European Commission
DG Environment

# Assessing the Economic Impacts of Soil Degradation

## Final Report

### Volume I: Literature Review

Final Version, December 2004

Study Contract
**ENV.B.1/ETU/2003/0024**

Benjamin Görlach
Ruta Landgrebe-Trinkunaite
Eduard Interwies

This report will be cited as follows:

Görlach, B., R. Landgrebe-Trinkunaite, and E. Interwies (2004): Assessing the Economic Impacts of Soil Degradation. Volume I: Literature Review. Study commissioned by the European Commission, DG Environment, Study Contract ENV.B.1/ETU/2003/0024. Berlin: Ecologic

# Contents

## List of Figures:

# List of Tables:

# List of Boxes:

# 1 Introduction

Soil performs a multitude of functions that are essential to human life. Apart from providing food, biomass and raw materials and serving as a habitat and gene pool, soil also performs storing, filtering and transformation, as well as social and cultural, functions. In this way, soil plays an integral part in the regulation of natural and socio-economic processes that are necessary for human survival, such as the water cycle and the climate system. Because soil forms the basis of many different human activities, it also has a significant economic value. However, this "fundamental" economic value of soil is barely recognised.

Soil *deterioration*, understood as an impairment of these different functions, occurs both naturally, and as a consequence of human influences. This study focuses only on man-made impacts on the soil functions, which are described as soil *degradation.* Like other parts of the environment, soil has come under increasing stress as a consequence of human activities. Intensive agriculture, land consumption for building, the contamination of soil through pollutant emissions and changing climatic conditions are but a few of the man-made pressures on soil. While healthy soil can withstand these pressures to a certain degree, the combination and the extent of the stresses has resulted in a slow, but widespread, degradation of soils in many parts of Europe.

Soil degradation has become an important concern for policy makers. The physical, chemical and biological effects of soil degradation on other media of the environment, ecosystems and human populations have been researched to some degree. However, so far, little has been written about the economic costs that soil degradation imposes both on the users of soil and on society as a whole.

## 1.1 Scope and Content

Although soil protection is recognised as a major policy issue in many European countries, only with the 6th Environment Action Programme (EAP) was it identified as a separate policy area of the European Community. In order to approach the issue systematically and create the basis for a Community-wide soil policy, the 6th EAP recommended a “thematic strategy” for soil protection. As a first step in this strategy, the European Commission published a Communication in April 2002 entitled “Towards a Thematic Strategy for Soil Protection” (European Commission, 2002), which outlined the scope of such a strategy and was the Commission’s first document to deal comprehensively with soil protection.

For building this thematic strategy, the European Commission prepared a work plan on soil protection for 2003 - 2004. The planned core elements include a proposal for a piece of soil monitoring legislation and a communication on soil erosion, soil organic matter loss and soil contamination. Furthermore, a progress report on technical, political and policy initiatives will be prepared by 2004. It can be assumed that the soil monitoring legislation to be proposed by 2004 will only be the initial basis for the Community's soil policy.

The Environment Directorate-General of the European Commission has the main responsibility for the development of the strategy and coordinates the process. The Commission’s Inter-Service Working Group includes members of the European Commission who represent the different EU policy areas relevant to the soil strategy. This group cooperates closely on the integration of soil protection into other EU policies. Furthermore, a total of five semi-permanent Technical Working Groups and the Advisory Forum have been established, each with a specific role and mandate. The Technical Working Groups address the following fields: erosion, organic matter, contamination, monitoring and research. Members of these groups include representatives of (new and old) Member States, EU institutions and a broad range of stakeholder organisations. The process is co-ordinated by DG Environment.[1] Figure 1 presents the organisational set-up of soil policy development.

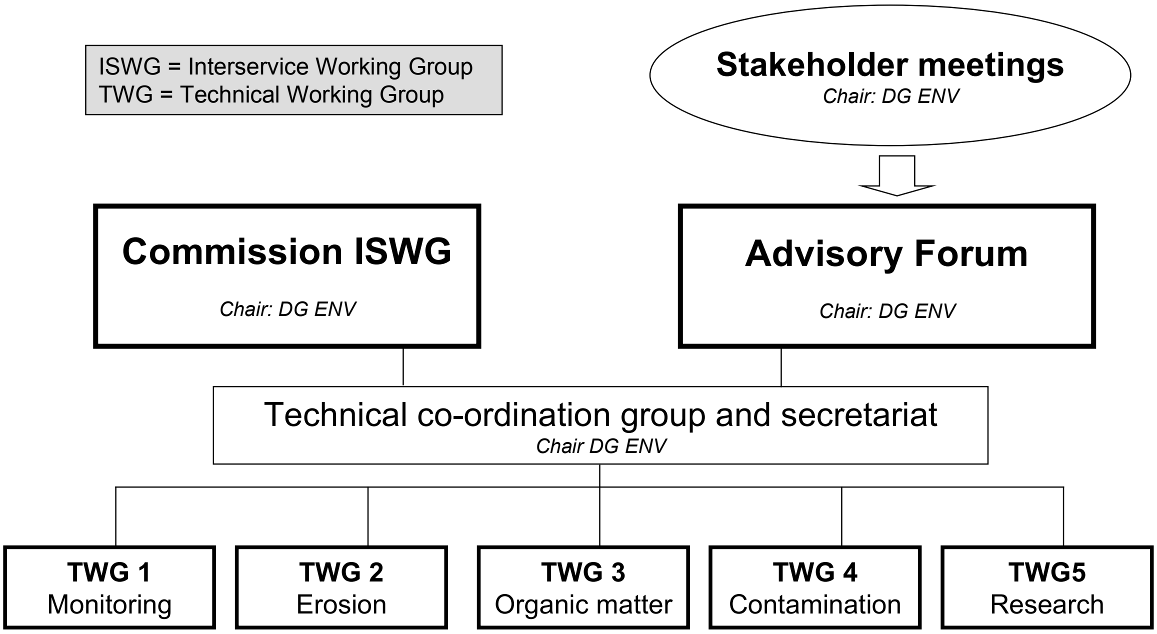

**Figure 1: Soil Policy Development - Organisational Set-up**

The project "Assessing the Economic Impacts of Soil Degradation" (Study Contract ENV.B.1/ETU/2003/0024) is a contribution to support the activities of the Technical Working Groups preparing the "Thematic Strategy for Soil Protection". This volume, which contains a literature review, is the part of the project that will assess the economic impacts of the main types of soil degradation. Other results of the project are documented in separate volumes, including a description of five case studies and of the data base used (Volume II) and a study which estimates the economic impacts of soil degradation in Europe (Volume III). The project is carried out by Ecologic – Institute for International and European Environmental Policy, and by the French Geological Survey BRGM. This volume has been contributed by Ecologic.

Work on this document was carried ahead of other parts of the project, between September 2003 and March 2004. The literature covered in this volume therefore represents the state of work in Spring 2004. This applies both to academic publications and to the results of the Working Groups established under the Thematic Strategy development. This document therefore refers to draft versions of the WG reports, as the final versions were only available in mid-2004. These can be found under http://forum.europa.eu.int/Public/irc/env/soil/library.

The economic assessment of soil degradation trends in Europe is based on a survey of existing studies and a review of the relevant literature that assesses and quantifies in economic terms the impact of different types of soil degradation. This literature review

---

[1] For more information, please see: http://europa.eu.int/comm/environment/soil/.

surveys empirical research and quantitative estimates of soil degradation impacts in different European countries in order to give an overview of the relevance of the problem. It is supported by five case studies, which will investigate for specific sites the effects that soil degradation has on soil functions, and thereby on the economic uses of soil.

The studies surveyed in this volume include estimates for a variety of impacts associated with soil degradation, both direct (e.g. yield losses due to compaction or salinisation) and indirect (e.g. losses in property values of agricultural land due to erosion, replacing eroded nutrients through fertilisation, etc.). Likewise, the analysis includes on-site as well as off-site effects of soil degradation. And, along with the direct use values of soil (e.g. for farming or forestry), it also addresses non-use values and indirect use values (or ecosystem services).

At the same time, the different impacts will be assessed subject to data availability. One function of the literature survey is to give an indication of the previous research on the different types and impacts of soil degradation, and the amount of evidence that is available. While all known effects will be mentioned, only those problems for which data are available will be examined and quantified in detail. This pertains in particular to indirect and off-site impacts, as well as to the patrimonial values attached to soil.

For those values and impacts where no data is currently available, the aim is to give a rough indication of the magnitude of the respective phenomena. This includes qualitative (non-monetary) assessments as well as transfer values inferred from related problems. Part of the study is therefore the identification of data gaps and the associated uncertainties.

The analysis will take account of the regionally diverse conditions of soil types and particular aspects of the soil degradation problem in the EU Member States. In particular, only those Member States and regions where the different soil degradation processes are most prevalent will be considered in the assessment. Thus, the objective is to cover those areas that account for about three-quarters of the economic impacts of soil degradation.

## 1.2 Outline of the Study

This literature review consists of two parts. The first part, comprising chapters 2 and 3, focuses on soil specific issues, and the second part (chapter 4) on economic issues.

Chapters 2 and 3 are of an introductory nature and set the conceptual background for the economic discussion (Chapter 4). While Chapter 2 surveys the dynamics of soil degradation process in a general form, Chapter 3 addresses different types of soil degradation in greater detail. In order to quantify relevant soil degradation factors, Chapter 2 provides an overview of the available indicators and potential data sources. The survey focuses exclusively on human-induced soil degradation, leaving aside the natural deterioration process that occur without human interference. Both Chapters 2 and 3 present a review of the available research literature on soil degradation processes and, in order to ensure an approach complementary to the work of the Commission and the Technical Working Groups, follow the method presented in the working papers available in the CIRCA library and the European Environment Agency technical reports. For the same reason, the issue of soil degradation and its impacts in Chapters 2 and 3 generally adheres to the DPSIR assessment framework.

Chapter 4 focuses on economic issues, presenting economic estimates and methodology to assess the impacts of soil degradation. This chapter introduces and critically evaluates the methods that are used to quantify the economic impact of soil degradation in hopes of developing a coherent methodology.

Finally, Chapter 5 summarises the main findings and concludes with remarks important to understanding the main concepts, methods and issues that are discussed in the scientific and economic literature on soil, indicating in particular the existing data gaps and proposing a possible methodology for the further economic evaluation of soil degradation.

# 2 Typology and Measurement of Soil Degradation

This chapter provides an overview of the main issues related to soil degradation discussed in the relevant literature and the working papers of the Technical Working Groups. The chapter will establish key concepts of soil quality and soil degradation (see Chapter 2.1), as well as discussing possible ways and past efforts to measure soil degradation (see Chapter 2.2). Chapter 3 will then focus in more detail on the different forms of soil degradation, and on their distribution and severity in Europe. The analysis and description of the different forms of soil degradation will largely be based on the DPSIR assessment framework.

## 2.1 Dynamics of Soil Degradation

Soil degradation refers to the loss of soil functions that is caused by human intervention. By contrast, soil deterioration is a wider term and describes both man-made degradation and deterioration that takes place without human influence. Soil deterioration processes occurring under natural conditions are part of the soil formation process and generally lead to a relatively slow deterioration of soil properties (e.g. water erosion in areas with relief, sedimentation, etc.). By contrast, soil degradation resulting from human activities is a process that lowers the current and/or future capacity of the soil to support human life (Oldeman et al. 1991 in EEA 1995). This study only focuses on (human-induced) soil degradation.

Soil degradation will be analysed according to the DPSIR approach, which is briefly introduced in chapter 2.1.1. The dynamics of soil degradation will be described following the four steps:

- In its natural state, soil performs a variety of different ***functions*** – most are ecological functions, but also can be social and cultural. Soil ***quality*** is indicated by its functions in relation to its service or potential. Although not strictly part of the DPSIR approach, these basic concepts are central to understanding soil degradation as a process. The notions of soil functions and soil quality are introduced in chapter 2.1.2.
- The description of human-induced soil degradation sets out with the ***drivers*** and ***pressures*** of soil degradation, i.e. those human activities and influences that cause soil degradation. Possible human-induced causes of soil degradation are discussed in chapter 2.1.3.
- The partial or complete loss of soil functions as a consequence of human influence implies a deterioration of soil quality. This process is described as ***soil degradation***. Soil degradation can occur in different forms and to different extents, and may be irreversible (see Chapter 2.1.4).
- Soil degradation, where it occurs, has different impacts. The ***direct impacts*** are the changes that take place in the soil itself (i.e. the loss of functions and the associated physical, chemical and biological changes). The ***indirect impacts***, by contrast, are the effects on other media (see chapter 2.1.7).

### 2.1.1 The DPSIR approach applied to soil degradation

This study broadly follows the DPSIR model, which is also used in the working papers of the Technical Working Groups. The indicator approach was chosen in order to consider the relevance of information to policy and decision making. Policy relevance is now commonly assessed with reference to the **P**ressure / **S**tate / **R**esponse system (PSR) developed by the OECD, or the expanded version known as the **D**riving forces / **P**ressure / **S**tate / **I**mpacts / **R**esponse (DPSIR) assessment framework adopted by the EEA. The DPSIR assessment framework offers a basis for analysing the inter-related factors that impact the environment, in order to ensure that issues are covered in a comprehensive way and that all important aspects are analysed. The EEA's DPSIR framework represents the seminal approach to analysing the cause-effect relationships of man-made environmental degradation processes with a view to possible policy responses.

In general, the DPSIR model has the form of a chain of events in which each link relates to the others (EEA, 2001a; 2001d): the main economic sectors are driving forces, whose activities give rise to pressures on the environment in the form of pollutant emissions, land use, etc. These pressures affect the state of the environment. A degraded environment in turn has impacts on other ecosystems and on the organisms inhabiting them. To bring about a change for the better, society needs to introduce responses, formulated and implemented through policies and targets. When the DPSIR framework is applied to soil degradation, it addresses the following causal chain of:

- **Driving forces**: human populations and human activities such as land development, recreation and tourism, agriculture, transport, industry/energy, mining, natural events, climate change and water stress.
- **Pressure**: emissions of pollutants to air, water and land; land use/consumption; agricultural intensification and management practices; deforestation; forest fires; waste disposal; and extraction of natural resources.
- **State**: effects of pressure on the physical, chemical and biological quality of soil, which leads to different forms of soil degradation.
- **Impacts**: effects of the altered physical, chemical and biological quality of soil on the soil itself, i.e. changes in soil functions; and on other environmental media, ecosystems and human population, e.g. changes in population size and distribution, human health, change of biodiversity (soil habitats and species), plant toxicity, change in crop yields, changes in forest health and productivity, contamination of surface and ground water, climate change and water stress.
- **Response**: the societal responses to environmental issues, such as the Thematic Strategy for Soil Protection or the CAP reform.

