driving force / pressure indicators proposed by the EEA
- GISCO and driving force / pressure indicators
- Proposed indicator framework model
- Remarks and conclusions

Introduction to GISCO databases and tools
The geographic information system of the European Commission (GISCO) databases and tools are developed, maintained, updated and distributed by Eurostat, located in Luxembourg. GISCO is a multi-layered, multi-scale geographic reference database containing topographic and thematic layers. The system is developed so that it can be used as a practical tool for policy-makers, who are able to view the spatial component of data sets, bring in supplementary data, and carry out spatial analysis and overlay functions. There are five different scale layers: 1:25 million, 1:10 million, 1:3 million, 1:1 million, and 1:100 000, of which the 1:1 million is most common. Tools have been developed for standardised cartographic production, which can be customised for advanced spatial analysis functions. The ArcView mapping tool has a series of Avenue scripts developed for inexperienced ArcView users. The ArcInfo mapping tools represent a suite of AML programs that are suitable for use by experienced ArcInfo users

The GISCO themes that are related to soil erosion are: environment, hydrography, land resources, altimetry, administrative boundaries, infra-regional statistics, and community support frameworks.

Environment
Potential and actual soil erosion risk databases are available for southern Europe. Actual soil erosion risk maps are derived by

combining four sets of factors: soil erodibility, rain erosivity, slope angle and vegetation cover. Soil erodibility is assigned a value between 1 (low) and 3 (high), on the basis of soil physical properties. Rain erosivity is assigned a value between 1 (low) and 3 (high), based on the Fournier precipitation index and the Bagnouls-Gaussen aridity index. Slope angle is assigned a value between 1 (very gentle to flat) and 4 (very steep), on the basis of a variety of topographic sources (topographic maps, digital elevation models and satellite imagery). Vegetation cover is assigned a value of 1 (fully protected) or 2 (not fully protected) from the Corine land cover database (Figure 1). This represents a simplified universal soil loss equation (USLE) approach and results in a map at 1:3 million scale. The potential soil erosion risk is derived by excluding the vegetation cover. The actual soil erosion risk map available at GISCO is only available for Portugal, because at the time the soil erosion maps were created only the Corine land cover (LC) map of Portugal was available.

Land quality maps are also only available for southern Europe, and combine factors in a similar manner to the potential and actual soil erosion risk maps. Land quality maps combine four sets of factors: soil, climate, slopes and land improvements, on a 1:3 million scale.

Hydrography

The hydrography databases include rivers and lakes' coverages on a 1:3 million scale and catchment boundaries on a 1:3 million scale. JRC (ISPRA) is currently preparing a catchment boundaries database on a 1:1 million scale for inclusion in the GISCO databases in the near future.

Land resources

Climate data are provided from 5 308 stations in the EU (12 Member States). The two main climatic variables are precipitation (average, maximum 24-hour rainfall, number of rain days, average snowfall, number of snowfall and snow cover days) and temperature (average, maximum, minimum, absolute monthly maximum and minimum, number of frost days). Other climate attributes include relative humidity, vapour pressure, atmospheric pressure, bright sunshine, evapotranspiration, wind speed and cloud cover. There are more gaps in these records because of inconsistencies in the definitions and measurement procedures used in different countries, or because of the short or irregular periods for which stations have been maintained.

The climate interpolated database is made on 50 x 50 km grid cells covering Europe and Magreb. The monthly data have been recalculated from long-term average daily data for the period 1975–99 for the following parameters: absolute minimum temperature; average minimum temperature; absolute maximum temperature; sum of precipitation; sum of potential evaporation; and sum of global radiation.

The land cover database is derived from the Corine land cover for the year 1990, and is distributed as grids of 100 m and 250 m resolution. The minimum mapable unit for land cover is 25 ha, being based on visual interpretation of Landsat and SPOT multispectral data. There are three levels of classification, with the third level having 44 land cover classes.

The soils database (version 2) from the European Soil Bureau (JRC Ispra) is currently available at GISCO, based on FAO nomenclature and on a 1:1 million scale. Attributes include soil mapping units (SMUs), polygons of the same soil type, and soil typological units (STUs), indicating the main soil types contained in SMUs. A more recent version is held at the European Soil Bureau (JRC Ispra), with a wider European coverage, and more detailed soil physical attributes.

Altimetry

The digital elevation model is a pan-European raster coverage providing elevation heights for 1 x 1 km grid cells on a 1:3 million scale.

Administrative boundaries

The nomenclature of territorial units for statistics (NUTS) regions serve as a base map of regional boundaries covering the entire EU territory. The NUTS nomenclature subdivides the EU economic territory into six administrative levels, from country (level 0), through regional (levels 1, 2, 3) to local (levels 4, 5) level. At present, three NUTS versions (V5, V6 and V7) for three scale ranges (1 million, 3 million and 10 million) are maintained at GISCO. The NUTS coverages provide the means to spatially present agricultural statistical survey and census data from the farm structure survey and Structural Fund databases. The boundary coverages delineate the regions while the point coverages provide a label for each region. Associated tables contain basic information such as the region's name and area.

Infra-regional statistics
The degree of urbanisation is derived from population census data from 1981 and 1991 on a 1:1 million scale. The coverage has three density classes: densely populated area (contiguous set of local areas with a population density greater than 500 inhabitants per km^2, and a minimum total population of 50 000 inhabitants); intermediate area (contiguous set of local areas, not belonging to the densely populated area, with a population density greater than 100 inhabitants per km^2, and a minimum total population of 50 000 inhabitants or adjacent to a densely populated area); and thinly populated area (contiguous set of local areas belonging neither to a densely populated nor to an intermediate area).The local area corresponds to the NUTS 5 administrative units of the Member States. Changes in the degree of urbanisation can indicate trends in the degree of soil sealing.

Community support
Databases found under the community support theme provide quasi socioeconomic information on regions that receive support from the EU.

The less-favoured areas, originally created at the Directorate-General for Agriculture, are part of the Structural Funds programme, which represents areas defined as regions where economic activities, from the agricultural point of view, are difficult to pursue. The criteria, developed though consultation with the Member States, include mountainous regions, areas in danger of de-population, and areas with specific handicaps (for example, desertification, marsh lands, salinisation). The coverage is provided on a 1: 3 million scale.

The Structural Funds is made up of five data sets that indicate the areas of the EU eligible for support from Structural Funds in the following periods: 1989–93; 1994–99 (12 Member States); 1994–99 (15 Member States); 1994–99 (15 Member States, update reference year 1997); and 2000–06 (15 Member States). The coverage is provided on a 1:1 million scale.

Overview of driving force / pressure indicators proposed by the EEA
Within the DPSIR assessment framework the EEA has provided a list of driving force (D) and pressure (P) indicators for soil in general (EEA, 2000), and soil erosion in particular (EEA-ETC / S, 1999). Agricultural intensification is identified as both a driving force (for soil erosion in particular) and a pressure indicator (for soil in general) (Figures 2.2 and 2.4 in the main text). Under agricultural intensification (or the degree of agricultural land use), the following characteristics can be identified: fertiliser use and trend (P); farm size and trend (D / P); field size and trend (D / P); crop yield and trend (D / P); and stocking rate and trend (P). Forest fires and deforestation are identified as pressure indicators for soil erosion.

GISCO and driving force / pressure indicators
GISCO databases, such as NUTS and Corine land cover, can be used together with farm structure survey (FSS) data from Eurostat to derive indicators of agricultural intensification (Figure 3). Farm structure survey data include information of crop type and area, crop yields, and livestock type and number at the NUTS 2 and 3 level. NUTS 2 data are collected on a bi-annual basis and are based on representative surveys, whereas the NUTS 3 data are census information collected on a decade basis. Therefore trends in crop yields and livestock stocking rates can be detected at the NUTS 2 level. Correspondence tables that relate crop types to Corine land cover types can be used to spatialise or disaggregate the agricultural statistical data. Both Eurostat and the JRC are currently conducting research in the domain of relating farm structure survey data to the Corine land cover data set.