In this study, only the three intermediate steps – Pressures, State and Impact – will be considered; however, due to the economic angle of the study, the impacts, especially the economic impacts, will be at the centre of the analysis. The driving forces and pressures are discussed jointly in chapter 2.1.3; the state is described in the chapters 2.1.4 and in more detail in Chapter 3; and the impacts in Chapter 2.1.7 and in more detail in Chapter 4.3. The possible responses to soil degradation are not at the core of this study.

The DPSIR assessment framework applied to soil degradation is presented in Figure 2:

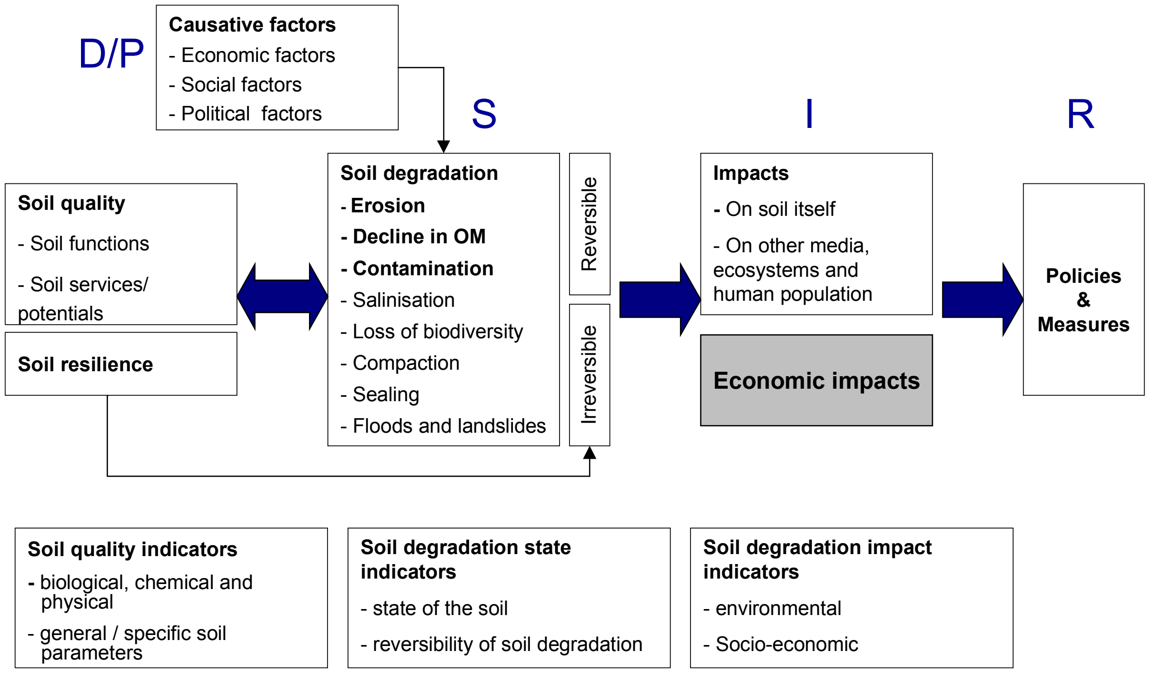

**Figure 2: The DPSIR Assessment Framework Applied to Soil Degradation**

### 2.1.2 Soil functions and soil quality

Soil performs a multitude of key environmental, economic, social and cultural functions that are vital for life. These functions could be classified into the following groups, as described in the relevant literature (European Commission, 2002; van Lynden, 1995; 2000; Blum, 1990; 1998; Council of Europe, 1990) and taken up by the WG on Research TG 9 (2003):

- **Food and other biomass production**: Food and other agricultural production, as well as forestry, are totally dependent on soil. Almost all vegetation, including grassland, arable crops and trees, need soil for the supply of water and nutrients and to fix their roots.
- **Storing, filtering and transformation**: Soil stores and partly transforms minerals, organic matter, water and energy, and diverse chemical substances. It functions as a natural filter for groundwater, the main source of drinking water, and releases $CO_2$, methane and other gases in the atmosphere.
- **Habitat and gene pool**: Soil is the habitat for a huge and diverse number of organisms living in and on the soil, all with unique gene patterns. It therefore performs essential ecological functions.
- **Physical and cultural environment for mankind**: Soil is the platform for human activity and is also an element of landscape and cultural heritage.
- **Source of raw materials**: Soils provide raw materials such as clay, gravel, sands, minerals, peat and water.

While the first three functions are mainly (but not exclusively) natural or ecological functions, the last two are clearly related to human activities.

The concept of soil functions offers a sound basis to assess soil resources and soil quality (García Álvarez et al., 2003). The capacity of soil to perform certain functions is commonly viewed as a central component of any description of soil quality. At the same time, it is difficult to provide a single universally acceptable definition for soil quality. Due to the variety of soil functions, soil can be used for different purposes. Soil quality means different things to different users of the soil. For example, in the Netherlands, a multi-functionality approach is used to assess soil quality, with the declared remediation objective of restoring multi-functionality where it has been lost through degradation (Beinat and Nijkamp, 1997). Soil quality here is understood as soil's potential to support the wide variety of soil use options that are possible in an undisturbed state (Moen and Brugman, 1987; van Lynden, 1995).

### Box 1: Soil Functions, Services and Potentials

The WG on Research TG 9 (2003) introduces the ISO 11074-1 definition of soil quality,[2] which measures soil quality as "all current positive or negative properties (biological, chemical and physical) with regard to **soil functions** and **soil uses**". The Working Group proposes, however, to adapt and develop this definition by using the term "**soil services or potentials**" instead of "soil uses". The Working Group explains that soil services and potentials introduce a dynamic element to the definition, with **soil services** referring to the capacity of soil to provide services to society and to the environment, and **soil potentials** referring to soil services that can be used in the future. The Working Group on Research TG 9 lists the following soil services and potentials:

- Nature – Countryside, green areas;
- Agriculture (plant and animal production) and Forestry;
- Residential / Commercial;
- Recreation / Leisure; and,
- Industry / Mines / Storage of waste and residues.

However, this interpretation of soil quality is still under discussion, e.g. because the distinction between services, potentials and land uses is unclear. It will therefore not be pursued further in this study. Instead, the ISO definition based on soil functions and uses will be adhered to. The concept of soil services, however, resurfaces in connection with the concept of **ecosystem services** (classified as indirect uses, cf. Box 6).

### 2.1.3 Causes and drivers of soil degradation

The focus of this study is on soil degradation, i.e. the man-made part of soil deterioration. In the investigation of man-made causes and drivers of soil degradation, socio-economic and political factors can be identified, as well as pressures exerted via other environmental media (e.g. climate change).

There are various types of human activities that cause soil degradation. Among these, deforestation and agriculture are clearly the most important. In terms of the area affected, deforestation and agriculture affect 38 per cent (84 m ha) and 29 per cent (64 m ha), respectively, of the total degraded area (van Lynden, 1995). While agriculture does not necessarily lead to soil degradation, there is some evidence that the move to intensive agriculture has aggravated the impact on soil quality, whereas traditional farming practices

---

[2] At the EU level, the term "soil quality" is relatively new and the WG on Research TG 9 (2003) discusses the differences between the terms "soil quality" and "soil health". For the purpose of this study, the term "soil quality" will be used.

are better suited to conserve soil functions. However, the abandonment of agricultural land can also induce erosion (e.g. if terraced soils are no longer maintained). Unsustainable agricultural practices and inappropriate land management can lead to different forms of soil degradation. Table 1 lists the main causative factors that can be identified and shows how they relate to different soil degradation types.

### Table 1: Overview of the Causative Factors of Soil Degradation[3]

| Causative factor | Definition | Soil degradation type |
|---|---|---|
| Agricultural causes | Improper management of cultivated arable land: intensive agriculture (incl. greater specialisation and monocultures; insufficient or excessive use of fertilisers and plant protection agents; shortening of the fallow period in shifting cultivation; poor water and irrigation management; absence or bad management of erosion control measures; improper use of heavy machinery; etc. | Erosion (water or wind), compaction, salinisation, contamination (by pesticides or fertilisers), organic matter decline, biodiversity decline |
| Overgrazing | Actual overgrazing of vegetation by livestock and trampling, a phenomenon of excessive numbers of livestock. | Soil compaction and decrease of plant cover, both of give rise to water or wind erosion, organic matter decline and biodiversity loss |
| Over-exploitation of vegetation for domestic use | A degeneration of the remaining vegetation, e.g. excessive gathering of fuel wood, fodder, (local) timber, etc. | Erosion |
| Deforestation or removal of natural vegetation | (Near) complete removal of natural vegetation (usually primary or secondary forest) from large areas, e.g. by converting forest into agricultural land, large scale commercial forestry, road construction, urban development, etc. | Erosion, organic matter decline, biodiversity decline, floods, landslides |
| Industrial activities | All human activities of a bio-industrial nature: industries, power generation, mining, waste disposal, infrastructure and construction, etc. | Soil contamination of different kinds (either point source or diffuse), salinisation, soil sealing |
| Urbanisation and transport | Increasing surface area consumption for residential uses or tourism as well as associated transport infrastructure | Soil sealing, soil contamination through storm water runoff, floods, landslides, habitat fragmentation |

Apart from these human-induced causes of soil degradation, there is also a number of other environmental parameters that strongly influence soil quality. This includes climatic

---

[3] This classification of causative factors and soil degradation types is based on the GLASOD study (van Lynden, 2000); and also adapted from Umali (1993); UNECE (2001) and EEA (1995; 2003b).

conditions (such as average temperatures), extent of snow coverage, distribution and amount of rainfall, vegetation cover, the frequency and extent of forest fires, but also the biodiversity of above-soil fauna and flora. Clearly, these factors are influenced – and some of them increasingly disturbed – by human activity. However, because the causal linkages between human activities and other ecosystems and their indirect impact on soil are only partly understood or even quantified, they have not been included systematically here.

### Box 2: An Economic Perspective on the Causes of Soil Degradation

When approaching the issue of soil degradation from an economic perspective, it is puzzling why farmers, as the main users of soil, would employ practices that contribute to soil degradation, while they will be the ones who suffer most from the consequences of degradation. Instead, it should be in the economic interests of farmers and other soil users to avoid soil degradation. There are, however, a number of possible reasons why this might not be the case:

**Lack of information and knowledge.** Although there is rich traditional knowledge on the causes and effects of soil degradation, and on the appropriate conservation measures, knowledge about the possible impacts of modern industrialised farming practices or other land uses may be scarce. This also applies to the case of contamination, where remediation is now necessary for substances that were considered uncontroversial just decades ago.

**Lack of financing.** The switch to less damaging soil uses and soil management practices may be associated with higher initial costs, e.g. for investments into conservation measures, or because less intensive soil use decreases returns. If soil users do not have access to credit to finance these costs, it is possible that damaging practices are maintained against better knowledge.

**Time preference.** The benefits of soil conservation accrue in the future, while the costs have to be covered now. By contrast, the costs of soil degradation will often become manifest only after a delay of several years or even centuries. If the soil user values his present income much higher than future benefits, practices which lead to degradation may be individually rational in a strict economic sense, even though society as a whole may have different values (see below, cf. Boardman, 2003).

**External effects.** Only part of the cost of soil degradation is actually covered by the user (the on-site costs), whereas the off-site costs are borne by other parties, or by society as a whole. For example, in the case of erosion, it has been estimated that the off-site costs through siltation and infrastructure damage exceed the on-site costs. The same can occur in the case of contaminated land, in cases where the polluter cannot be identified, cannot be held liable, cannot bear the costs or has gone bankrupt. The consequence of such external effects is that soil users do not base their decisions on the full, social costs of soil degradation, but consider only the private cost (see also Boardman, 2003).

**Market failure.** Sandler (1993) and Shortle and Abler (1998) maintain that land degradation is promoted by the failure of markets to reward landowners for the public good functions that soils fulfil, such as carbon sequestration and the provision of habitat and watershed functions. Markets will only reward those soil functions that are exploited economically, such as the provision of food and raw materials. Consequently, a landowner will have an economic incentive to preserve these marketable functions. By contrast, the provision of a habitat and the sequestration of carbon do not create a private benefit for the landowner –

instead, the benefit accrues to all members of society. Therefore, except for altruistic motives, the landowner has no incentive to preserve these functions.

**Land ownership/property rights.** As Garett Hardin demonstrated in his seminal article on “the tragedy of the commons”, the collective ownership of land resources may be a cause of soil degradation (Hardin, 1968). In the classic example, it is economically profitable for each individual farmer to leave a large number of his livestock on the commonly owned land. However, the sum of the individual decisions will lead to overgrazing. Arnalds and Barkarson (2003) argue that such problems can still be observed on common grounds on Iceland used for sheep grazing. A similar problem occurs when the owners of rented land also lack incentives to preserve the environment. A similar problem occurs in the case of rented lands: here, the tenants lack incentives to preserve the rented land beyond the rental term.

**Perverse subsidies.** Agriculture, as one of the most important use of soil, is heavily influenced by subsidies and price guarantees. In some cases, these subsidies may even promote soil degradation; one example is the support of maize, a crop that leaves a large part of the soil uncovered, thereby causing erosion (cf. Boardman et al., 2003; De Graaff and Eppink, 1999). Although the reform of the European Common Agricultural Policy aims to reduce these impacts by making subsidy payments conditional on compliance with environmental and other standards, it remains to be assessed whether this process will be successful in removing all environmentally harmful subsidies (Kraemer et al., 2003)

### 2.1.4 Soil degradation processes

Soil degradation is generally understood as the human-induced worsening of soil quality, meaning the partial or entire loss of one or more functions of the soil (Blum, 1990; 1998; Council of Europe, 1990; van Lynden, 1995). The final phase of the degradation process is land desertification, when soil loses its capacity to carry out its functions. Although the literature (Oldeman et al., 1991 in EEA, 1995; van Lynden, 1995; also see Table 2) provide various classifications of soil degradation types, this study will follow the typology that was put forward in the Communication “Towards a Thematic Strategy for Soil Protection” (European Commission, 2002). It identifies the most endangering threats to soil in Europe as:

- Soil erosion;
- Soil contamination (local and diffuse);
- Soil salinisation;
- Decline in soil organic matter;
- Soil sealing;
- Floods and landslides;
- Soil compaction; and,
- Loss of soil biodiversity.

The eight threats to soil listed above could be grouped according to changes in physical, chemical and biological properties of soil (adopted from EEA (2001a); OECD, (2001a); Cavigelli et al. (1998)):

- **Physical degradation** mainly leads to soil loss due to, e.g. wind, water and tillage erosion, and floods and landslides; to changes of soil structure due to, e.g. soil compaction, and partial or complete covering of soil due to, e.g. sealing.
- **Chemical degradation** mainly leads to changes of chemical properties of soil (loss of chemical equilibrium), e.g. accumulation of heavy metals and other (toxic) substances, due to, e.g. soil contamination or salinisation.
- **Biological degradation** mainly leads to reduced soil biota's activity and diversity, which are, respectively, due to decline in organic matter content and biodiversity in soil.

### 2.1.5 Overview: the spatial distribution of soil degradation

Using a different categorisation of soil degradation types, Oldeman et al. (1991 in EEA, 1995) provides a rough estimation of the area in Europe (excluding Russia) affected by major types of soil degradation.

**Table 2: Areas Affected by Major Types of Soil Degradation**

| Soil degradation type | Area affected (million ha) | Percentage of total European land area |
|---|---|---|
| Water erosion | 115 | 12 |
| Wind erosion | 42 | 4 |
| Acidification | 85 | 9 |
| Pesticide contamination | 180 | 19 |
| Nitrates and phosphates | 170 | 18 |
| Soil compaction | 33 | 4 |
| Organic matter losses | 3.2 | 0.3 |
| Salinisation | 3.8 | 0.4 |
| Waterlogging | 0.8 | 0.1 |

Note: Different soil degradation types can affect the same area, so the numbers cannot be added.

### 2.1.6 Soil vulnerability and resilience

The different soil threats are unevenly spread across the Europe, because not all soil types are equally susceptible to the different threats to soil. Whether excessive pressures on soil lead to a degradation of soil quality, and to what extent this occurs, depends on the capacity of the soil to deal with pressures and changing conditions. The various soil types that can be found in Europe respond differently to degradation threats; this is reflected in the concepts of *resilience* or *vulnerability*.

- The concept of **resilience** indicates the ability of a soil to resist adverse changes and to return to its original equilibrium after disturbance (WG on Research TG 9, 2003). In the longer term, the damage inflicted on the soil through a degradation process depends on the following parameters: the intensity of the pressure on soil, the extent of the degradation that follows (i.e. the loss of soil functions), and the flexibility of the soil to restore and replace the lost soil functions. In this context, it is crucial to establish whether soil degradation has surpassed a critical threshold beyond which restoration is no longer possible.

- An alternative approach is to assess the **vulnerability** of a soil to a specific degradation process (van Lynden, 1995; Batjes and Bridges, 1991). This includes site-specific parameters such as soil type, structure and texture. In addition to the environmental parameters of soil, other factors, such as topography, climate, vegetation and management practices, determine the vulnerability of the soil to certain soil degradation form (van Lynden, 1995).

While soil vulnerability is a static characteristic that describes the response of soil to certain changes in its environment, soil resilience is a dynamic measure that indicates the ability of soil to recover from degradation. Which of the two is more applicable depends on the context of the analysis. In general, the concept of resilience is broader, but more difficult to define and measure. By contrast, different measures of soil vulnerability are available. For example, Fraters (1994) has developed a qualitative assessment of the vulnerability of the main soil types for four soil degradation types (see Table 3).

## Table 3: Vulnerability of European Soils to Degradation

| Degradation type | Erosion | Compaction | Acidification | Pollution |
|---|---|---|---|---|
| **Soil type**[a] | | | | |
| Black earth | Slight | | | |
| Sands | Moderate | High | High | High |
| Acid loams | High | High | High | High |
| Non-acid loams | High | High | Moderate | Moderate |
| Clays | Slight | Moderate | Slight | Slight |
| Acid shallow | High | | High | High |
| Non-acid shallow | High | | | Slight |
| Semi-arid | High | | | |
| Salt-affected | Moderate | | | |
| Wet | | Moderate | Slight | High |
| Peat and muck | | Depends on land use and/or recovery type | | |

[a] The description of different soil types is presented in the Annex (see Table 15).

The resilience of soil also depends on the **intensity** of the degradation process. In order to describe the intensity of a degradation process, it is important to assess not only the extent and impact of the degradation process itself, but also the possibility of regeneration and the time required for regeneration. The literature divides **degradation intensity** into two stages:

- Long term harmful effects depend on the sensitivity of entire ecosystem and exceed a time limit of 50 years (Chadwick and Kuylenstierna, 1990);

- Ultimate physical degradation: soil degradation is beyond a point of no return within 50-75 years (Morgan, 1987).

The Commission Communication “Towards a Thematic Strategy for Soil Protection” (European Commission, 2002) states that “soil is essentially a non-renewable resource with potentially rapid degradation rates and extremely low formation and regeneration processes”. Therefore, certain forms of soil degradation and their consequences are **irreversible.** These include (EEA, 2003b):

- Soil losses due to soil erosion and soil sealing;
- Local contamination due to waste accumulation; and,
- Deep subsoil compaction which tends to accumulate and cannot be easy reversed.

Other form of soil degradation can be improved with adequate measures, such as clean-up and remediation plans set up to eliminate local contamination (EEA, 2001a; 2002b). These soil degradation forms and their impacts are **reversible** and include (Blum, 1998):

- Contamination which is technically reparable;
- Soil compaction through degradation of soil structure in the top layer;
- Damage caused by salinisation, which is technically reparable; and,
- Effects of depletion of nutrients and organic matter, which are technically reparable.

Whether soil degradation is reversible is generally site-specific, as the reversibility depends on soil properties, the type and severity of degradation, as well as the tendency of the degradation to increase or decrease (van Lynden, 1995).

Because of the multitude of functions that soil performs, soil degradation is an equally complex process. While specific patterns of soil degradation can be identified, it is not always possible to identify a particular threat to soil. Consequently, different types of soil degradation will often occur in conjunction, or will mutually reinforce each other (e.g. compaction may cause biological degradation, etc., van Lynden, 1995). In the assessment of the causes and drivers of soil degradation, this has to be taken into account: the same type of land use that is sustainable on one area of soil may be highly damaging on another area that has already been degraded. The impact that human activity will have on soil therefore depends on the past “degradation history” of a site; furthermore, activities leading to immediate degradation of one type may indirectly contribute to other forms of soil degradation. For an analysis of the causative factors of soil degradation, it is therefore necessary to consider these inter-relations, which are summarised in table 4.

## Table 4: Interactions Between Different Types of Soil Degradation[4]

| Degradation type | Interaction with other threats |
|---|---|
| Soil erosion | Soil erosion by reducing the potential of soils to absorb rainfall may increase the severity of flooding events.<br>Erosion leads to accelerated decline in organic matter.<br>Increasing soil erosion negatively affects soil biodiversity (decreases activity and species diversity of soil biota and the amount of microbial biomass). |
| Compaction | Soil compaction may give rise to water and wind erosion.<br>Soil compaction by reducing the potential of soils to absorb rainfall may increase the severity of flooding events.<br>Soil compaction may cause biological degradation. |
| Soil sealing | Increased soil sealing may intensify flooding.<br>Increased soil sealing may increase soil contamination. (Runoff water from sealed housing and traffic areas is normally unfiltered and contaminated with chemicals).<br>Increased soil sealing may reduce soil biodiversity. (Soil sealing affects the fragmentation of habitats). |
| Floods and Landslides | Floods can contribute to soil contamination (by washing out pollutants and depositing them elsewhere). |
| Contamination | Stress factors such as soil contamination and acidification have negative effects on soil biodiversity. |
| Salinisation | Increasing soil salinisation may reduce soil biodiversity (as those species of fauna and flora that are not tolerant to increased salinity cannot survive). |
| Decline in organic matter | Soil biodiversity is closely related to soil organic matter, because soils with an adequate amount of organic C have a good structure, allowing water and air infiltration and help provide favourable biological habitats.<br>Decline in organic matter intensifies soil erosion, on the other hand, adequate amount of organic C makes soil more resistant to erosion. |
| Loss of biodiversity | When biological activity of soil is reduced, the soil is less stable and more prone to erosion, as well as leaching and runoff cause water contamination. |

---

[4] Adapted from van Lynden (1995) and OECD (2003).

### 2.1.7 Impacts of soil degradation

With the introduction of the concept of soil quality, more attention is being paid to the assessment of the **impacts of soil degradation** on the ability of the soil to perform its functions (WG on Erosion, 2003b). The impacts of soil degradation relate to the changes in the soil itself and to the impact on other environmental media or human activity. The latter entail consequences for other components of the ecosphere that depend on soil, such as the climate system or the water cycle.

In this way, the impacts of soil degradation may be separated into direct and indirect impacts (Fons-Esteve, 2003; EEA, 2001a; 2000b):

- ***Direct impacts*** mean any changes in soil functions; whereas
- ***Indirect impacts*** mean effects on other media, ecosystems and human populations, for example: changes in population size and distribution; human health; changes of biodiversity; plant toxicity; changes in crop yields; changes in forest health and productivity; contamination of surface and ground water; climate change; and water stress.

In addition to the terms direct and indirect impacts, literature (WG on Erosion, 2003b) distinguishes between the on-site and off-site impacts. For example, the impacts of soil erosion on the soil itself are defined as on-site impacts (WG on Erosion, 2003b). These include the loss of topsoil, which disrupts soil functions, such as depletion of soil's filter and buffer capacity. The off-site impacts of soil degradation are transmitted through other media of the environment. For example, off-site impacts of soil erosion include sedimentation in downstream areas, causing a decline in water quality. Off-site effects also include the contamination of groundwater, caused by contaminated lands. In this case, while the impact on groundwater is not spatially separated from the contaminated land itself, they are nonetheless classified as off-site, as the impact affects another environmental medium. The distinction between on-site and off-site effects is also relevant to the economic assessment of soil degradation, and will be discussed in greater detail in chapter 4.3.1.

## 2.2 Measurement of Soil Degradation

This chapter will focus on the measurement of soil degradation processes and impacts. The assessment of soil degradation impacts is directly linked to the definition of soil quality. Soil quality **indicators** can be used to evaluate it quantitatively; however, there is no agreement on one common indicator for soil quality. Indicators are measurable properties of soil indicating how well the soil performs different functions. The description of soil *degradation* therefore begins with an overview of indicators that measure soil *quality* (2.1.2), investigating whether soil degradation can be measured as a negative change in these soil quality indicators.

### 2.2.1 Soil quality and soil degradation indicators

Soil quality cannot be measured directly. Rather, its assessment is achieved through the identification and measurement of physical, chemical or biological **indicators**, which are usually connected by simple empirical functions (WG on Research TG 9, 2003). Soil indicators serve to describe the situation, risks and possible trends. The identification and selection of soil quality indicators and their relationship (models/functions) is under way in the

European Union (WG on Research TG 9, 2003). Soil quality indicators are selected because of their relationship to specific soil properties and soil quality in general (e.g., traditional physicochemical indicators, such as soil organic matter or pH-values, are widely used indicators because they can provide information about a wide range of properties, such as soil fertility, soil structure, soil stability; or, e.g. biological indicators such as structural biodiversity, microbial biomass, etc.) (WG on Research TG 9, 2003; USDA, 2001).

WG on Research TG 9 (2003) claim that the comparison of several studies on soil showed a lack of a common approach or methodology; thus, “the resulting data sets were inconsistent, and allow neither for a comprehensive assessment of the soil qualities and their relationship to other environmental or health properties nor for setting up target levels or limits of soil quality parameters”. A common methodology to study and evaluate soil in different environmental settings is urgently needed (WG Research TG 9, 2003).

Since it is impractical and impossible to measure every ecosystem or soil property, many researchers have proposed a minimum data set, which is the smallest set of soil properties or indicators needed to measure or characterise soil quality (see Table 5).

**Table 5: Example of a Minimum Data Set of Indicators for Soil Quality**

| | **Soil parameter/indicator** | **Relationship to soil quality/functions** |
|---|---|---|
| Physical | Soil structure | Retention and transport of water and nutrients, habitat for microbes, and soil erosion |
| | Depth of soil and rooting | Estimate of crop productivity potential, compaction |
| | Infiltration and bulk density | Water movement, porosity, and workability |
| | Water holding capacity | Water storage and availability |
| Chemical | pH | Biological and nutrient availability |
| | Electrical conductivity | Plant growth, microbial activity, and salt tolerance |
| | Extractable nitrogen (N), phosphorus (P), and potassium (K) | Plant available nutrients and potential for N and P loss |
| Biological | Microbial biomass carbon (C) and N | Microbial catalytic potential, repository for C and N |
| | Potentially mineralizable N | Soil productivity and N supplying potential |
| | Soil respiration | Microbial activity measure |
| | Soil organic matter | Soil fertility, structure, stability, nutrient retention, soil erosion, and available water capacity |

Adapted from: USDA (2001); Doran et al. (1996); Larson and Pierce (1994); and Seybold et al. (1998).

In order to describe soil degradation, it is necessary to move from the measurement of soil quality to the measurement of changes in soil quality brought about by soil degradation. Consequently, soil degradation can either be measured as the worsening of soil quality, or by regarding the different soil functions and the extent to which they are affected by soil degradation.

For some types of soil degradation, the *state* of degradation can be described sufficiently through the change in quality indicators (e.g. decline in organic matter or soil biodiversity loss). For other degradation types, it is necessary, or at least helpful, to use individual indicators, which aim to describe the degradation process directly (e.g. tons of eroded soil in the case of soil erosion, or pollutant immissions in the case of soil contamination).

### 2.2.2 Sources of data

This section briefly reviews the work that has been carried out on the development of environmental indicators, with a particular focus on soil issues at the international level and in the European Union.

In recent years, different concepts for various environmental indicators have been developed at international and national levels. Relevant international and national indicator concepts are oriented in the structuring of environmental information primarily towards the DPSIR approach (Schramek, 2002).

A wide range of initiatives and processes requires indicators as tools to support the policy making process. At the international level, two main organisations are working on the development of indicators; they are the Organisation for Economic Co-operation and Development (OECD) and the United Nations (UN). Within the European Union, the Statistical Office of the European Union (Eurostat) and the European Environment Agency (EEA) are the main agencies working on the development of indicators. The soil relevant indicators that are developed by these organisations are summarised in Table 6.

Although the OECD and the UNSD have developed soil issue relevant indicators, there are no data related to these indicators available for different countries. The EEA European Topic Centre on Terrestrial Environment (ETC/TE) has the most developed indicator set and data set on these indicators (still incomplete, however) related to different soil degradation types. A main EEA Core Set of terrestrial environment related indicators and sub-indicators is being developed in the five areas of soil pollution (contamination), soil erosion, urban environment, coastal environment and natural hazards. The defined ETC/TE indicators do not have specified positions in the DPSIR framework.

In practice, it is indeed problematic to develop indicators according to the DPSIR[5] classification categories (Schramek, 2002). In many cases, for example, a clear differentiation between driving forces and pressure was not possible. Due to the fact that the environmental pollution (pressure) is almost always of anthropogenic origin (driving forces), it is often impossible to clearly differentiate driving forces and pressure indicators. Similar problems arise with regard to the differentiation of state and impact indicators in practice. Categorisation always follows from the perspective from which the process of environmental impact is judged (Schramek, 2002). For example, soil erosion in tonnes per hectare and year can be regarded not only as a state indicator for the loss of valuable soil material, but also as an impact indicator for the damage of water bodies into which eroded material is washed. Schramek (2002) claims that, due to complex interdependencies between the loss of soil and the destruction of soil functions, simple systems of cause and effect are difficult to define. Moreover, because of this complexity, no sound or scientifically based impact indicators were discovered on soil erosion and diffused soil contamination.