Proposed indicator framework model
Agricultural intensification should not be regarded as the sole driving force indicator for soil erosion, as there is not a proven link between agricultural intensification and land degradation. Intensive farming often encourages good conservation practices, because land becomes scarce and increases in value, and therefore farmers adopt, by necessity, soil nurturing practices. Other driving forces may be just as, or even more, important. Anthropogenic changes in agricultural practices, urbanisation and tourism may cause changes in land use and vegetation. In addition, increase in the

frequency and area of forest fires may cause changes in the natural vegetation. Decrease in the local human population may lead to the abandonment of terrace maintenance, because of insufficient labour, whereas a sudden increase in population, due to migration, may put vulnerable soils under greater risk of erosion. Climate indicators are also important factors, such as in Mediterranean areas where 300 mm rainfall is seen as the threshold annual rainfall amount — with areas receiving less than 300 mm rainfall per year being better kept as natural vegetation and areas receiving more than 300 mm rainfall being suitable for rain-fed agriculture.

Land cover changes and precipitation indicators, on the other hand, are seen as better pressure indicators for soil erosion, as these directly influence the degree of soil erosion. Land cover changes, including forest fires and deforestation, can be detected by combining the reference land cover database, Corine land cover, with vegetation changes indices from NOAA-AVHRR and SPOT Vegetation. Precipitation regimes can be detected using the GISCO climate coverages and the monitoring agriculture by remote sensing (MARS) meteorological database.

Remarks and conclusions
GISCO databases provide EU-wide geo-referenced bio-physical and socioeconomic information, generally on a scale of 1:1 000 000. An actual and potential soil erosion risk map based on a simplified USLE approach is available. Agricultural intensification can be assessed by combining farm structure survey and Corine LC data. But agricultural intensification trends are only possible at NUTS 2 level, which may be regarded as being too coarse for application to soil erosion issues. There is currently ongoing research at the JRC and Eurostat in regard to combining agricultural statistical data collected at administrative level and raster information of land cover provided by the Corine LC. It is argued that agriculture intensification, in isolation, could be misleading and therefore it is proposed to include human population, land development, tourism, transport, natural events and climate change with agricultural intensification for driving force indicators of soil erosion. Land cover change and precipitation can be used for pressure indicators of soil erosion, as they are seen to be directly influencing the degree of soil erosion. Land cover change can be detected by combining the Corine LC with vegetation change monitoring techniques (AVHRR/Vegetation). Precipitation can be derived from the GISCO climate and/or the MARS meteorological databases.

Regional assessment of the impact of soil erosion by water

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Soil erosion indicators of state
Soil erosion is a natural process, occurring over geological time. Most concerns about erosion are mostly caused by water and are related to accelerated erosion, where the natural rate has been significantly increased by human activities that cause changes in land cover and management.

In Europe, soil erosion is caused mainly by water and, to a lesser extent, by wind. In the Mediterranean region, water erosion results from intense seasonal rainfall on often fragile soils located on steep slopes. The area affected by erosion in northern Europe is more restricted and moderate rates of water erosion result from less intense rainfalls falling on saturated, easily erodible soils. However, these findings are based on fragmentised and non-standardised information.

Soil erosion is widely recognised to be patchy both in time and in space. A major event may occur in one place but leave the adjacent field or plot untouched. In addition the lack of widespread soil loss measurements hamper effective interpolation between the limited sites available. Soil loss measurements or observations typically stretch over a period of three to five years, and make temporal extrapolations difficult. The lack of data and the patchy nature of soil erosion make the development of an indicator of state a difficult process.

Ultimately, it is the area that is affected by soil erosion and an estimate of the expected magnitude in a particular area that policy-makers need to know in order to formulate a sound soil protection policy. Regional soil erosion assessment is therefore needed on a European scale in order to make objective comparisons that may provide a basis for further environmental analysis, economic statements or policy development. This paper deals with methods to present soil erosion on a regional scale.

The revised DPSIR assessment framework

The result of the application of the DPSIR and MF/MI assessment tools to soil erosion is the identification of a set of policy-relevant indicators. However, it has to be recognised that there is a huge difference between actual soil erosion and soil erosion risk, which is not adequately reflected in the present framework (EEA-ETC/S, 1999). Indicators describing the driving forces and pressures may affect the risk of soil erosion, but they may not affect soil erosion in itself. A mechanism is therefore needed to jointly estimate the actual erosion and the risk, based on links between the identified driving force and pressure indicators, and based on an estimation or measurement of what is actually happening. It is proposed to modify the current DPSIR assessment framework (EEA-ETC/S, 1999; EEA, 2000) to include some of the considerations in a revised DPSIR scheme, presented in Figure 2.5 in the main text. Agricultural intensification is seen as the most important driving force. However, tourism and transport could be added to the list. The effect that driving forces have in common is that they change the land cover, which is the major pressure indicator for soil erosion.

Processes of soil erosion by water

Slope sediment transport processes consist of weathering followed by transport of the regolith. For both weathering and transport, the processes can conveniently be distinguished as chemical, physical, biological and anthropogenic. Most slope processes are assisted by the presence of water, which helps chemical reactions, makes masses slide more easily, carries debris as it flows and supports the growth of plants and animals.

Material may be detached by raindrop impact and flow traction, and transported either by saltation through the air or by overland water flow. Combinations of these detachment and transport processes give rise to the three main processes, rainsplash, rainwash and rillwash.

Runoff is the most important direct driver of severe soil erosion. Processes that influence runoff must therefore play an important role in any analysis of soil erosion intensity, and measures that reduce runoff are critical to effective soil conservation.

Regional assessment methods of soil erosion

Methods

Regional assessment methods of soil erosion include distributed point data, factor or indicator mapping and process modelling. All of these methods require calibration and validation, although the type of validation needed is different for each category. There are also differences in the extent to which the assessment methods identify past erosion and an already degraded soil resource, as opposed to risks of future erosion, under either present climate or land use, or under scenarios of global change.

One important form of erosion assessment is from direct measurements or field observations of erosion features and soil profile truncation. The main advantage of measurements is that they are unambiguous where they exist, and give a good indication of the current state of degradation of the soil resource. The main disadvantage of field observations is that they provide little or no information about when erosion occurred, which has little bearing on current or prospective erosion hazards. The distributed point data method requires validation to standardise differences in measurements, in the intensity of study of different areas and in the clarity of suitable features on different soil types. On their own these methods cannot provide a complete picture except for small sample areas, and require the use of other methods to interpolate between areas.

Since many of the processes and factors that influence the rate of erosion are well known, it is possible to rank individual factors for susceptibility to erosion, providing a series of erosion indicators. Individual indicators may be mapped separately, but it is more problematic to combine the factors into a single scale, by adding or multiplying suitably weighted indicators for each individual factor. There are difficulties both about the individual weightings and about the assumed linearity and statistical independence of the separate factors. The method should therefore be most effective for identifying the extremes of high and low erosion, but less satisfactory in identifying the gradation between the extremes. Despite these theoretical limitations, factor or indicator mapping has the considerable advantage that it can be widely applied using Europe-wide geographic data on topography, soils, climate and land cover / use.

The third method for Europe-wide soil erosion assessment is the application of a process model. Process models have the potential to respond explicitly and rationally to changes in climate or land use, and so have great promise for developing scenarios of change and what-if analyses of policy or economic options. Although it is the most generally applicable and replicable method, the challenge is to relate coarse scale forecasts to available erosion rate data, much of which is for small erosion plots and catchments. Nevertheless this method has the potential to provide a rational physical basis to combine factors which can be derived from coarse scale GIS, and overcome the difficulties about weighting and inter-correlation which are encountered in purely factor-based assessments. Set against the advantages, process models can only incorporate the impact of past erosion where this is recorded in other data, such as soil databases. Models also generally simplify the set of processes operating, so that they may not be appropriate under particular local circumstances.

A number of approaches that present a regional assessment of soil erosion by water have been reviewed: Glasod, hot spots, RIVM and Corine. Both the Glasod and hot-spot maps were classified as methods based on distributed point data; the RIVM and Corine maps were classified as factor- or indicator-based maps.

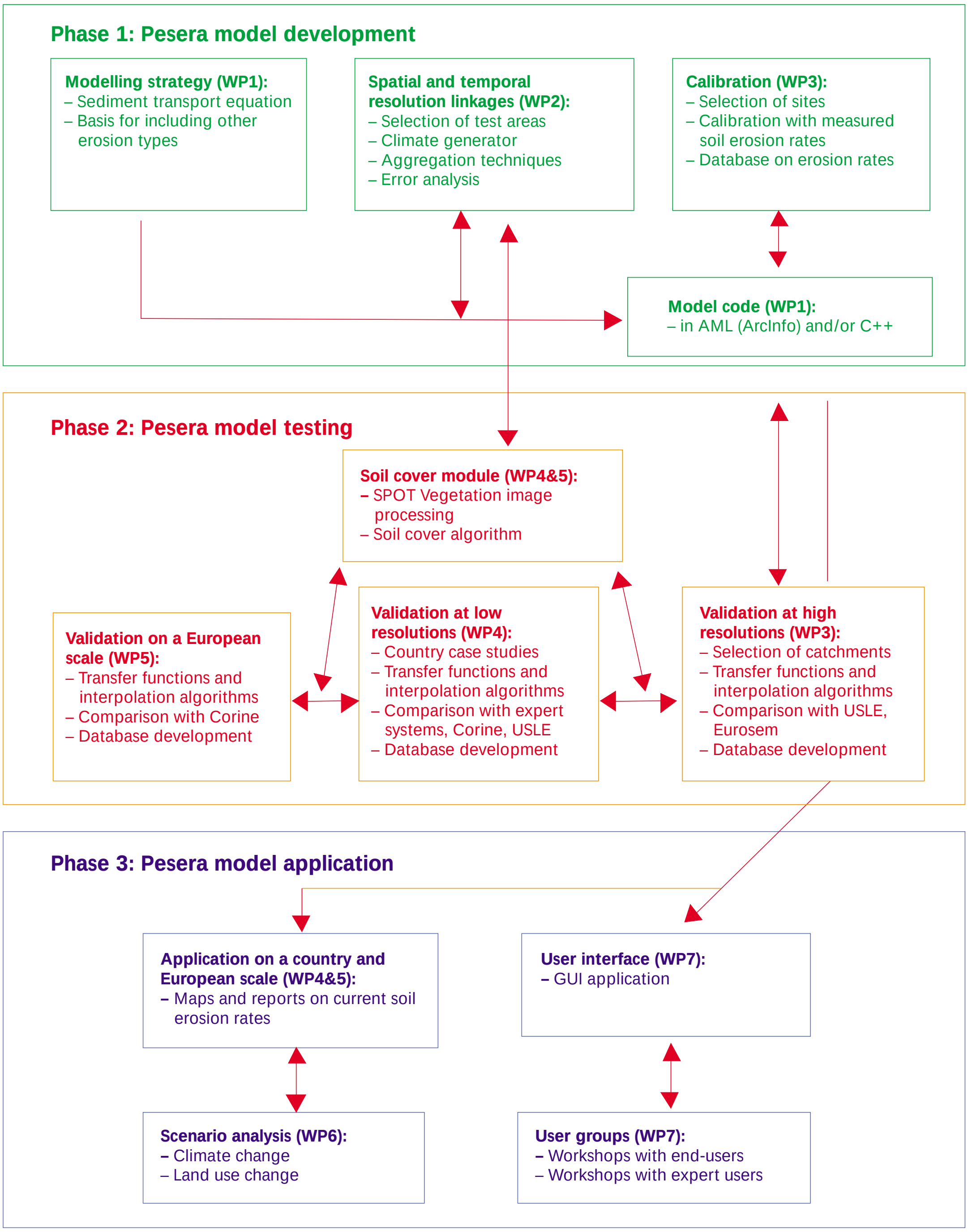
The Corine soil erosion risk maps are the result of an overlay analysis of factors based on topography, soils, precipitation and land cover maps, enabling the evaluation of the soil erosion risk category. The methodology is based on a considerable simplification of the universal soil loss equation (USLE), a regression based model, for which there is a massive database for US conditions, but little systematic data for Europe. Potential soil erosion risk is defined as the inherent risk of erosion, irrespective of current land use or vegetation cover, and represents the worst possible situation. Actual soil erosion risk reflects the protective influence provided by present land cover, and the dangers inherent in changes in land use practices. The Corine assessment is restricted to southern Europe, whereas present needs for erosion data apply to the whole of Europe.

The RIVM approach combines a baseline assessment of erosion risk with climate and economic projections to generate scenario projections for 2010 and 2050. RIVM makes explicit use of scenario projections, a feature lacking in other approaches, but the map at 50 km resolution cannot readily be interpreted at sub-national scales. The approach also has the advantage of combining physical and economic elements within a single framework. The erosion impact module generates a water erosion risk index based on three main parameters: terrain erodibility, rainfall erosivity, and land use pressure. The RIVM soil erosion model is a factor model, like Corine, but, although initiated six to eight years later, is in many ways a still more simplified approximation to the imperfect USLE model. Neither the 50 km resolution nor the implementation of the factors contributing to erosion is seen as providing a state-of-the-art assessment.

The purpose of the hot-spot study was to support the joint message on the need for a pan-European policy on soil, identifying 'hot spots' of degradation in Europe and examining environmental impacts leading to change and particularly degradation of soil functions. The work involved compilation of data available and incorporation into a GIS. The data provides general or particular information about water erosion for approximately 60 sites or small regions across Europe, with measured erosion rates, which could be placed on the map at 35 sites classified in three broad zones. The sporadic distribution and episodic occurrence of soil erosion and the uneven density and quality of local measurements makes the data set very ill-suited to effective interpolation. However, the data set could be very meaningfully used in combination with factorial or process modelling methods.

The main objective of the global assessment of soil degradation (Glasod) project was to strengthen the awareness of decision-makers on the risks resulting from inappropriate land and soil management to the global well-being. Glasod is based on responses to a questionnaire that was sent to recognised experts in all countries. The dependence on expert judgments provides very little control or objectivity in comparing the standards applied by different experts for different areas. An updated version of the European part of the (Glasod) map was made on the basis of completed and returned questionnaires. The degree of detail of the