---

[5] see Chapter 2.1.1 for a discussion on the DPSIR assessment framework.

## Table 6: Overview of Soil-Related Indicators[6]

| Soil threat | OECD | UNSD | EEA / ETC/TE |
|---|---|---|---|
| Erosion | Risk of soil erosion by water<br>Risk of soil erosion by wind | Area affected by soil erosion<br>Land affected by desertification | Erosion risk of soil<br>Loss of organic matter in top soils<br>Soil erosion |
| Decline in OM | - / - | - / - | Loss of organic matter in top soils |
| Contamination | - / - | Arable and Permanent Crop Land Area<br>Use of Fertilisers<br>Use of Agricultural Pesticides<br>Forest Area as a Percent of Land Area<br>Wood Harvesting Intensity | Soil contamination from local sources, % of total (*)<br>Progress in management of contaminated sites, as degree of completeness of management steps compared to estimated total efforts %<br>Expenditures on remediating contaminated sites, € per capita and year<br>Risk of contamination of surface and groundwater from contaminated sites<br>Heavy metal accumulation in soil<br>Soil contamination by pesticides<br>Application of sewage sludge on agricultural land |
| Salinisation | - / - | Area affected by salinisation | - / - |
| Biodiversity loss | - / - | - / - | - / - |
| Compaction | - / - | - / - | - / - |
| Sealing | | Area of Urban Formal and Informal Settlements | Land cover changes in the surroundings of designated areas<br>Proximity of transport infrastructure to designated areas<br>Fragmentation of ecosystems and habitats by transport infrastructure<br>Soil sealing<br>Land take by transport infrastructure<br>Agriculture land cover changes<br>Landscape diversity |
| Floods and landslides | | Area affected by waterlogging | Population affected by natural hazards |

---

[6] Adapted from: OECD (2001a); United Nations Statistical Division (UNSD), Commission on Sustainable Development (CSD) of the United Nations; EEA (2003a), EEA, 2001a.

# 3 Types of Soil Degradation

In the following, each soil degradation type will be described in more detail following the DPSIR approach (cf. chapter 2.1.1). First , the definition of each particular type of soil degradation for the purpose of this study will be defined. Next, the **geographical** dimension of each threat will be described. Then, possible **driving forces** and/or **pressures** will be listed. Finally, the **impacts** of each soil degradation type will be presented. As the main focus of this study is an assessment of impacts of soil degradation, a response to the impacts of soil degradation types will be not reviewed in this study. In order to collect comparable information on soil quality, the indicators proposed by the literature and existing indicators (cf. chapter 2.2) for each soil degradation type will be listed.

## 3.1 Soil Erosion

### 3.1.1 Definition

Erosion is a physical phenomenon resulting from the removal of soil particles by water or wind, transporting them elsewhere (European Commission, 2002; EEA, 2003b; WG on Erosion, 2003b). Although erosion occurs as a natural geological process, human activities have intensified soil erosion, making it one of the most widespread form of soil degradation.

### 3.1.2 State - Geographical distribution

Soil erosion is regarded as one of the major and most widespread forms of land degradation (EEA, 2003c). About 17 per cent of the total land area in Europe (excluding Russia) is affected by soil erosion to some degree (Oldeman et.al., 1991 in EEA 2003b; EEA, 2003c) (also see Table 2 and Table 7). Water erosion is a more common form of erosion, contributing to 92 per cent of the total affected area. Wind erosion is also prevalent in some parts of western Europe and Central and Eastern Europe (EEA, 2003b; 2003c).

Three zones of erosion can be distinguished in Europe: a southern zone characterised by severe water erosion; a northern loess zone with moderate rates of water erosion; and an eastern zone where the two zones overlap and where former intensive agricultural practices caused significant erosion problems (EEA, 2000b). Within all three zones, there are areas where erosion is more serious, the so-called **hot spots**. Erosion is also an important problem in Iceland (EEA, 2000b).

The largest area with a high erosion risk is southern and western Spain (covering 44 per cent of the country’s territory), with local erosion hotspots on the southern coast (EEA, 1995, 2000b). In Portugal, one-third of the country is at a high risk of erosion. In France, Italy and Greece, the areas with a high erosion risk cover from 1 to 20 per cent of the land surface respectively. In Central and Eastern Europe, Bulgaria and Slovakia are mostly affected by soil erosion, where around 40 per cent of land is affected. (EEA, 2003b, 2003c) Table 7 provides an overview of the extent of erosion in Europe.

### Table 7: Extent of Soil Erosion in Europe (million ha)[7]

| | Erosion type | Light | Moderate | High | Extreme | Total |
|---|---|---|---|---|---|---|
| EU-15 | Water erosion | 12.8 | 11.9 | 1.4 | 0.0 | 26.2 |
| | Wind erosion | 1.0 | 0.1 | 0.0 | 0.0 | 1.1 |
| | Total | 13.8 | 12.0 | 1.4 | 0.0 | 27.3 |
| New Member States | Water erosion | 4.5 | 29.2 | 14.7 | 0.0 | 48.4 |
| | Wind erosion | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 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 |
| | 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 |
| | Total | 0.8 | 25.1 | 6.5 | 1.7 | 34.2 |
| Europe (excl Russia) | Water erosion | 18.9 | 62.0 | 22.6 | 1.1 | 104.6 |
| | Wind erosion | 1.6 | 7.2 | 0.0 | 0.7 | 9.5 |
| | Total | 20.5 | 69.2 | 22.6 | 1.8 | 114.1[8] |

### Box 3: Prediction Models for Soil Erosion

To predict areas at risk of erosion, different models are being developed. For example, there are different maps created for water and wind erosion (CORINE, 1992; van Lynden, 1994; EEA, 2003b). According to a CORINE (1992) estimation, in Europe, 115 million ha are affected by water erosion; 42 million ha are affected by wind erosion, of which 2 per cent are severely affected (EEA, 1995). The mapping of soil, evaluation and definition of its risk to erosion have been undertaken on various scales in Europe, as well as at the national and regional levels. For example, the Pan European Soil Erosion Risk Assessment (PESERA) project is currently calibrating a spatial model to quantify soil erosion by water and assess its risk across Europe (WG on Erosion, 2003b).

### 3.1.3 Possible causes

In general, Northern and Western Europe are principally prone to erosion due to a combination of factors, such as their post-ice age topography, immature soils and climate (e.g. extremes of rainfalls and snowmelts) (WG on Erosion, 2003b). In addition, the Mediterranean region is particularly vulnerable to erosion due to long dry periods followed by

---

[7] EEA, 2003c.

[8] 17.4 per cent of total land area.

intense rainfall on steep slopes with fragile soils (WG on Erosion, 2003b). The increase in frequency and extent of forest fires in the Mediterranean region has also had a significant impact on soil erosion (EEA, 2003b). In some parts of the Mediterranean region, severe erosion has lead to a complete loss of the soil cover (EEA, 2003b). In addition, Sauerborn et al. (1999) and EEA (2003b) predict that the effects of soil erosion will worsen in the future due to climate changes that could influence rainfall patterns in ways that would increase soil erosion in central Europe.

Erosion is also caused by unsustainable agricultural practices (e.g. large-scale farming and overgrazing, and poor water and irrigation management) and land cover patterns (e.g. sparse vegetation) (UNECE, 2001; EEA, 2003b). In addition, in topographically complex landscapes, severe degradation is caused not only by wind and water, but also by tillage, mainly due to the use of heavy and powerful tilling machinery (EEA, 2003b). Tourism and transport may also be important driving forces in localised areas (EEA, 2003b; 2003c). Moreover, some intrinsic features of a soil can make it more prone to erosion (e.g. a thin layer of topsoil, sandy or silty texture or low organic matter content).

### 3.1.4 Impact

Serious erosion is generally irreversible. According to WG on Erosion (2003), due to very slow rates of soil formation, losses of soil exceeding 1 t/ha p.a. (tonne per hectare and year) can be considered irreversible over a period of 100 years. Moreover, extreme rainfall events can cause losses of soil of more than 100 t/ha p.a.. In South East England, for example, wind erosion has been recorded at 21 t/ha p.a. over a 30 year period. Moreover, in more than one third of the total land area of the Mediterranean basin, average yearly soil losses exceed 15 t/ha (UNEP, 2000). As the topsoil is eroded and washed away, the fertility and productivity of the remaining soil is reduced. Farmers have to apply more fertilisers to compensate for yield losses (EEA, 2003b). While *losses of soil in t/ha p.a.* are a direct impact of soil erosion, the consequent damages to natural ecosystems and water bodies are indirect impacts. For example:

- Soil material eroded from agricultural land can physically disturb natural ecosystems.
- In water bodies, sediment desposits can have severe implications for aquatic life and human health (EEA, 1995). Nutrients and contaminants (e.g. pesticides, fertilisers, heavy metals, etc.) are attached to eroded soil particles. When these particles are carried downstream, the water and aquatic ecosystems of rivers and seas become contaminated, which can also damage water reservoirs, ports and canals.
- Water erosion typically affects crop production through a decrease in plant rooting depth, as well as removal of plant nutrients and organic matter. Sometimes water erosion can lead to uprooting of plants and/or trees, together with dissection of the terrain by rills and gullies (EEA, 1995).
- The water-holding capacity of the soil can also be lowered through erosion, leading to an increased occurrence of floods and landslides.

### 3.1.5 Soil erosion indicators

The degradation of soil due to erosion can be quantified as:

- *area affected by erosion (ha);*
- *area under risk of erosion (ha);*

- *mass of eroded soil (tonnes);*
- *actual losses of soil (t/ha p.a.);*

Schramek (2002) made a comprehensive overview of relevant OECD, EEA, CDS, Eurostat and other soil erosion relevant indicators, which can be used to assess soil erosion:

- *actual soil erosion risk (t/ha p.a.);* (State indicator for water erosion. Can be calculated with mathematical prediction models. Since agricultural activities are the main driving force of soil erosion, this indicator can be separated for agricultural and non-agricultural land).
- *sediment loads in water bodies (t);* (Monitored impact indicator. Used quantify off-site or indirect impacts of soil erosion through water in compartments next to the eroded area).[9]
- *Monitored sediment loads in rivers (t/m$^3$ p.a.);* (Impact indicator to evaluate off-site damage by sedimentation in compartments next to the eroded area).
- *Model based calculations of sedimentation from arable land;* (Impact indicator to evaluate off-site damage by sedimentation in compartments next to the eroded area).
- *Costs of disposal of sedimentary material (€);* (Impact indicator to evaluate off-site damage by sedimentation output in compartments next to the eroded area).

## 3.2 Decline in Organic Matter

### 3.2.1 Definition

Soil organic matter (OM) has a very complex origin and resulting composition which depends on carbon (C) dynamics. It is composed of organic material (e.g. plant root remains, leaves), living organisms (e.g. bacteria, fungi) and humus. As such, soil OM is constantly built up and decomposed, so that C is released to the atmosphere as $CO_2$ and recaptured through the process of photosynthesis (European Commission, 2002). Soil OM plays multiple roles the physical, chemical and biological properties of soil, i.e. it strongly influences soil structure and therefore supports plant growth; it contributes to energy and nutrient storage and supply and thus supports soil biota; and it contributes to the filtering function of soils by providing a specific binding capacity for numerous pollutants (WG on Research TG 3, 2003). In addition to biomass production function, soil OM is responsible for the environmental functions of soil (e.g. maintenance of water and air quality).

### 3.2.2 State - Geographical distribution

EEA (1995) claims 3.2 million hectares suffer from losses of nutrients or OM in Europe (see Table 2). The WG on Organic Matter (2003) argues that the data availability on OM matter at the European scale is limited, and that currently, the most comprehensive data on the

---

[9] The author also indicates, that “methodological approaches to measure sediment loads in river and streams do in fact exist, but monitoring results are unsuitable as impacts indicators for soil erosion”, because the monitored sediment provides no indication of its agricultural origin or the size of the catchment area. Methodical approaches to calculate sedimentation from arable land with models are still not “sufficiently advanced to permit their use as impact indicator”.

content of OM are based on the soil type database complemented by land cover, climate and topography. According to these factors, “hot spots” with very high amounts of C can be identified in the sub-boreal and alpine soils, and in peat and other organic soils (WG on Organic Matter, 2003).[10] Due to a combination of the natural and human-induced factors (such as intensive agriculture), the decline of OM is of particular concern in the Mediterranean region. According to the European Soil Bureau (cited in European Commission, 2002; and WG on Organic Matter, 2003), nearly 75 per cent of soils there have a low (3.4 per cent) or very low (1.7 per cent) OM content. The problem is, however, not restricted to the Mediterranean area. Figures for England and Wales show that the percentage of soils with less than 3.6 per cent OM rose from 35 per cent to 42 per cent in the period of 1980-1995 (due to changing management practices). In the same period, in the Beauce region, south of Paris, soil OM has decreased by half for the same reason (European Commission, 2002). In contrast to arable land, forest and grassland have a relatively high carbon content.

### 3.2.3 Possible causes

Intensive forms of land use (e.g. monoculture and specialisation of farming when decomposing OM in the soil is not sufficiently replaced), as well as land uses not adapted to site restrictions, lead to a decline in the OM content in soil (European Commission, 2002; WG on Research TG 3, 2003). In addition, deforestation and conversion of forest or permanent pastures to arable land is also an important factor leading to the loss of soil organic matter. For example, WG on Organic Matter (2003) find a loss of carbon from 20 to 50 per cent in arable lands. Positive farm management practices, in contrast, tend to build up more organic matter in the soil (e.g. conservation tillage, organic farming, permanent grassland, farmyard manure and compost) (European Commission, 2002).

A special type of OM decline is related to the extraction of peat from mires and peatlands (Joosten and Clarke 2002, EEA 1995). Peat is used as an organic fertiliser in agriculture, but mainly in horticulture. For this end, in 1999, 24.6 m $m^3$ of peat were produced in the old and new EU Member States.[11] Traditionally, peat has also been widely used as a fuel; in parts of Finland, Ireland, Sweden and the Baltic Countries, peat continues to be a regionally important source of energy. In 1999, these six countries used an estimated 14.3 m tonnes of peat for energy production. Peat is also used for other purposes, such as a filter and absorbent material, as litter in animal husbandry, as building material and as an input for whisky production. Potential future uses for peat include the remediation of degraded soils and as topsoil replacement for the regeneration of former open-cast mining sites.

### 3.2.4 Impact

A decline in soil OM content leads to both direct and indirect impacts:

- Soil OM plays a central role in maintaining key soil functions, such as keeping soil structure, retaining water and as a nutrient reserve, and is thus an essential determinant of soil fertility.