Pesera project scientific structure Figure A3.7



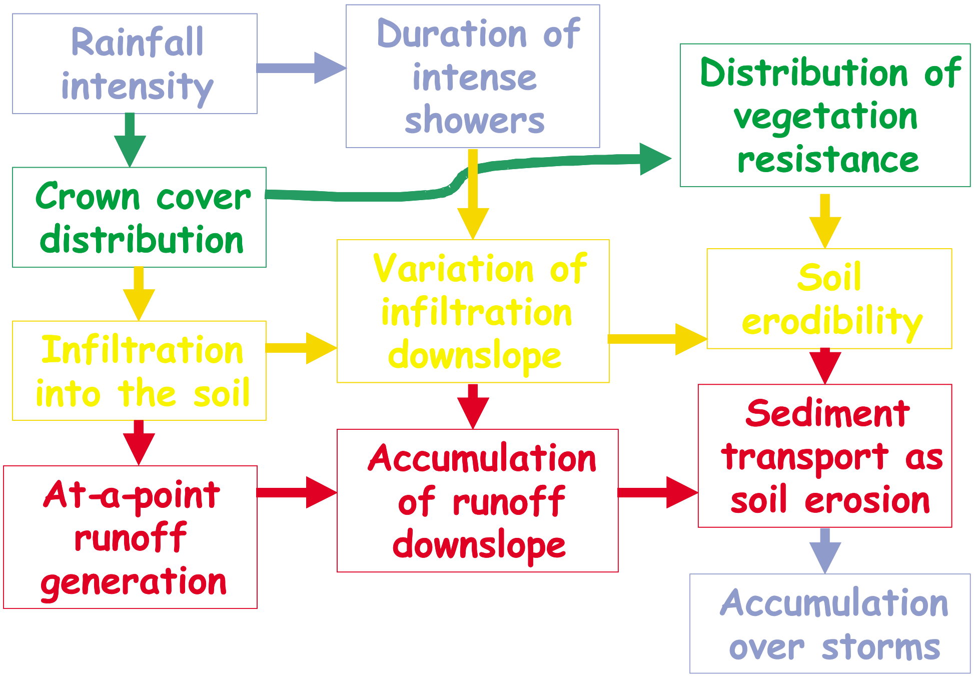
information received varies greatly. It must also be noted that the scale of the maps (1:10 000 000) limits the detail that can be shown, providing a minimum resolution of approximately 10 km. Despite its limitations, it is the only approach which has been applied on a worldwide scale.

Although the USLE has been the most widely applied model in Europe, it is now widely considered to be conceptually flawed, and other models are now emerging, based on runoff thresholds or the MIR (minimum information requirement) approach applied to the more complex USDA WEPP model. The pan-European soil erosion risk assessment method is presented in the next section as a new method to forecast soil erosion based on a process model in combination with validation against field measurements.

Process modelling to assess regional soil erosion: Pesera

Process modelling methods allow for a more quantitative forecast, which is important as a critical control on soil erosion. Current models are designed to assess soil erosion at

Figure A3.8 The Pesera model structure



high resolutions, and are not suitable to develop regional soil conservation strategies. The pan-European soil erosion risk assessment project (Pesera), an EU fifth framework project (Gobin et al., 1999), has developed a physically based and spatially distributed model to quantify soil erosion in a nested strategy of focusing on environmentally sensitive areas relevant on a European scale (Gobin and Govers, 2002).

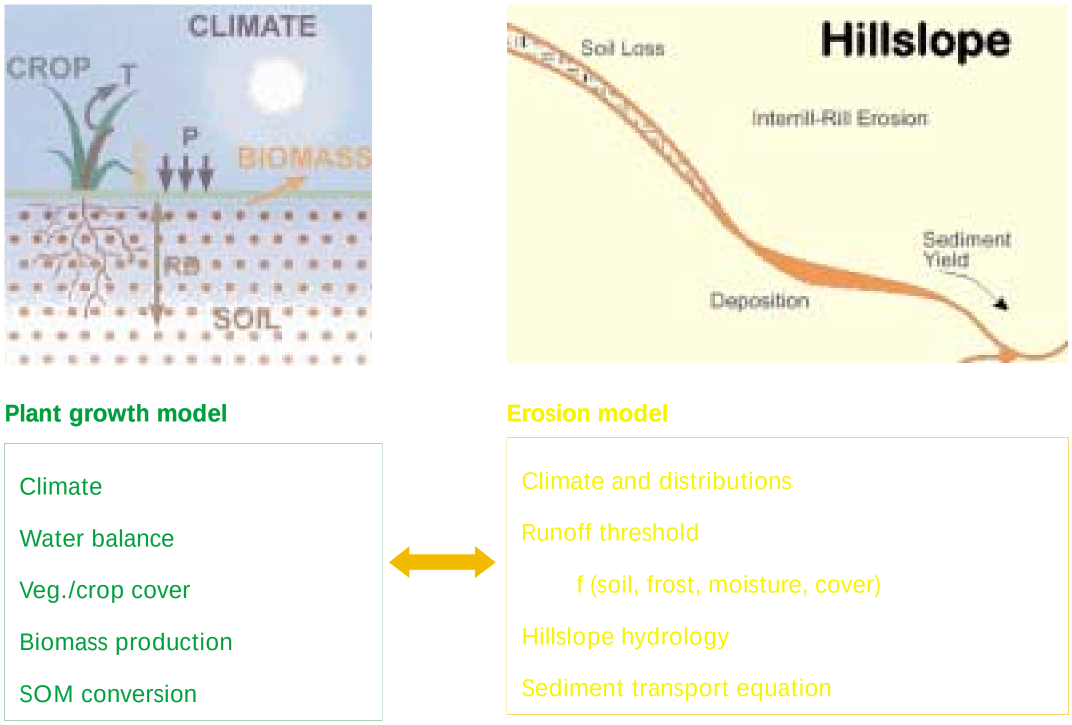
The objectives of Pesera are threefold and link to three well-identified project phases (Figure A3.7).

Project phase 1 focuses on the development of a process-based and spatially distributed model to quantify soil erosion and assess its risk across Europe. The model is intended as a regional diagnostic tool, replacing comparable existing methods, such as the universal soil loss equation, which lack a sound physical basis and compatibility with higher resolution models. The model will be calibrated and validated with existing information on soil erosion rate measurements and a prediction error will be attached to model outputs. This will entail the development of a modelling strategy, sensitivity analysis, temporal and spatial aggregation / disaggregation techniques, error analysis and calibration with the aid of soil erosion rate measurements across Europe. A database will be compiled on existing soil erosion measurements from plots and small catchments across Europe.

Project phase 2 deals with validation and comparison with other erosion risk assessment methods across Europe and at three different resolutions (field to catchment, country and pan-European scale). Linking existing data sets to model parameters through transfer functions, interpolation algorithms and statistical methods will demonstrate the model's flexibility and robustness. The use of 10-daily vegetation cover from NDVI and SPOT Vegetation / HRVIR will enable calculated estimates of seasonal variations in soil erosion. Accurate spatial databases will be compiled from existing information on factors affecting erosion in Europe (climate, soil, topography, land cover) and upgraded using satellite imagery and computational techniques.

Project phase 3 deals with application of the model, development of a user-friendly interface and establishment of user groups at both national and European level. Quantification of the erosion problem enables evaluation of the possible effects of future changes in climate and land use, scenario analysis and impact assessment according to cost-effectiveness, technical feasibility, social acceptance and implementability. End-user groups and expert-user groups will actively participate in model testing and in evaluating the project's progress and results. Research networks will be established in order to provide feedback on the project's progress and results, and to ensure continuation.

Figure A3.9 The integration of a plant growth model and erosion model into the Pesera model enables quantitative forecasts of land cover and erosion



To date, the model development has been finalised (Figure A3.8). The model produces a quantitative forecast of soil erosion and plant growth, and therefore it has the potential to respond explicitly and rationally to changes in climate or land use, offering great promise for scenario analysis and impact assessment (Figure A3.9). Set against this advantage, the model can only incorporate the impact of past erosion where this is measured and thus requires numerous and good data sets needed for testing. The model simplifies the set of processes operating and may therefore not be appropriate under particular local circumstances. The Pesera model is currently being calibrated and validated at different resolutions and across different agro-ecological zones. Examples include Andalucia and France (Kirkby and King, 1999; Kirkby et al., 2000). Test runs at high resolution have demonstrated a satisfactory goodness-of-fit (Gobin and Govers., 2001b).