---

[10] The dominant effect of low temperature and high moisture explains this high accumulation of organic matter.

[11] All numbers and evidence in this box quoted from Joosten and Clarke (2002).

- Soil OM content determines its capacity to absorb pollutants. When its biological activity is reduced, soil is more prone to leaching, affecting ground and surface water quality.
- A decline in OM leads directly to a loss of biological activity and biological diversity of soil.
- As C is a major component of soil OM, soil is one of the biggest pools of C, which in turn plays a major role in the global C cycle. Research indicates that approximately 2 Gt[12] of C are captured (sequestered) in soil OM annually (Lal, 2000; European Commission, 2002).[13]

## Box 4: Peat Extraction as a Special Type of Organic Matter Loss

In one crucial respect, peat mining differs from other examples of OM decline: in other cases, soil degradation is normally an unintended side-effect of other activities. By contrast, if peat is extracted for commercial or private use, this is an intentional process, which carries its benefits in the commercial value of peat as a resource. Seeing it from the point of view of an economic analysis of soil degradation, however, provides a different perspective.

Similar to other mining processes, the concept of resource costs, rather than that of environmental costs, is applicable. Although peat is accumulated over time, it is essentially non-renewable in the timeframe of an economic analysis. Therefore, if peat is extracted for human use, the value of the peatland declines. This also includes the ecological functions of mires that are disturbed or destroyed if peat is extracted: In addition to the extractive uses of peat as a resource, peatlands also perform a number of functions in situ. These include the regulation of global and local climate through carbon sequestration, biodiversity maintenance and the storage and purification of water.

- In their function as carbon sinks, mires form a substantial part of the global carbon cycle. Other than that, bogs and mires also have a considerable influence on the local and regional climate.
- Regarding the function of biodiversity maintenance, peatlands perform valuable functions because they provide a very special niche to the species inhabiting them. Bogs provide particular conditions, including a scarcity of oxygen in the root layer and a scarcity of nutrients. Consequently, very specific species can be found there.
- Another important function of peatlands is the storage, filtering and purification of water. Water in mires is generally of a high quality and provides good drinking water after humic acids have been removed.
- Next to these ecological functions, peatlands also assume important social and cultural functions, e.g. if they are used for recreational activities such as hiking and hunting. Subsequent layers of peat also act as an archive of natural conditions and human life in past centuries.

Consequently, a trade-off is necessary between the foregone ecological functions and the benefits resulting from human uses of peat (see also Box 6 on ecosystem services).

---

[12] 1 gigatonne equals 10 billion tons (1 Gt = $10^9$ t).

[13] This amount can be compared to the 8 Gt of anthropogenic C emitted to the atmosphere annually, which underlines the importance of soil organic matter to climate change.

Although there are no comprehensive monetary assessments of the economic and ecological value of peatlands, it is evident that, in many cases, the ecological functions of peatlands were only recognised after they already had been lost. For example, in Ireland, it has been estimated that 80 percent of all bogs have been lost over the last century. Large-scale, mechanised turf extraction schemes in the 1940s, afforestation and intensification of agriculture, as well as land reclamation and drainage, have seriously depleted the area of peatland suitable for conservation.

### 3.2.5 Decline in organic matter indicators

*Soil organic matter content by volume (%); by mass (%); and carbon (C) contained in soil (t)* could quantitatively express the decline in organic matter in soil. ETC/TE proposes one state indicator related to decline in organic matter, namely *loss of organic matter in top soils* (see also Table 6), however no data are provided. For the assessment of the decline of OM due to peat use as a resource, *annual peat extraction (t)* could be used.

## 3.3 Soil Contamination

### 3.3.1 Definition

While **diffuse soil contamination** is difficult to localise**, local soil contamination** (or point-source) problems occur in specific sites. Contaminants related to both diffuse and local soil contamination comprise, e.g. heavy metals, organic compounds, etc.. The Working Group on Contamination proposes a two-level definition of contaminated sites:

- **Potentially contaminated site**: “site where an activity is or has been operated that may have caused soil contamination”.
- **Contaminated site**: “site with confirmed presence of dangerous substances caused by man in such a level that they may pose a risk to a receptor in such a way that remediation is needed. The risk is evaluated on a site-specific base”.

In addition, considering the impact of a contaminated sites on other relevant fields, the WG on Contamination (2003) proposes a definition for **megasites**: “site where pollution is so bad that it has EU dimension (meaning that the site is relevant for existing EU policy)”.

### 3.3.2 State - Geographical distribution

Soil contamination is one of the most widespread types of soil degradation in Europe: 180 million ha are affected by pesticides; 170 million ha by nitrates and phosphates; and 85 million ha by acidification (Oldeman et al., 1991 in EEA, 1995) (see also Table 2). EEA (2003b) and van Lynden (2000) give the most comprehensive overview of diffuse pollution in different countries; however, these sources concentrate mainly on Central and Eastern European countries. According to them, acidification is the most widespread type of soil contamination in Poland (10 million ha, including natural acidification). A high concentration of heavy metals is estimated in Lithuania (nearly 3 million ha).[14] Contamination by pesticides is also common in Romania (more than 4 million ha).

---

[14] The high concentrations can partly be explained by high natural background levels (EEA, 2003b).

The data on local soil contamination are incomplete due to the various classification systems used in different countries (EEA, 2003b). EEA-UNEP (2000) and EEA (2003b) report that the Nord-Pas de Calais in France, the Rhein-Ruhr region in Germany, Belgium, the Netherlands and the south of United Kingdom are the largest and probably most heavily affected areas, as they are concentrated around the most industrialised regions in Northern Europe. Furthermore, the Saar region in Germany and France, the Bitterfeld region in the East of Germany, the Po area in northern Italy, and the so called Black Triangle region located at the corner of Poland, the Czech Republic and the Slovak Republic are the areas with a high probability of local soil contamination (EEA-UNEP, 2000; EEA 2003b).

### 3.3.3 Possible causes

The causes of soil contamination are manifold. Hazardous substances are emitted at all stages of the product chain, from the raw material and the production processes, from the use of products and from the handling of products as waste. Emissions can arise from:

- **Point sources**, like industrial installations; industrial plants that are no longer in operation; storage installations; industrial accidents (also past); improper industrial and municipal waste disposal; and mines. Due to the large variety of influencing activities, different pollutants might cause contamination in different countries or regions.
- **Diffuse sources**, like agriculture, atmospheric deposition and consumer products. The pollutants can reach the soil via dry or wet deposition, such as atmospheric deposition of acidifying and eutrophying compounds; potentially harmful chemicals; deposition of contaminants from flowing water or eroded soil itself; or via waste disposal. The pollutants can reach the soil also via the direct application of substances such as plant protection agents (e.g. pesticides), fertilisers (e.g. farmyard manure, mineral fertilisers), the spreading of sewage sludge and compost. Fertilisers and sewage sludge can also contaminate soil with heavy metals.

### 3.3.4 Impact

Due to the wide variety of soil pollutants and concentrations, as well as natural factors such as soil type and climate conditions, the impacts of soil contamination may be extremely varied. In general, soil contamination affects both the soil itself and the other media. The direct impacts include:

- Soil contamination restricts buffering and substance conversion capacities of soil.
- The contamination of soil causes the uptake of contaminants by soil biota.

In terms of the effects on other media, soil contamination primarily affects groundwater. However, ecosystems and human health, are also strongly affected by soil contamination:

- The contamination of soil leads to the leaching of pollutants, especially nitrate (due to intensive application of fertilisers), into the ground- and surface water.
- The contaminated soils remove greater amounts of nitrogen from the soil back into the atmosphere as nitrous oxide through the denitrification process than would occur naturally. Nitrous oxide, as one of the greenhouse gases, consequently influences the climate change process.
- The contamination of soil and groundwater causes the uptake of contaminants by plants.

- The contaminated soil itself, as well its effects on other media, affects public health (e.g., ingestion by children in playgrounds) and thereby restricts potential uses of the soil.

### 3.3.5 Soil contamination indicators

The following could serve as main indicators to quantify soil contamination.

- *Area affected by contamination (ha);*
- *Number and average size (ha) of sites in different impact categories;*
- *Heavy metal content of soil (mg/kg dry soil material);*
- *Organic pollutant contents of soils (µg or mg/kg dry soil material);*

Schramek (2002) made an overview of the most comprehensive list of indicators relevant to diffuse soil contamination developed by the OECD, EEA, Eurostat and CSD. The state and impact are listed bellow:

- *$N_{(min)}$ contents in soils (mg $NO_3$ + $NH_4$ per 100g soil)* (State indicator for soil eutrophication);
- *Heavy metal content (mg/kg)* (State indicator for inorganic contaminants);
- *Actuatable heavy metals prop. (% of heavy metal content)* (State indicator for inorganic contaminants);
- *Organic pollutions content (µg or mg/kg dry soil material)* (State indicator for organic contaminants);
- *Hypothetical nitrate conc. (in mg $NO_3$/l) in recharged groundwater* (Impact indicator for nitrate contamination of ground water and nitrous oxide emissions);
- *Comparison of predicted with actually monitored on-site biocenose* (Impact indicator for toxic effects for plants, animals and people).

In addition, ETC/TE defines four soil pollution indicators:

- *Soil contamination from localised sources, including information on:* Progress in management of contaminated sites, expenditures on remediation, and risk of contamination of surface and groundwater from contaminated sites.
- *Heavy metal accumulation in soil;*
- *Soil contamination by pesticides; and,*
- *Application of sewage sludge on agricultural land.*

However, data are not available for all of these.

## 3.4 Soil Salinisation

### 3.4.1 Definition

Salinisation is defined as the accumulation of soluble salts (sodium, magnesium, and calcium) on or near the surface of the soil, to the extent that soil fertility and productivity are severely reduced (European Commission, 2002; EEA, 2003b).

### 3.4.2 State - Geographical distribution

In Europe, the surface area affected by salinisation is estimated to be 3.8 million ha (Oldeman et al, 1991 in EEA, 1995; Szabolcs, 1991) (see also Table 2). Salinisation is strongly tied to site-specific soil properties and climatic conditions, and its distribution is therefore restricted to South Eastern Europe, where semi-arid or arid conditions prevail (Fraters, 1994; EEA, 1995). Soil salinisation affects nearly 1 million ha in the Mediterranean countries. In Spain, 3 per cent of the 3.5 million ha of irrigated land is severely affected and another 15 per cent is under serious risk (MMA, 2001; European Commission, 2002). In the Hungarian plain, for instance, more than 20 per cent of the region are affected by salinisation and alkalinisation (Fraters, 1994; EEA, 1995). In Romania, it is estimated that 200,000 ha have been salinised, which represents about 6 per cent of total irrigated land (Fraters, 1994; EEA, 1995).

### 3.4.3 Possible causes

Salinisation is caused by the demands of growing urbanisation, industry and agriculture. In the case of agriculture, improper irrigation practices contribute to the problem, e.g. by using irrigation water with a high salt content. Salinisation is particularly problematic in regions where low rainfall, high evapotranspiration rates of saline soil moisture or soil textural characteristics impede the washing out of the salts, which subsequently build up in the soil surface layers. It may also arise through the intrusion of salt water from the sea or from saline fossil sources (EEA, 1995). On a smaller scale, salinisation in Nordic countries is caused by the winter maintenance of roads with salts (European Commission, 2002).

### 3.4.4 Impact

Salinisation has direct negative effects on soil biology and soil structure (alkalinisation), which consequently leads to loss of soil stability (EEA, 1995). It negatively impacts agricultural yields (crop productivity). Gardner (1997) in EEA (2003b) estimates that in the Central Asian Republics, salinisation reduced cotton yields from 280 to 230 tonnes/km$^2$ between the late 1970s and the late 1980s, despite the increased use of fertilisers. Salinisation may also have important off-site effects, because salt that has moved to the upper layer of the soil can be carried to other areas by the wind (EEA, 2003b).

Salinisation is generally reversible; however, above certain thresholds, remediation is very expensive, if not impossible. Most of the severely affected areas are abandoned without any attempt at rehabilitation; for example, this applies to about 300,000 ha of affected soil in Russia (Stolbovoi and Fischer, 1997; EEA, 2003b).

### 3.4.5 Soil salinisation indicators

The following indicators could serve to quantitatively evaluate soil salinisation:

- *area of soil affected by salinisation (arid / semi-arid zones / coastal regions) (ha);*
- *groundwater salinity (mg/l); and*
- *salt content in soil (Ca, Mg, Na; Cl, $SO_4$, $HCO_3$) (mg/l).*

ETC/TE does not indicate any indicator related to soil salinity.

## 3.5 Loss of biodiversity

### 3.5.1 Definition

Soil is one of the most diverse habitats and contains the most diverse collection of living organisms. Soil biodiversity reflects the mix of these living organisms, which include: micro-organisms (bacteria, fungi, etc.), micro-fauna (protozoa, nematodes, etc.), meso-fauna (acari, springtails, etc.) and macro-fauna (insects, earthworms, etc.) (OECD, 2003). Soil structure and soil biota are interdependent; thus, soil quality and soil resilience both depend on soil biodiversity.

### 3.5.2 State - Geographical distribution

No comprehensive data exist on the status of soil biodiversity in Europe. Due to the high macro-, meso- and micro-biological diversity, as well as seasonal effects of a different nature and magnitude, the biological quality of soil cannot easily be predicted. WG on Research TG 3 (2003) claim that, although research on soil biodiversity has been carried out in European countries, it is still impossible to reliably quantify the richness and evenness of microbial species due to methodological difficulties and gaps in knowledge on the structural and functional biodiversity of soil organisms.

### 3.5.3 Possible causes

Agricultural practices are the main stress factor for soil biodiversity. Depending on management practices and land use types, agricultural practices can have both positive and negative impacts on soil biota. For example, organic farming results in an increased mass and activity of soil organisms and increased N mineralisation, thereby increasing soil fertility. The misuse or overuse of many agricultural practices, such as intensive soil tillage, pesticide use and monocultures, have negative effects on soil biodiversity.

Soil biodiversity as an inherent value of soil is affected by all forms of soil degradation, in particular soil erosion, contamination, acidification, salinisation and compaction. The OECD (2003) claims that there is a strong link between soil erosion and soil biodiversity. Loss of soil biodiversity intensifies soil erosion, while erosion negatively affects soil biodiversity, decreases activity and species diversity of soil biota, and reduces the amount of microbial biomass. In addition, soil biodiversity is closely related to soil organic matter, since soils with adequate amounts of organic carbon have good structure, allow more water and air infiltration and help provide favourable biological habitats (OECD 2003).

### 3.5.4 Impact

The loss of soil biodiversity negatively affects:

- food web functioning (from organic residues to fungi and bacteria and to grazers and predatory organisms) and consequently crop yield.
- soil formation, nutrient cycling, nitrogen fixation, C sequestration, resilience of the soil to endure pressures, recycling of organic waste, infiltration rate, water holding capacity and bioremediation capacity.
- soil structure by affecting the stabilisation of organo-mineral complex (OECD, 2003).

- the genetic resources present in the soil, including moral and ethical consequences (WG on Research TG 3, 2003).

### 3.5.5 Loss of soil biodiversity indicators

The quantification of soil biodiversity is highly difficult due to its extremely complex nature. Nevertheless, there are some studies on biodiversity indicators, e.g. OECD (2003). They propose the following minimum set of indicators:

- Micro organisms (soil microbial biomass and number, microbial activity, soil microbial diversity and community structure, plant micro organism relationships);
- Meso- and macrofauna (e.g. nematodes, earthworms, microarthropods) and a typology of biogenic structures; and,
- Total organic carbon (C), biomass ratio C biomass/total C; C metabolic quotient, $CO_2$ production, Shannon-diversity index.

The first two indicators allow to quantitatively evaluate the *decline in a number of species (%)*, expressing the impact of a loss of soil biodiversity. The third indicator is directly correlated with the organic matter content of the soil; therefore, the indicators of loss of organic matter might be used to express loss of soil biodiversity as well (see also 3.2.5). Moreover, the possibility of using soil biodiversity as an indicator to monitor the efficiency of soil bioremediation processes is also under discussion (OECD, 2003).

ETC/TE does not indicate any indicator relevant to loss of soil biodiversity.

## 3.6 Soil compaction

### 3.6.1 Definition

Soil compaction is a form of physical soil degradation. According to the WG on Research TG 1 (2003), “compaction is a process of densification and distortion in which total and air-filled porosity and permeability are reduced, strength is increased, soil structure partially destroyed and many changes are induced in the soil fabric and in various behaviour characteristics”.

### 3.6.2 State - Geographical distribution

Preliminary estimates in 1991 show that the area in Europe (excluding Russia) affected by soil compaction may equal or exceed 33 million ha (Oldeman et al., 1991 in EEA, 1995, see also Table 2). Soil compaction is widely distributed but tends to be most prevalent in agricultural areas and forest regions where heavy machinery is continuously used. Almost all agricultural soils in developed countries are affected by soil compaction to a certain degree (WG on Research TG 1, 2003). Deep soils with less than 25 per cent clay content are most sensitive to subsoil compaction (Hebert, 1982 in EEA, 1995). According to the EEA (1995), such sensitive soils are common in Belgium, north-western France, Germany, the Netherlands, Poland and Russia. Van Lynden (1995; 2000) in EEA (2003b), indicates that soil compaction is one of the main forms of soil degradation in Central and Eastern Europe (including Russia) and has affected over 62 million ha, or 11 per cent of the total land area.

In arable land with annual ploughing, both topsoil and subsoil compaction should be considered (WG on Research TG 1, 2003). Contrary to the topsoil, the subsoil is not loosened annually; therefore, the soil compaction is accumulative there, and in the long run a more or less homogenous compacted layer is created. The compaction of topsoil can easily be dealt with by reworking the soil, and can eventually be reversed if the biological processes in the soil remain undisturbed; however, deep compaction of subsoil is persistent and cannot easily be reversed (EEA,1995).

Depending on soil type (low or high compactibility), the vulnerability of soil to compaction differs (WG on Research TG 1, 2003). For example, sandy soils are, in general, resistant to soil compaction. Soil moisture has a dominant influence on soil compactibility. For example, dry structured soils are more resistant to soil compaction. With the increase of moisture in soil, soil compactibility also increases.

### 3.6.3 Possible causes

Soil compaction is mostly caused by the repetitive and cumulative effects of heavy machinery use on the same piece of agricultural land (especially on wet soils). Animal grazing is the second major cause of soil compaction.

### 3.6.4 Impact

Soil macro pores are the most vulnerable pores to soil compaction (WG on Research TG 1, 2003). Created by soil biological processes, macro pores determine to a large extent the physical and biological qualities of soil. In most cases, macro pores are continuous and therefore form routes for air and water in the soil. The indirect impacts of compaction on other media include:

- soil compaction results in reduced water infiltration capacity and increases the volume of surface runoff, which also accelerates other soil degradation forms, such as water erosion and flooding.
- the increased volume of surface runoff may also transport nutrient and agro-chemicals into water courses and thereby contribute to water pollution.
- soil compaction also changes the quantity and quality of biochemical and microbiological activity in the soil. Due to soil compaction, the biological activity is reduced. This affects organic matter development and soil biodiversity and, as a result, soil productivity.
- the worsened plant growing conditions due to soil compaction result in higher vulnerability of the crops to diseases (WG on Research TG 1, 2003).
- a poor aeration of soil due to soil compaction may cause a loss of soil nitrogen and emissions of greenhouse gases through denitrification in anaerobic sites.

### 3.6.5 Soil compaction indicators

The *area affected by different degrees of compaction (ha)* and the *density of the topsoil (kg/m$^3$)* may serve as a key indicators in order to quantitatively evaluate the soil degradation due to soil compaction. In addition, farm structure should be considered, as compaction occurs more frequently on large farms. ETC/TE does not indicate any indicator for soil compaction.

## 3.7 Soil sealing

### 3.7.1 Definition

There is hardly any internationally recognised definition of soil sealing. The European Commission (European Commission, 2002) defines soil sealing as the covering of soil for built-up areas, roads or other land developments. Blume (1992) defines it as the anthropogenic isolation of the land from the atmosphere by covering with impermeable substances like tar, concrete or buildings. The most general definition, which will be also considered in the current study, is given by the WG on Research TG 5 (2003): “soil sealing is the separation of soils by layers and other bodies from totally or partially impermeable material from other compartments of the ecosystem, such as biosphere, atmosphere, hydrosphere, antrophosphere and other parts of the pedosphere”.

### 3.7.2 State - Geographical distribution

Soil sealing has the greatest impacts in urban and metropolitan areas, where large areas of the land are covered with buildings and infrastructure. Over the past 20 years, built-up areas have been steadily increasing all over Europe (EEA, 2003b).

The EEA (2002b, 2003b) reports that Belgium, Denmark and the Netherlands are the countries with the highest share of built-up area (between 16 per cent and 20 per cent of total land area). In the Mediterranean countries, i.e. southern France, Italy, southern Spain and the Mediterranean islands, urbanisation has been increasing in the coastal zones, where tourism is the main driving force (EEA-UNEP, 2000; EEA, 2003b).

In Central and Eastern Europe, the extent of built-up area was more or less constant during the late 1970s and the first half of the 1980s (EEA, 2003b). Political and economic changes during the late 1980s resulted in the development of new infrastructure, the migration of rural populations to the cities and the development of new settlements (Baltic Environmental Forum, 2001; EEA, 2003b), with consequent increases in soil sealing. Slovakia and the Czech Republic have the highest percentage of built-up area (about 8 per cent of the total land area). Pressure is increasing in some coastal zones of the Baltic Sea region, for example along the Baltic Sea coast of Germany, Latvia and Russia (Coalition Clean Baltic, 2002; EEA, 2003b).

### 3.7.3 Possible causes

According to EEA (2002b, 2003b), soil sealing in Western Europe, is mainly the result of the steady increase in the number of households and average residential space per capita since 1980. This trend has accelerated since 1990 (EEA, 2001c; 2003b). At the same time, road infrastructure increased, adapting to increasing travelling distances (EEA, 2000a; 2003b). The demand for both new constructions and better transport infrastructures continues to rise.

### 3.7.4 Impact

Due to soil sealing, most of the natural soil functions are hampered, although not all of them are completely disrupted. In addition to these direct impacts, soil sealing can also result in:

- fragmentation of habitats and disruption of migration corridors for wildlife (EEA 2003b)

- soil sealing can have a major impact on water quality: runoff water from housing and traffic areas is normally unfiltered and may be contaminated with harmful chemicals.
- sealed areas may also have a great impact on surrounding soils by changing water flow patterns, increasing a runoff of water and eventually resulting in a higher risk of floods (PIK, 2000; EEA, 2003b).
- the increasing demand for land for new residential areas or industrial facilities has resulted in development in areas at high risk of flooding (UNECE, 2000b; EEA, 2003b).

Soil sealing can be regarded as part of land use, and as the last step within the consumption of land for human use (WG on Research TG 5, 2003). It is almost irreversible (European Commission, 2002).

### 3.7.5 Soil sealing indicators

Soil degradation due to soil sealing can be quantified through key indicators such as:

- *area sealed with buildings and other structures (built-up area) (ha / %); or*
- *area affected by different degrees of sealing, (ha / %).*

ETC/TE proposes a list of soil sealing and land cover changes indicators such as :

- *built-up areas (as percentage of total land);*
- *present increase of build-up areas (%);*
- *land take by urban sprawl (urban share for major cities in Europe, i.e. the distance under which more than 40 per cent of the are can be considered as urban (km).*

## 3.8 Floods and landslides

### 3.8.1 Definition

Floods and landslides are mainly natural phenomena, but can be enhanced by anthropogenic activity (WG on Research TG 1, 2003). **Floods** are caused by natural phenomena - unusual long-lasting or excessive rainfalls. **Landslides**, in generic terms, mean slope movements; however, they can take very diverse forms, such as slides, falls and debris flows (WG on Research TG 1, 2003). The variety of landslide forms is caused by the great diversity of initiating mechanisms (such as erosion, deformation, dissolution and rupture under static or dynamic loads); different topographical conditions (such as height and gradient of the slope, etc); lithology (characteristics and susceptibility of materials, such as solid, plastic, liquid, viscous); structure (overhang, fracturing, superimposed layers); characteristics of the water table; and the relative proportion of water and solid materials.

### 3.8.2 State - Geographical distribution

Floods and mass movements occur more frequently in areas with highly erodible soils, steep slopes and intense precipitation, such as the Alpine and the Mediterranean regions (EEA, 2000b; European Commission, 2002). In Italy more than 50 per cent of the territory has been classified as having a high or very high hydro-geological risk, affecting 60 per cent of the population or 34 million people. More than 15 per cent of the territory and 26 per cent of the population face a very high risk (European Commission, 2002).

### 3.8.3 Possible causes

In addition to natural factors, both floods and landslides are strongly related to human activities. Climate change in this case has a very important role, causing a whole range of possible effects on the weather pattern, which in turn accelerate floods and landslides.

Floods can be caused by inappropriate soil and land use management. Inappropriate agricultural practices and land use planning, as well as river derogation, may have an impact on flood magnitude and frequency. Floods may also be intensified by erosion, which is aggravated by deforestation or the abandonment of land (European Commission, 2002). In addition to erosion, soil compaction and soil sealing can increase the risk of floods.

In Europe, the threat of landslides is increasing due to population growth, summer and winter tourism, intensive land use and climate change. Terracing, mining and deforestation are additional human activities associated with landslides. Heavy rainfall, earthquake and snowmelt are natural processes that can cause landslides. Land use planning in mountainous and coastal areas can positively or negatively influence the landslide risk.

### 3.8.4 Impact

Floods and mass movements of soil cause erosion, pollution with sediments and loss of soil resources, with major impacts for human activities and human lives, damage to buildings and infrastructure and loss of agricultural land (European Commission, 2002).

#### Box 5: Waterlogging as a Consequence of Flooding

Waterlogging describes a state of water saturation of soil that fills all air spaces and causes plant roots to die from lack of oxygen. Waterlogging may be a result of a rising water-table, of excessive irrigation, or of accidental or deliberate flooding. It reduces soil functions by driving the air from the soil. This has an impact on many biochemical processes in the soil, and may even trigger the release of hazardous substances previously safely stored in the soil. Waterlogging also increases the risk of compaction and, in dry areas, the risk of salinisation through capillary rise of saline groundwater. Oldeman et al. (1991 in EEA, 1995) estimate that 0.8 million ha are affected by waterlogging in Europe (see also Table 2). According to the same sources, waterlogging occurs mainly in a few scattered sites across Europe (primarily along the Black Sea coast and the lower Danube Valley).

Although data on social and economic effects of landslides are now available from numerous countries, landslides are often not well understood (WG on Research TG 1, 2003). Due to the diversity, frequency and wide geographical distribution of landslides, it is difficult to evaluate their impacts comprehensively. The main impacts of landslides are centred in mountainous and coastal areas.

### 3.8.5 Indicators for floods and landslides

*Area affected by floods (ha) and area affected by landslides (ha)* could serve as the main indicators to quantitatively identify soil degradation due to floods and landslides.

The ETC/TE identifies one indicator related to floods and landslides, i.e. *population affected by natural hazards (including floods and landslides)* (see Table 6). The UNSD proposes the *area affected by waterlogging* as one relevant indicator.

# 4 Economic Assessment of Soil Deterioration

## 4.1 Introduction

For the greater part of human history, soil has literally formed the basis of all economic activity. Classical economic thinkers usually included soil, along with capital and labour, as one of the three basic production factors. Indeed, one of the earliest and most influential pieces of resource economics focused on soil and its capacity to provide enough food to sustain human populations. In 1798, Thomas Malthus provided the first economic theory of soil utilisation and degradation, arguing that population growth and economic growth would eventually be restricted by the scarcity of fertile soil.

However, as the economic relevance of the primary sector has declined in relative terms, so has the importance of soil as a production factor. In addition, the “green revolution”, by introducing better fertilisation and cultivation methods, has resulted in substantial yield increases, concealing the fact that over-intensive agriculture and other pressures threaten to reduce the fertility of soil permanently. Partly as a consequence of the marginal economic role that the agricultural sector plays in industrialised countries, research into the economic aspects of soil degradation focuses mainly on those regions where soil continues to be an influential economic factor, such as in developing countries in Africa and South Asia (cf. e.g. Anderson and Thampapillai 1990, Blume et al. 1998, Botschek et al. 1998, Cuffaro and Heins 1998, Lutz et al. 1994). Most of the soil-related research in environmental economics and agronomics tends to focus on the farm-level decisions and trade-offs between soil conservation and intensive agriculture. In Europe, by contrast, little attention is paid to the economics of soil degradation. This is partly because the agricultural sector in Europe does not lend itself to economic analysis, as it is heavily influenced by the Common Agricultural Policy. Thus, farmers’ decisions are motivated primarily by support mechanisms, and are therefore shaped by policy rather than by economic considerations (Boardman et al. 2003).

## 4.2 Economic Valuation of Soil Degradation

Besides its use for agriculture, horticulture and forestry, soil performs a number of different functions that support a variety of human uses (cf. chapter 2.1.2). Not all soil functions are of direct and measurable economic relevance: soil also has ecological, cultural and aesthetic functions, for instance as an archive of human and natural history, or by fulfilling spiritual or religious functions. Such functions cannot be adequately measured in economic terms, nonetheless, they contribute to the value of soil.