Conclusions

In order to formulate a European soil protection policy, policy-makers need to know the area affected by soil erosion on a regional scale, preferably on a pan-European scale. In addition, the magnitude of soil erosion in a particular area provides a useful measure for formulating soil conservation strategies.

Four methodologies have been reviewed that present a regional assessment of soil erosion by water. Both the Glasod maps and hot-spot map were classified as methods based on distributed point data, whereas the RIVM and Corine maps were classified as factor- or indicator-based maps. Methods based on questionnaire surveys (Glasod) or erosion measurement sites (hot spots) are inadequate on their own. In addition, differences between expert assessments and measurement methods reduce the comparability between the limited data available. Methods based on factors or indicators (RIVM, Corine) have the immediate benefit of accessing distributed climate data, soil maps, DEMs and land use maps that are available on a European scale. Corine makes explicit use of an adequate range of relevant indicators for southern Europe, but it is an imperfect implementation, for historical reasons of data availability, of a model (USLE) that is now no longer considered as state of the art. Although confined to southern Europe, Corine gives the best indication of a regional distribution of soil erosion of the four methods reviewed.

The major problems with soil erosion are firstly the temporal and spatial patchiness of the phenomenon and secondly the availability of widespread and long-continued soil loss measurements or observations. In such cases, interpolations between available sites are scientifically not justified. Current regional assessment methods, such as Pesera (Gobin et al., 1999), have therefore opted for risk analysis combining plant growth, runoff and sediment transport models. The Pesera model produces quantitative forecasts of land cover, runoff and soil erosion, and responds explicitly and rationally to changes in climate or land use. Since policy-makers have the most direct impact on soil erosion through land cover / use and land management policies, a process modelling such as the Pesera method enables further impact assessment and scenario analysis.

Data availability for soil erosion indicators at European level

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Determining the causes of soil erosion
From the review of the current indicators for soil selected by the EEA, it is concluded that, from a scientific and technical standpoint, the most appropriate indicator is the area affected by erosion (see Chapter 2 in the main text). However, because there is a serious lack of direct measurements of soil loss, by water and by wind, a surrogate parameter or indicator is needed.

Conventional wisdom suggests that the area actually affected by erosion should be directly related to the area at risk from erosion provided that the area at risk has been determined using an appropriate model of soil erosion together with the necessary spatial data sets. Soil erosion takes place at the field scale and the main problem is that the digital data sets used to quantify the factors causing erosion are usually too coarse (in terms of spatial resolution) to enable accurate estimation of soil losses at this scale.

Before considering modelling erosion risk further, the concept of risk must be defined.

A risk is the chance of a bad consequence or loss. Another definition of risk is the chance that some undesirable event may occur. Risk assessment involves the identification of the risk, and the measurement of the exposure to that risk.

The response to risk assessment may be to initiate categorisation of the risk and / or to introduce measures to manage the risk. In some cases, the risk may simply be accepted. In other cases, the priority will be to adopt a mitigation strategy.

Such risk management, traditionally a significant activity in the commercial sector, e.g. the insurance industry, has now been adopted in the environmental protection arena. A review of soil erosion risk models has been provided in Section 4.2 and in Gobin's and Kirkby's paper earlier in this annex.

Modelling soil erosion
For developing suitable indicators for soil erosion, a model-based approach is proposed for assessing soil erosion risk. As stated above, the availability of input data is a critical selection criterion when assessing soil erosion risk at the regional, national or continental scale. Even though a wide variety of models are available for assessing soil erosion risk, most of them simply require so much input data that applying them at these scales becomes problematic.

The most widely used is probably the universal soil loss equation (USLE) developed by Wischmeier and Smith (1978). The USLE has been used by Van der Knijff et al. (1999, 2000) to estimate the risk of rill and interrill erosion in Italy and Europe, using the appropriate national and European data sets.

A new harmonised European approach is currently being developed under the EU fifth framework programme. The project, pan-European soil erosion risk assessment (Pesera), will use the RDI model proposed by Kirkby et al. (2000). It includes a module for validation of the estimates at large scale.

Universal soil loss equation
The universal soil loss equation (USLE) (Wischmeier and Smith, 1978) has used widely because it is one of the least data demanding erosion models that has been developed and it has been applied at different scales. The USLE is a simple empirical model, based on regression analyses of soil loss rates on erosion plots in the USA. The model is designed to estimate long-term annual erosion rates on agricultural fields. Although the equation has many shortcomings and limitations, it is widely used because of its relative simplicity and robustness (Desmet and Govers, 1996). It also represents a standardised approach.

Soil erosion is estimated using the following empirical equation:

$$A = R \cdot K \cdot L \cdot S \cdot C \quad (1)$$

Where:

A: Mean (annual) soil loss
R: Rainfall erosivity factor
K: Soil erodibility factor
L: Slope factor
S: Slope length factor
C: Cover management factor

The data sources that were used to estimate the various USLE factors are summarised in Figure 1.

Rainfall erosivity
The USLE rainfall erosivity factor (*R*) for any given period is obtained by summing — for each rainstorm — the product of total storm energy *(E)* and the maximum 30-minute intensity (I_{30}). Unfortunately, these figures are rarely available at standard meteorological stations. Moreover, the workload involved would be rather high for any national or continental assessment. Fortunately, long-term average *R* values are often correlated with more readily available rainfall figures like annual rainfall or the modified Fournier's index (Arnoldus, 1978). A similar approach was used to estimate *R* for the whole of Europe (Van der Knijff et al., 2000).

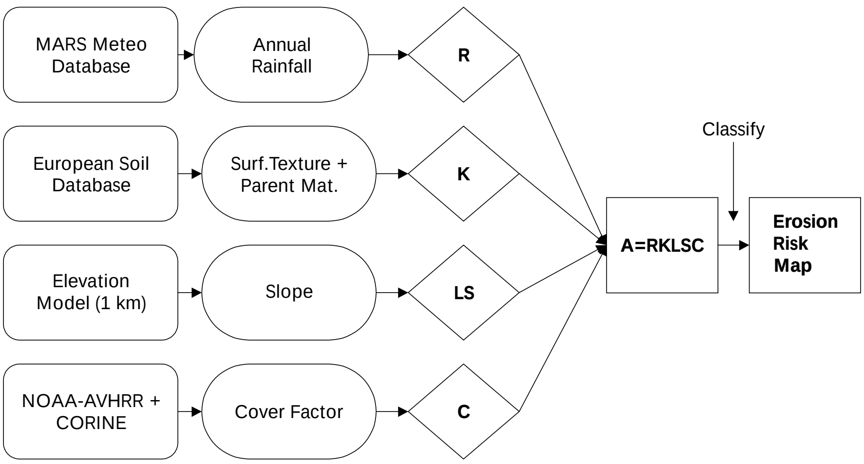
Soil erodibility
The *K* factor is defined as the rate of soil loss per unit of *R* as measured on a unit plot ('Wischmeier plot'). It accounts for the influence of soil properties on soil loss during storm events (Renard et al., 1997). In the Corine study, soil texture, depth and stoniness were used to estimate erodibility. Working at the Member State and European levels, Van der Knijff (1999, 2000) essentially used soil texture. At the European level, Le Bissonais and Daroussin (2001) have developed a set of pedotransfer rules to interpret the Soil Geographical Database of Europe for soil erodibility and soil crusting.

Slope and slope length
The slope and slope length factors (*S* and *L*, respectively) account for the effect of topography on soil erosion. It can be estimated from a digital elevation model (DEM).

Vegetation cover and management
The cover and management *C* factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978). Its value depends on vegetation cover and management practices. Van der Knijff et al. (1999, 2000) estimated *C* using a combination of satellite imagery and a land cover database based on Corine. Of those factors used in the USLE, it is probably the one accounting for the most variation in soil loss.

Soil erosion risk assessments
A proper validation of results obtained from applying an erosion model is hardly possible on a small scale (e.g. national, continental). Nevertheless, Van der Knijff et al. (1999, 2000) offer some comments on the general pattern shown on the maps of erosion risk that were produced for Italy and Europe using the universal soil loss equation (USLE).

Flowchart for creating an USLE-based erosion risk map Figure A3.10



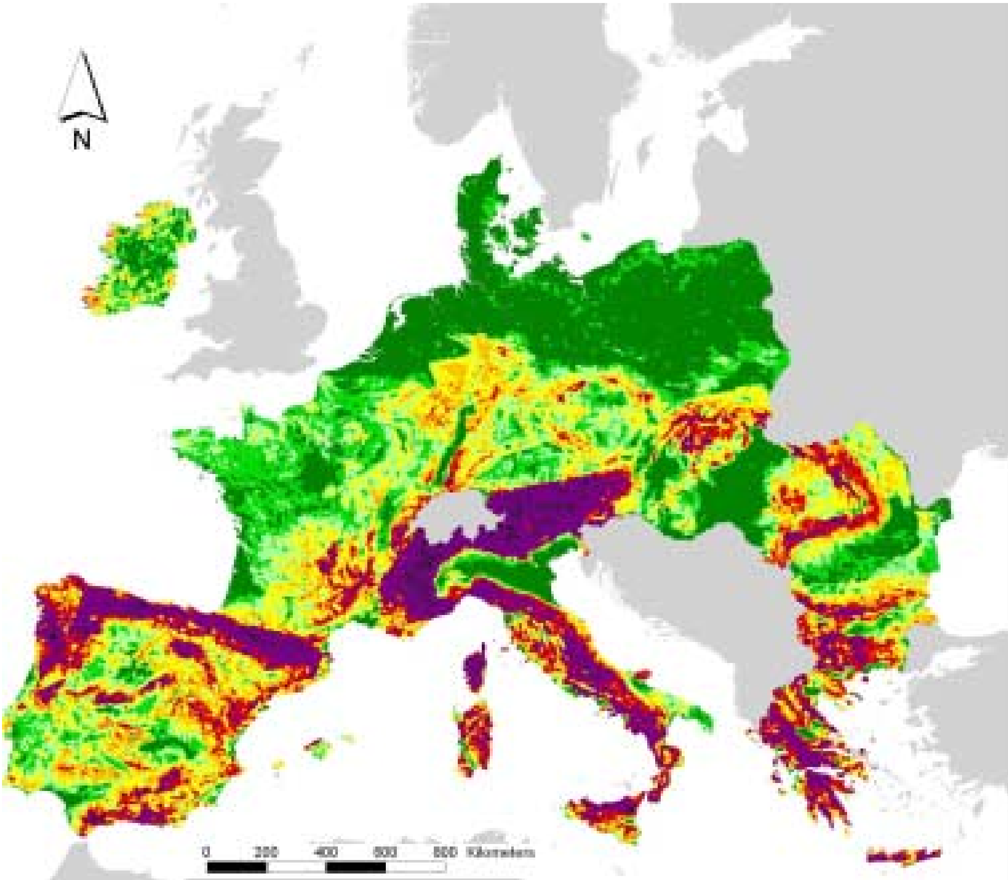
The most apparent contrast is between the north and south in Europe. In general, soil erosion risk seems to be underestimated for most of northern Europe. This is mainly caused by the rainfall erosivity factor, whose predicted values are generally much lower for northern Europe than for the south. Even though rainfall in the north is less 'aggressive' compared to the south, the differences shown on the map appear to be too extreme. In southern Europe, the risk assessments do not take past erosion into consideration. For example, some areas identified as being at high risk have already been seriously eroded and the chances of further soil loss are much reduced.

However, the work of Van der Knijff et al. (2000) is important because it is one of the first attempts to produce digitally a map of soil erosion risk by rill and interrill erosion for the whole of Europe. Its value lies in the fact that the estimates of erosion risk are based on standardised, harmonised data sets for Europe. Moreover, the model output can be estimates of actual soil erosion, by taking crop / vegetation cover into account, and estimates of potential erosion, by excluding the cover factor. These results, together with output from other modelling approaches, should now provide a basis for defining a new more physically based set of soil erosion indicators for environmental auditing.

There is scope for major improvements in such modelling by using more detailed digital elevation data, better representation of rainfall erosivity (i.e. more detailed rainfall measurements), and satellite data that have better spectral and geometric characteristics than the NOAA-AVHRR data that are currently available. Ideally, multi-temporal satellite imagery should be used in order to account for the interaction between vegetation growth and senescence over the year, and rainfall. Finally, more detailed soil data are required (especially soil depth, stone volume and surface texture).

Given such improvements in the basic data sets, the output from a model such as the USLE could provide a valuable indicator of soil erosion. Some of the indicators currently proposed such as fertiliser consumption, farm structure and sediment transport could then be useful but only for modifying a standardised estimation of soil loss determined using a standard model.

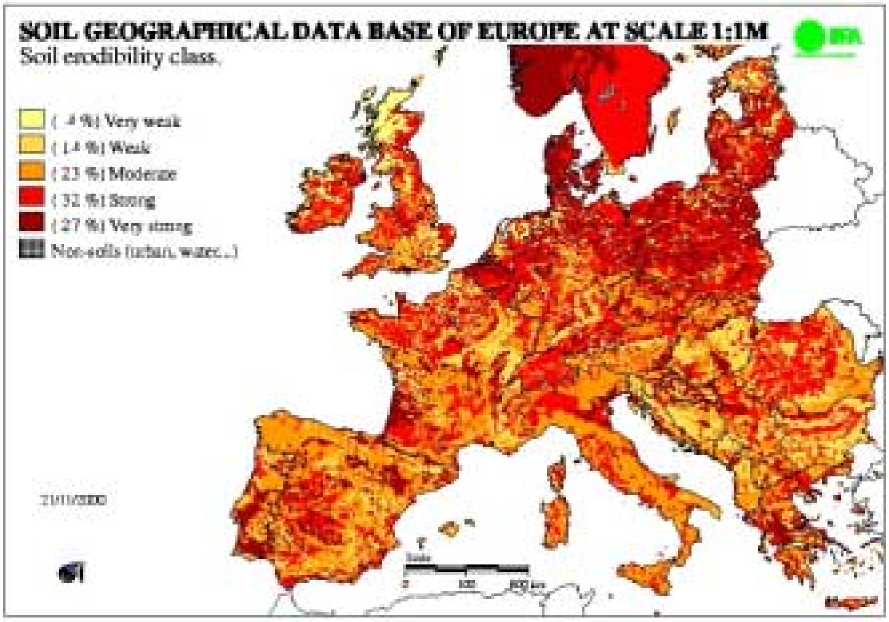
Figure A3.11 **Potential soil erosion risk in Europe**



Source: Van der Knijff et al., 2000.