Analytically, the economic valuation of soil *degradation* originates out from the economic approach to valuing soil *quality*. Soil degradation is a deterioration of soil quality, which can be understood as a loss of soil functions (cf. chapter 2.1.2). Consequently, the process of valuing soil quality can be described as moving from the *soil functions* (which are described by ecology) to the *uses of soil* (which are at the interface between ecology and economics) to the *valuation* of these uses (which is an economic task).[15] Turner et al. 2000 describe this process in the context of wetlands. Fig. 1 applies their approach to the valuation of soil:

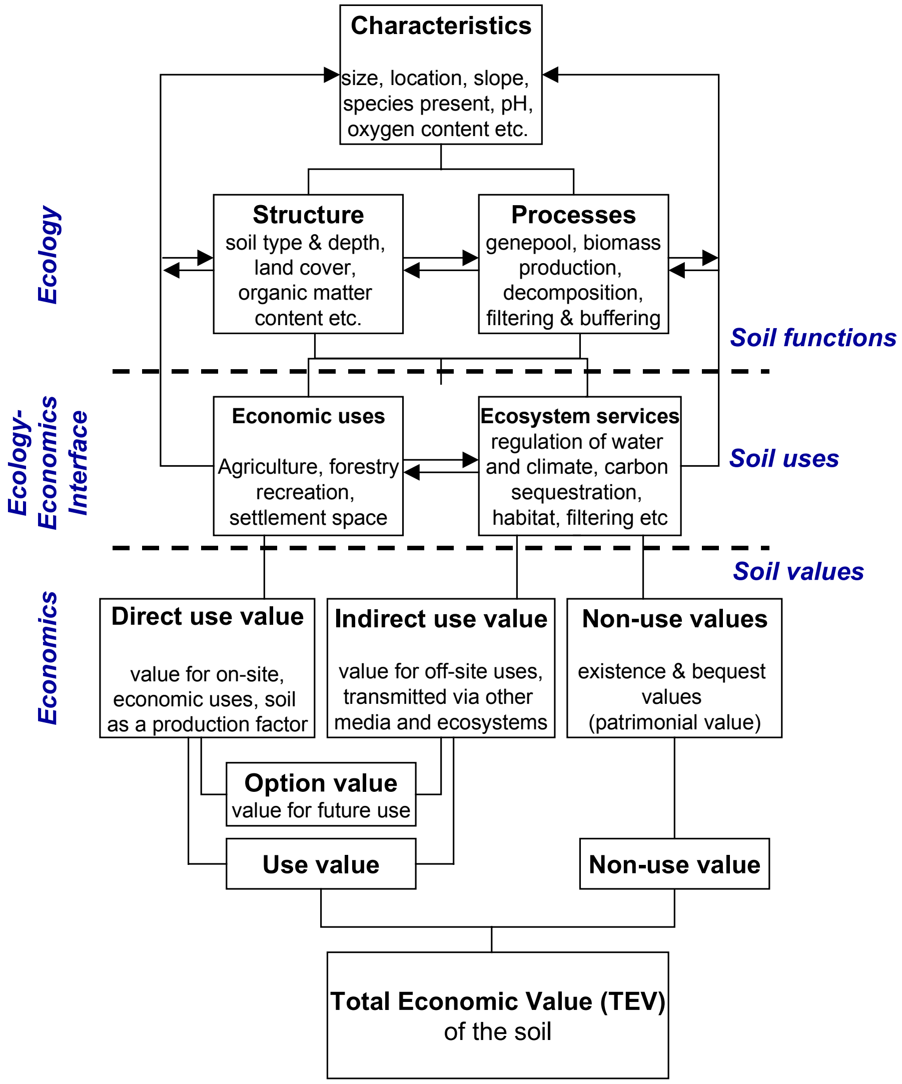

**Figure 3: Valuation of Soil, adapted from Turner et al., 2000**

This approach serves to assess the (absolute) value of soil as a resource. In theory, soil degradation could then be measured as the difference between the value of soil in its undegraded state (or the value in a specified base year), and the value of soil after degradation has occurred. In the schematic presentation of Figure 4, the value of soil

---

[15] In the EEA's DPSIR framework (cf. Section 2.1.1), changes in soil functions are described as the *direct impacts* of soil degradation, in contrast to the *indirect impact*, which encompasses the effect on soil users. It should be noted that soil *functions* are understood as biological and chemical processes that take place in the soil, and which are described from an environmental perspective. Soil functions can be, but need not be related to human uses. In contrast, soil *uses* are an anthropocentric concept. They describe the human uses of soil functions (e.g. agriculture), in so far as they are economically relevant.

degradation (C) would then be measured as the initial value of the soil (A) less the current value of the soil (B): C = A – B.

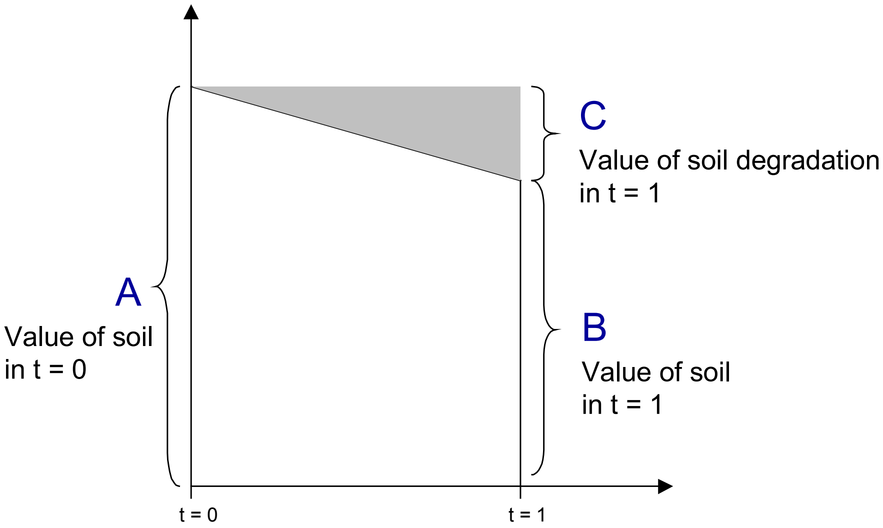

**Figure 4: The Values of Soil Quality and Soil Degradation**

In practice, however, such an approach would be impractical due to the enormous data requirements. Instead, a more practice-oriented approach is to measure soil degradation directly, i.e. only to focus on the *changes* in soil quality. In Figure 4, this means that only the shaded triangle is considered, while the area below the triangle is ignored.

Assessing the economic impact of soil degradation in this framework can be done as follows. First, soil degradation is a process whereby pressures exerted on the soil ecosystem lead to a partial or complete loss of soil ***functions***. This impact on soil functions means that the human ***uses*** of soil are also affected. Uses here include both direct, economic uses, as well as ecosystem services provided by soil. A typology of how different uses are affected by degradation is discussed in chapter 4.3. In the following, the impact of soil degradation on soil uses is ***valued*** in economic terms. To this end, different valuation methods can be applied. A discussion and categorisation of such methods is given in chapter 4.4.

## 4.3 Typology of the Economic Impacts of Soil Degradation

Soil deterioration makes itself felt in different ways, and there are different methods of classifying the economic impacts of soil degradation. The different impacts can be classified spatially into on-site and off-site effects, distinguished according to the economic values that are affected; they may also be grouped according to causality as direct and indirect impacts.

### 4.3.1 On-site vs. off-site effects

The spatial distinction between on-site and off-site impacts has already been introduced in chapter 2.1.7. In the economic context, this distinction is also of central relevance, taking account of the fact that economic impacts occur both at the site where degradation takes place (**on-site effects**), as well as in spatially remote areas (**off-site effects**). In addition, off-site effects can also be delayed temporally. The on-site effects are more manifest and self-evident consequences of soil degradation, as they directly affect the soil uses that take place at the site, such as agriculture, forestry or recreational activities. Also, while there may be temporal delays between the degradation and its effects, on-site effects tend to be more immediate than off-site effects. Off-site effects can account for a sizeable proportion of the total economic impact of soil degradation; however, as they are less directly related to soil degradation, it can be difficult to quantify precisely which off-site effect is related to which soil degradation process.

According to Pagiola (1999), the off-site effects can be further divided into regional and global effects. Regional effects occur in the vicinity of the affected area and are typically transmitted through the water cycle. They include the following processes:

- **Siltation of dams** that occurs as a consequence of erosion, thereby diminishing the capacity and the lifetimes of dams and reservoirs, leading to a higher cost of hydroelectricity;
- **Sedimentation of** waterways, leading to cleaning and maintenance costs;
- **Damage to irrigation infrastructure and pumping equipment**, either through sedimentation or salinisation;
- **Contamination of drinking water reserves** and associated health impacts as a consequence of soil contamination, salinisation or eroded particles.
- **Increased frequency of flooding events** if compacted or sealed soils can no longer hold large quantities of rainfall;
- **Increased dust concentrations** as a consequence of wind erosion may lead to health impacts and damage to houses and machinery (Brouwer et al. 2002, Riksen and De Graaff 2001);
- **Impact on the aquatic environment** as a consequence of erosion or contamination, including damage to fish stocks and other aquatic lifeforms, and transportation of phosphorus and pesticides in conjunction with the eroded sediment load in rivers.

It has been argued that, for developed countries, the off-site effects of soil erosion (e.g. through siltation) tend to be higher than the on-site costs. This view is expressed in FAO (1999) and supported e.g. by Furton (1997), Crosson and Stout (1983), Crosson (1986) and Clark et al. (1985) (see Furton (1987) for an overview of extimates). Pretty et al. (2000) estimate the off-site costs of soil erosion for the UK at £ 14 m per annum (in 1996 prices).

In addition, there are also global effects of soil degradation. Pagiola (1999) identifies three types of global off-site effects: the effects on climate change, biodiversity losses, and effects on international waters. Climate change effects arise through the reduced carbon storage in degraded soils.[16] Furthermore, soil degradation may diminish the biodiversity above and below-ground, leading to a reduced resilience of soil ecosystems when faced with changing land uses or climatic conditions. Finally, the global and international off-site effects that are

---

[16] With an estimated storage capacity of 3,200 – 3,500 Pg, the carbon contained in soils is the third largest global carbon pool, following the oceanic pool and the fossil pool. The soil carbon pool is 4.2 times larger than the atmospheric pool and 5.7 times the size of the biotic carbon pool (Lal 1999). Lal (2001) argues that up to 20 percent of the carbon content in eroded soil could be emitted to the athmosphere, leading to annual global emissions of 0.2 – 0.9 Pg C.

transmitted through the water cycle are similar to the regional off-site effects, with the difference that they affect transboundary river basins as well as oceans. This category also includes the contamination of global water bodies.

### 4.3.2 Use values and non-use values

A different way to categorise soil degradation is to consider the economic values affected by it. These can either be use values or non-use values. The ***use value*** is impacted if soil functions are currently used in one way or another, and if the capacity of soil to support these uses is diminished by the soil degradation. Uses can be agriculture or forestry, but also housing, tourism or recreational activities.

Within the category of use values, a further subdivision is possible between *direct* and *indirect* use value. Broadly speaking, the **direct use value** relates to the immediate uses of soil, e.g. if soil is used for agriculture. Direct use values are mainly related to the soil function of producing food and biomass (cf. chapter 2.1.2). By contrast, **indirect use values** are related to the other, ecological functions that soil fulfils, either by itself, or by sustaining other ecosystems. Examples include the filtering and buffering functions of soil, the decomposition of dead organic matter and wastes, and the role that soil plays in the natural carbon, nitrogen and sulphur cycles. In the terminology of ecological economics, the valuation of such ecological functions from the perspective of human uses is discussed under the heading of *ecosystem services* (see Daily et al. 1997 and Box 6 below for a discussion). For certain aspects of soil degradation, such as soil biodiversity, it is likely that the indirect use values will be far more affected than the direct use value.

In opposition to direct and indirect use values, there is also a ***non-use value*** of soil (also referred to as *value independent of use*, Perrings 1996). It is affected if the degradation of soil (and the ecosystems it supports) is experienced as a loss by someone who is not currently using it, or is intending to use it. Non-use values can take the form of *existence values*, based on the conviction that soil should be protected as a valuable resource in its own right, or they can take the form of *bequest values*, if the soil is to be preserved for use by future generations. Non-use values are typically much more difficult to assess economically than use-values. Finally, a category that falls between use values and non-use values is the *option value*. Soil is said to have an option value if it is uncertain whether, and in what form, it will be used at a later stage. The option value is relevant for example in the case of biodiversity loss: here, it is very difficult to assess whether the enormous variety of organisms that can be found in healthy soil can be useful in one way or another, or whether any particular organism will gain in importance under different circumstances.[17]

The advantage of classifying soil degradation according to the values affected by it is that the appropriate methods for the economic assessment can be derived more easily: for use values, market prices can usually be used as a proxy, whereas more indirect valuation methods are needed to assess impacts on non-use values.

---

[17] While such an assessment may be challenging, but possible, from a scientific perspective, it is even more difficult to evaluate the potential *economic* value of a decline in soil biodiversity.

### Box 6: The Concept of Ecosystem Services

The concept of ecosystem services has recently attracted some attention in ecological economic research. Analytically, ecosystem services form part of the indirect use values: soil is an integral part of many ecosystems and natural processes, including the regulation of the natural water cycle, nutrient cycling, the creation and absorption of biomass, the sustenance of biodiversity, and the natural carbon, sulphur and nitrogen cycles. These diverse functions are of enormous importance for human survival and for economic activity; however, so far, their economic value has not been assessed comprehensively.

This is due to several factors. First of all, the precise functioning and the interdependencies of ecosystems are still only partly understood. Partly as a consequence, the ecosystem services provided by soil are often taken for granted, and are only discovered when they are lost. Secondly, ecosystem services have the characteristics of a public good: the services provided by one ecosystem are dispensable as long as there are other ecosystems providing the similar services. Also, the benefits that soil supplies through the ecosystem services may accrue to spatially or temporally remote users, e.g. in the case of climate regulation.

The FAO Soil Biodiversity Portal (FAO, undated) provides some estimates of the value of ecosystem services provided by soil, based on a study by Pimentel (1997). They investigate the following ecosystem services: waste recycling, soil formation, nitrogen fixation, bioremediation of chemical pollution, biotechnology (genetic resources), biological pest control, pollination and the support of wild animals and ecotourism. The worldwide economic value of these services is estimated at US$ 1.542 billion, of which 49 percent is due to waste recycling alone.

Balmford et al. (2002) have reviewed the evidence on the economic value of different ecosystems. For the cases they investigate, they find that the economic gains of converting ecosystems to human use are actually negative. For the case of a Canadian wetland, the total economic value actually decreased by more than 40% as a consequence of conversion (from US$ 8800 to US$ 3700 / ha / y); for other ecosystems, they arrived at comparable results. The reason for this is that the loss of the non-marketed services provided by the ecosystems is not outweighed by the marginal benefits of conversion. The finding holds despite the fact that some particularly valuable ecosystem services, such as nutrient cycling and the provision of cultural values, were not considered due to a lack of data.