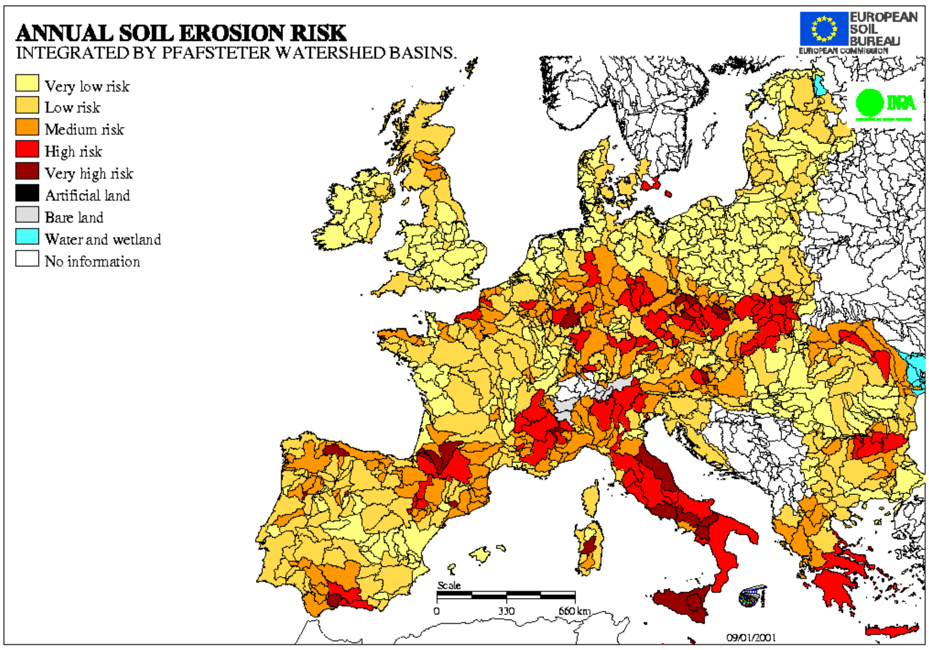
Environmental indicators for soil erosion
Environmental indicators for soil erosion are proposed in Table 1. Examples of soil erodibility and actual soil erosion risk aggregated by catchment are provided in Figures 3 and 4. Figure 2 shows the potential soil erosion risk in Europe.

Soil erodibility class across Europe — Figure A3.12



Source: ESB, INRA.

Actual soil erosion risk aggregated by catchment — Figure A3.13



Source: ESB, INRA.

Table A3.7 **Proposed environmental indicators and data availability at a European level**

Environmental Indicator	Policy relevant	Utility		Analytical soundness	Measurability			Effect	Comments
	Represen-tative	Easy to interpret	Com-parable	Scientific/ Techni-cally	Data available	Docu-mented	Updated		
Actual soil erosion	Yes	???	???	Yes	Rarely available	In part	No	Direct	Extent not known, expensive to measure
Soil erosion risk	Yes	Yes	Yes	Yes	Nationally	Yes	Periodically	Complex	Estimated from standard model e.g. USLE,
Soil erodibility	Yes	In part	Yes	Yes	National/regional	Yes	Yes	Complex	Can be calculated from a standard model
Soil texture	Yes	Yes	Yes	Yes	National/regional	Yes	Probably	Simple	Updated by new data becoming available
Soil depth	Yes	Yes	Yes	Yes	National/regional	Yes	Probably	Simple	Updated by new data becoming available
Soil drainage	Yes	Yes	Yes	Yes	National/regional	Yes	Probably	Simple	Updated by new data becoming available
Soil crusting	Yes	In part	Yes (?)	Yes	National/regional	Yes	Probably	Simple	Updated by new data becoming available
Soil storage capacity	Yes	Yes	Yes	Yes	National/regional	Yes	Probably	Simple	Updated by new data becoming available
Soil organic matter	Yes	Yes	Yes	Yes	National/regional	Yes	Probably	Simple	Updated by new data becoming available
Erosivity	Yes	No	Yes	Yes	National/EU	Yes	Yes	Simple	Data for actual and estimated (CGMS) yields
Topography (slope length)	Yes	No	Yes	Yes	National/EU	Yes	Probably	Simple	Updated by new data becoming available
Vegetation/crop cover	Yes	Yes	Yes	Yes	National/EU	Yes	Yes	Simple	Dichotomy between intensive indoor and outdoor stocking
Erosion control measures	Yes	Yes	Yes	Yes	Rarely available	In part	No	Direct	Usually piecemeal

Annex IV — Soil erosion glossary

Term	Definition	Source
Accelerated erosion	Erosion in excess of natural rates, usually as a result of anthropogenic activities	1
Actual erosion risk	The inherent risk of erosion under the current land use or vegetation cover	
Actual erosion	Measured erosion	
Bank erosion	Erosion of the riverbank	
Coastal erosion	Erosion of the coast, resulting in the retreat of the coastline	
Erosion	(i) The wearing away of the land surface by rain or irrigation water, wind, ice or other natural or anthropogenic agents that abrade, detach and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere, including such processes as gravitational creep and so-called tillage erosion; (ii) the detachment and movement of soil or rock by water, wind, ice or gravity.	1
Erosion risk	Risk of erosion. It can be used as a surrogate indicator of actual erosion	
Geological erosion	The normal or natural erosion caused by natural weathering or other geological processes. Synonymous with natural erosion over a geologic time frame or large geographic area	1
Gully erosion	The erosion process whereby water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, often defined for agricultural land in terms of channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 m to as much as 25 to 30 m	1
Interrill erosion	The removal of a fairly uniform layer of soil on a multitude of relatively small areas by splash due to raindrop impact and by sheet flow	1
Mass movement	Dislodgement and downslope transport of soil and rock material as a unit under direct gravitational stress. The process includes slow displacements such as creep and solifluction, and rapid movements such as landslides, rock slides, and falls, earthflows, debris flows and avalanches. Agents of fluid transport (water, ice, air) may play an important, if subordinate, role in the process	1
Potential erosion risk	The inherent risk of erosion, irrespective of current land use or vegetation cover	
Rill erosion	An erosion process on sloping fields in which numerous and randomly occurring small channels of only several centimetres in depth are formed; rills can be obscured by tillage	1
Risk	The potential for realisation of unwanted, adverse consequences to human life, health, property or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring and the consequence of the event given that it has occurred	2
Risk analysis	A detailed examination including risk assessment, risk evaluation and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks	2
Risk assessment	The process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society or the environment	2
Risk estimation	The scientific determination of the characteristics of risks, usually in as quantitative a way as possible. These include the magnitude, spatial scale, duration and intensity of adverse consequences and their associated probabilities as well as a description of the cause and effect links	2
Saltation	A particular type of momentum-dependent transport involving: (i) the rolling, bouncing or jumping action of soil particles 0.1 to 0.5 mm in diameter by wind, usually at a height < 15 cm above the soil surface, for relatively short distances; (ii) the rolling, bouncing or jumping action of mineral grains, gravel, stones or soil aggregates effected by the energy of flowing water; (iii) the bouncing or jumping movement of material downslope in response to gravity	
Sediment	Transported and deposited particles or aggregates derived from rocks, soil or biological material	1
Sedimentation	The process of sediment deposition	1

Term	Definition	Source
Sheet erosion	The removal of a relatively uniform thin layer of soil from the land surface by rainfall and largely unchannelled surface runoff (sheet flow)	1
Soil erosion	Erosion of the soil. Soil erosion consists in the removal of soil material by water or wind. It is a natural phenomenon but it can be accelerated by human activities	3
Tillage erosion	The downslope displacement of soil through the action of tillage operations	1
Water erosion	The breakdown of solid rock into smaller particles and its removal by water. As weathering, erosion is a natural geological process, but more rapid soil erosion results from poor land use practices, leading to the loss of fertile topsoil and to the silting of dams, lakes, rivers and harbours	3
Wind erosion	The breakdown of solid rock into smaller particles and its removal by wind. It may occur on any soil whose surface is dry, unprotected by vegetation (to bind it at root level and shelter the surface) and consists of light particles. The mechanisms include straightforward picking up of dust and soil particles by the airflow and the dislodging or abrasion of surface material by the impact of particles already airborne	3

Sources

1	*Glossary of soil science terms*, Soil Science Society of America (SSSA), 1998
2	*Glossary of risk analysis terms*. Society for Risk Analysis http://sra.org/glossary.htm
3	EEA glossary of environmental terms

Annex V — Processes of soil erosion

Over 90 % of non-glacial landscapes consist of soil-covered hillslopes, with the remainder being river channels and flood plains. Although soil covered surfaces are not generally the most active part of the landscape, they provide almost all of the material, which eventually leaves a river catchment through the channel ways. The processes by which material is weathered and transported to the streams are therefore vital to an understanding of how the landscape transports weathered debris on hillslopes (the regolith) and delivers sediment to stream channels. Agriculture strongly affects the rate and types of hillslope processes, and the way in which farmland is managed can dramatically influence whether soil erosion remains at an acceptable level, or is increased to a rate which leads to long-term and perhaps irreversible degradation of the soil.

Slope sediment transport processes are of two very broad types, first the weathering and second the transport of the regolith. Within each of these types, there are a number of separate processes, which may be classified by their particular mechanisms into groups (Table 1), although many of these processes occur in combination. Most slope processes are greatly assisted by the presence of water, which helps chemical reactions, makes masses slide more easily, carries debris as it flows and supports the growth of plants and animals. For both weathering and transport, the processes can conveniently be distinguished as chemical, physical and biological.

An additional important anthropogenic process is tillage erosion, which is the result of ploughing, either up- and downslope or along the contour. Each time the soil is turned over, there is a substantial movement of soil. Up- and downhill ploughing produces a direct downhill component of movement as the turned soil settles back. Contour ploughing can move material either up and down, according to the direction in which the plough turns the soil. Contour ploughing in which the soil is turned downhill moves approximately 1 000 times as much material as soil creep. Contour ploughing in both directions (soil turned uphill and then downhill or vice-versa), or ploughing up- or downhill produces a smaller net movement, but the overall rate is still about 100 times greater than natural soil creep. Sediment transport is more rapid using modern heavy machinery than with primitive ploughs, but it is clear that tillage erosion may have been responsible for more soil movement in the last few centuries than natural soil creep during the whole of the Holocene. The accumulated effect is often seen in the build-up of soil behind old field boundaries.

Classification of the most important hillslope processes Table A4.1

	Weathering processes	Transport processes	Type (S/T)
Chemical	Mineral weathering	Leaching ionic diffusion	S T
Physical	Freeze-thaw Salt weathering Thermal shattering	Mass movements Landslides Debris avalanches Debris flows Soil creep Gelifluction Tillage erosion Particle movements Rockfall Through-wash Rainsplash Rainflow Rillwash	 S S S T T T S T T T T
Biological	Faunal digestion Root growth Microbial activity	Biological mixing (often included within soil creep)	T

Types: T = transport limited; S = supply limited removal (see below).

Table A4.2 **Types of soil erosion by water**

	Transportation	Mode
Detachment by	Through the air	In overland flow
Raindrop impact	Rainsplash	N/A
Overland flow traction	Rainflow	Rillwash gully erosion

Soil erosion by water

Although a small amount of material is washed through the soil, the more important erosion processes take place at the surface. Material may be detached by two processes, raindrop impact and flow traction; and transported either by saltation through the air or by overland water flow. Combinations of these detachment and transport processes give rise to the three main processes, rainsplash, rainwash and rillwash, as indicated in Table A4.2.

Raindrops detach material through the impact of drops on the surface. For the largest drops, the terminal velocity is 10 m s^{-1}, but they only attain this after falling through the air for about 10 metres. If their fall is interrupted by hitting the vegetation, drops hit the ground at a much lower speed, and have much less effect on impact. As drops hit the surface, their impact creates a shock wave, which dislodges grains of soil, or small aggregates and projects them into the air in all directions. The total rate of detachment increases rapidly with rainfall intensity. Where the raindrops fall into a layer of surface water which is more than about 5 mm thick, the impact of the drop on the soil surface is largely lost.

Raindrop impact is also effective in breaking down soil aggregates into constituent soil particles. These particles are re-deposited between aggregates on and close to the surface, forming soil crusts, which seal the surface, and limit infiltration by filling the macropores between the aggregates. These crusts may make the surface more resistant to erosion, but their greatest importance is in increasing runoff from storm rainfall. Susceptibility to water erosion is closely linked to the creation of soil crusts by rain falling on unprotected surfaces, and the destruction of crusts by tillage, freeze-thaw and drying.

If water is flowing with sufficient force, it exerts a force on the soil, which is sufficient to overcome the resistance of soil particles. Resistance is due to friction, which increases with particle size, and cohesion between grains, which increases with the specific surface area of contact, and hence decreases with particle size. Resistance is lowest for small non-cohesive grains, particularly silts and fine sands with a low clay content.

For rainsplash, grains are detached by drop impact and jump through the air. Transportation through the air, in a series of hops, is able to move material both up- and downslope, but there is a very strong downslope bias on slopes of more than about 5 %. The net rate of downhill transportation, therefore, increases with slope gradient, and decreases with the grain size transported. The rates of material transport by rainsplash are generally low.

For rainflow, grains are detached by raindrop impact, and carried farther than for rainsplash within a thin layer of flowing water. Both rainsplash and rainflow are most significant in areas between small channels, or rills, which form on the rapidly eroding surface, and are commonly grouped together as interrill erosion processes.

Where flow is sufficiently intense to entrain soil particles directly, small channels or rills are formed on the surface, and material is eroded by rillflow, which is concentrated along these drainage lines. In cultivated land, resistance to erosion is commonly low within the cultivated layer, but increases considerably at the plough pan, which may be a layer of increased resistance, and also forms a transition to the undisturbed and more consolidated unploughed soil beneath. Rills therefore rarely penetrate beneath the plough layer, and are generally obliterated by later cultivation, as farmers seek to prevent further erosion.

Under extreme storms, and where gradients are at least locally steep, erosion may lead to greater incision, forming gullies, which are too large to be obliterated by normal tillage. The development of gullies can fragment farmland, and by steepening gradients to adjacent fields, lead to rapid extension of a gully network, which makes cultivation impracticable. Remediation of gully systems requires radical measures, including the possible re-grading of entire landscapes.

Runoff is the most important direct driver of severe soil erosion. Processes that influence runoff must therefore play an important role in any analysis of soil erosion intensity, and measures that reduce runoff are critical to effective soil conservation.

Perhaps the most important control on runoff is the degree of crusting of the soil surface, which has a very strong influence on infiltration and therefore runoff rates. Of secondary, but still major, importance is the micro-topography of the soil surface and the sub-surface soil structure, particularly the presence or absence of macropores in the form of cracks and / or voids between soil aggregates. Micro-topography consists of random roughness on the surface, together with cultivation features such as plough ridges and terracing. Both fine-scale micro-topography and crusting evolve over the year, in relation to tillage and the growth of crops or uncultivated vegetation, their harvesting or grazing, and the disposal of surface residues.

Soil erosion is a natural process, occurring over geological time, and most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human action. These actions have generally been through stripping of natural vegetation for cultivation, indirect changes in land cover through grazing and controlled burning or wildfires, through re-grading of the land surface and / or a change in the intensity of land management, for example through poor maintenance of terrace structures. Increasing use of mechanised cultivation has also led to a substantial increase in rates of tillage erosion.

Erosion literature commonly identifies ‘tolerable’ rates of soil erosion, but these rates usually exceed the rates that can be balanced by weathering of new soil from parent materials, and can only be considered acceptable from an economic viewpoint.

Soil erosion by water is only one form of soil degradation, which includes erosion by mass movements, wind deflation / deposition and other geomorphological processes. Soil is also significantly degraded by salinisation, particularly in arid areas, areas with salt-rich parent materials and where water tables are high.

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