While it may not be possible to derive quantitative analogies from the studies, a general conclusion can be inferred nonetheless: in the cases of ecosystems which provide multiple services or which are of a regional importance for other, dependent ecosystems, the ecosystem benefits may well reach an order of magnitude that is equal to or larger than the direct use value of the ecosystem in question. This applies in particular to ecosystems that are rich in species and in biological activity, such as wetlands, floodplains, bogs and forests.

### 4.3.3 Direct and indirect effects

Finally, a distinction is possible between direct and indirect effects. Direct effects are the effects of soil degradation itself, i.e. the loss of soil functions and the immediate economic impact this has, as described above. Indirect effects, by contrast, result from land users' responses to soil degradation. For example, they may arise if soil degradation forces farmers to abandon cultivated land, and instead to clear areas of natural habitat or take marginal lands and steep slopes under cultivation, leading to aggravated soil degradation in other areas. However, the distinction between direct and indirect effects is applied infrequently in the literature on soil degradation, and is not defined clearly. For these reasons, the distinction between direct and indirect effects will not be applied in this study.

## 4.4 Typology of Valuation Methods

Different methods have been put forward to assess the economic impact of soil degradation in monetary terms (see van den Bergh 1999 for a general overview). In general, all valuation methods serve to put a price on “environmental quality”, a good which is not traded in the market. Therefore, prices have to be inferred in other ways: either by comparing related products and markets, such as agricultural produce, or by eliciting consumers’ willingness to pay for the conservation of environmental features by means of surveys and questionnaires.

As different valuation methods approach the problem of soil deterioration from different angles, there are no clear-cut rules about which of these methods should be applied in which cases, and how they can best be combined. In addition, not all of the different methods can be applied to all types of soil degradation. Also, some of the different economic impacts mentioned above (on-site vs. off-site, use values vs. non-use values) require the use of particular valuation methods. The multitude of valuation methods brings with it the danger of double counting; likewise, it can be difficult to judge whether a combination of different assessment methods does cover the “true” and full economic impact of soil deterioration.

As a broad-brush classification, the total damage cost of soil degradation can be divided into

- the cost of damage that is not prevented (**damage cost**), and
- the cost of measures to prevent or alleviate damage (**damage avoidance cost**).[18]

Different valuation methods that can be used to assess these cost categories are discussed below. The ***damage costs*** can be assessed trough the lost production value (4.4.1), as well as through hedonic pricing (4.4.2) or the travel cost approach (4.4.3). By contrast, mitigation and replacement cost approaches (4.4.4 - 4.4.5) are methods that are used to estimate the ***avoidance cost***. Stated preference methods (4.4.6) can be used for both categories, depending on the specification of the survey.

The economic impact of soil degradation will normally apply to both cost categories: part of the damage is suffered unmitigated, while other parts of the damage are avoided through mitigation and conservation measures. Therefore the two can be combined to yield the full cost of soil degradation.[19] In the following, the cost components and associated measurement method will be discussed in more detail.

---

[18] Note that the cost of preventing or alleviating damage only serves as a lower-bound proxy for the damage that is avoided by these measure: it should not be confused with an analysis of the possible or optimal policy responses to soil degradation.

[19] The combination of the different cost categories requires several assumptions: normally, damage cost and damage avoidance costs are two different sides of an economic trade-off, related to the decision on which damages to suffer and which to avoid. As both form part of the total damage, they are considered together here. This assumed i.a. that the decision on which damage to suffer and which to avoid has been taken in an economically rational way. Also, it is assumed that the mitigation and avoidance measures have been chosen, designed and implemented cost-efficiently.

### 4.4.1 Lost production value

The most widely used, and intuitively most appealing method for the calculation of the costs of soil deterioration is to consider the extent to which soil deterioration affects production values, typically measured as reductions in agricultural, horticultural or forestry output. One main advantage of this approach is that it is based on market prices for the agricultural or other yield, and thereby circumvents the need to estimate hypothetical soil values.

The main problems associated with this approach are the following

- It can be difficult to assess the correct baseline for agricultural productivity – part of the yield losses due to soil degradation will be masked by increases in agricultural productivity, and by increases in other inputs, such as labour and fertiliser. Productivity increases may even overcompensate the impact of declining soil fertility. Once the effects on diminishing yields become visible, the soil may already be irreversibly damaged.
- In developed countries, “normal” market prices for agricultural output are hardly available, as agricultural markets are heavily influenced by subsidies and guaranteed prices. In the case of “perverse subsidies”, these payments may indeed even encourage the adoption of agricultural practices that further soil deterioration (Boardman et al. 2003).
- If the lost production is used as the basis for valuation, then the value of soil deterioration will depend on the agricultural activity in the region. Degradation of intensively used farmland will be valued more highly than soil deterioration in remote areas; and degradation in rich countries will be valued more highly than in poor ones. This valuation is anthropocentric as it does not necessarily reflect the “ecological value” of soil.
- From a wider economic perspective, it is assumed that all else remains equal. For example, in an isolated market, if crop yields declined as a consequence of soil degradation, it would be expected that the price of a crop would rise. This would increase profits from the remaining harvest and thus counterbalance part of the income loss. In assessments of the output losses from soil deterioration, these effects are frequently neglected, as they would require more detailed economic modelling.

### 4.4.2 Hedonic pricing

Hedonic pricing is a valuation method which infers the value of environmental features from the prices of other, traded goods. It is applicable in those cases where the prices of other goods are directly influenced by environmental factors (Pearce and Howarth 2000). One frequently used example is the housing market, where the value of two (otherwise comparable) properties will differ, depending on the environmental amenities in the vicinity of each site. Thus, if the proximity to a hazardous waste site leads to a measurable drop in property prices (compared to other houses in comparable locations), this difference in prices gives a measure of the external cost of the waste site. In the context of soil degradation, this method has mainly been applied to incidences of soil contamination.

### 4.4.3 Travel cost

The travel cost method can be used for the valuation of any natural resource which is intensively used for recreation. The underlying assumption is that the expenses that visitors incur in order to see a natural resource gives an indication of the value of the resource. Next to the cost of travelling itself, this includes the time for travelling, entry fees and on-site expenses. However, this method is problematic because of its data requirements. Also, it can only be used to value resources that are accessible for tourist uses. In the context of soil degradation, it is only applicable insofar as the amenity value of a natural resource depends on soil health. It may prove extremely difficult to establish to what extent this is the case.

### 4.4.4 Replacement cost

The replacement cost approach measures the cost of measures undertaken to restore soils to their original state. On a smaller scale, this can also include the use of imported soil from other regions. However, this approach is not applicable on a macro level, as it implies robbing one area for the sake of restoring another, which obviously amounts to a zero-sum game when applied to larger regions.

One obvious problem with this approach is that it assumes that soil *can* be replaced at all. While this holds for the rehabilitation of a partial loss of soil functions, or for the import of soil on a local scale, it is not feasible to replace soil *as such*. By way of an example, Daily et al. (1997) mention the case of human-engineered hydroponic systems that are used to shelter seeds and provide physical support for maturing plants, thereby replacing one function of soil. According to FAO figures, the cost of this man-made replacement amounts to US$ 55,000 / ha (FAO 1990). Apart from the fact that this option covers only *one* out of the multitude of functions that soils provide, it is only feasible on a limited and local scale.

### 4.4.5 Mitigation & repair cost / defensive expenditure

This includes the costs of limiting the impacts of soil degradation, mostly through measures that try to enhance damaged soil functions to restore soil productivity (e.g. conservation works, soil terracing, drainage in the case of waterlogged soil, gypsum application in the case of salinisation, hedges to prevent wind erosion, or the decontamination of contaminated land). FAO (1994) argues that natural restoration represents one possibility for replacing eroded soil. The authors calculate that land would have to be taken out of intensive cultivation for approximately 50 years in order to balance a topsoil loss of 5 mm through natural soil replacement processes. The costs of this approach consist of the foregone production that is lost by turning to more extensive land uses.

By contrast, most measures discussed under the heading of mitigation and repair costs will not deliver a full restoration of all soil functions to pristine conditions, but rather enhance those soil functions that have the greatest economic relevance. In this sense, mitigation measures will often cure the symptoms rather than the disease – e.g. by applying more fertiliser to soil that is affected by erosion or falling organic matter levels.

While mitigation and repair costs are incurred to limit the on-site impacts of soil degradation, the category of **defensive expenditure** includes such measures that are implemented to limit the off-site-impacts of soil degradation. This includes the cost of stabilisation works in order to prevent landslides, and the cost of dredging rivers and irrigation channels in order to remove eroded sediment. Where the diminished capacities of soil to retain stormwater lead to an increased likelihood of flooding, flood protection measures can also be counted as defensive expenditure.

### 4.4.6 Stated preference methods

Stated preference methods include several valuation methods, the most frequent of which are contingent valuation and conjoint analysis. Common to all these methods is that they elicit the value of a natural resource by means of a survey: individuals are asked to state what value they place on an environmental good or feature. In a survey, a representative sample of interviewees are asked either what they would be prepared to pay for the conservation of a resource (Willingness-to-pay, WTP), or what sum they would demand as compensation if the resource was lost (Willingness to accept compensation, WTA).

Thus, stated preference methods can be used to infer the value of a natural resource, and, consequently, the cost that a damage to a resource would imply. In addition, it can also be employed to elicit willingness to pay for mitigation and conservation measures. Stated preference methods are the only methods which are suitable to estimate non-use values. Unfortunately, there is no empirical evidence that has estimated the non-use value of soil.

Stated preferences methods are popular with environmental economists, as they create a model market for goods that are not tradable, rather than inferring valuations indirectly from consumer behaviour. However, the applicability of such methods is limited by the high data requirements. There have been only a few applications to soil as such; e.g., three Australian case studies estimated consumers' willingness to pay a premium price for bread produced with non-erosive practices (Dragovich 1990, 1991; Yapp, Young and Sinden 1991).

A frequent criticism is that stated-preference methods will only deliver credible results if the interviewees are sufficiently aware of the functions and services provided by soil, and of its non-renewable character. However, this may not often be the case. Although this caveat limits the usefulness of stated preference methods for the valuation of soils, they remain indispensable as they are the only way to measure value categories such as non-use values.

Table 8, adapted from Riksen and De Graaff (2001), exemplifies the categorisation of damage types and the associated valuation methods.

**Table 8: Damage Types and Valuation Methods for Wind Erosion**

| Location of effects | Physical effects | Economic effects |
|---|---|---|
| On-site effects | | |
| On the soil | Soil and organic material translocated<br>Degradation of soil structure<br>Loss of fertilisers, pesticides | Soil fertility decline / lost output<br>Mitigation cost (labour for tillage)<br>Replacement cost for agrochemicals |
| On the crop | Loss of seeds and plants<br>Damage of stem and leaf | Replacement cost<br>Lost output |
| Equipment | Damage to equipment | Repair cost |
| Off-site effects | Sedimentation in ditches, on roads<br>Eutrophication of rivers<br>Dust in machinery<br>Effects on non-users | Defensive expenditure / clean-up cost<br>Value of lost ecosystem services<br>Repair cost<br>Reduced non-use /patrimonial values |

## 4.5 Intertemporal Aspects of Valuing Soil Degradation

The valuation methods explained above make it possible to estimate the economic impacts of soil degradation at a given point in time. Yet, as soil is essentially a non-renewable resource, the economic impact of soil degradation will be felt for several decades or even centuries. It is therefore necessary to account not only for the current impact of soil degradation, but also to consider the future impacts.

The standard economic approach to dealing with costs and benefits that accrue in the future is to discount them: based on the assumption that individuals value costs and benefits in the present higher than future costs and benefits, the latter are divided by a discount factor. This allows to calculate the *net present value* of the current and future impacts of soil degradation:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}$$

where t indicates the time period;
T indicates the time horizon that is considered;
$C_t$ indicates the cost of soil degradation in the period t; and
r is the discount factor that is applied.

In the literature on soil degradation, there is some discussion concerning the appropriate discount factor to be applied, and the time period that should be considered. Standard discount rates for the valuation of natural resources and conservation projects normally range from 3 to 6 percent (ASTSWMO 1998). However, some experts argue that discounting should not be applied at all, as they object to the idea that natural resources preserved for the future should be valued less than resources that are available today.

Along these lines, Young (1998) argues that standard discounting procedures are not applicable to soil degradation, since they implicitly assume a substitutability of resources. Following this assumption, the consumption of resources (including soil) in the future can be discounted, as other technologies will be developed which allow a more productive use of the remaining resources, or a substitution of the resources with man-made capital. Young denies that this holds for soil as a non-renewable resource, since there may not be any substitutes or alternatives for degraded soils. Rather, if production is shifted to marginal lands because other land has been degraded, this will lead to more and accelerated degradation, requiring higher inputs of labour, fertiliser and machinery to deliver the same yields.

As a consequence of these effects, Young (1998) argues that a discount rate of zero should be applied to the valuation of soil degradation. This would imply that future losses are balanced directly against the current costs, without discounting. Young argues that costs should be considered for a period of 500 years.

One way of dealing with the problem of discounting is to consider only the cost of soil degradation *per annum* for the base year. This does not fully avoid the question of discounting, because the costs of longer-term measures still have to be annualised; however, it circumvents the choice of a discount rate for future benefits of soil protection. The costs per annum can then be combined with a qualitative assessment of how the costs are expected to develop over time, including an assessment of the uncertainty associated with this forecast. The trade-off of current benefits against future costs is then left to the audience, and can be decided e.g. in consultation with relevant stakeholders.

**Box 7: Discounting Investment Decisions on Soil Conservation Measures**

Apart from the intertemporal valuation of soil as a resource, discounting is also relevant in the context of investment decisions with regard to soil conservation measures. One possible consequence of discounting is that soil conservation projects will hardly ever appear economically viable. Some soil conservation measures involve high investments up-front, e.g. for terracing. By contrast, the business-as-usual alternative without conservation measures causes no extra costs in the present, while the damage occurs only after an extended period. Although the damage may then be serious and irreversible, the fact that future costs are discounted means that the future degradation impacts weigh much lighter than the costs of conservation measures, which are borne immediately. The further in the future soil degradation lies, the stronger this effect becomes: at a discount rate of 6 percent, costs that arise 30 (50) years from now will only enter the present-value calculation with $^1/_6$ ($^1/_{20}$) of their nominal value. As the full impact of soil degradation processes is often felt only years or decades from the present, the discounting of future costs and benefits implies that investment decisions on soil conservation measures can be biased against conservation. Along these lines, Anderson and Thampapillai (1990) demonstrate the influence of the discount rate and planning horizon on the decision of soil conservation measures. In the empirical evidence that they quote, with a zero discount rate, it would take up to 40 years before the benefits of soil conservation measures exceeded their costs. If the future benefits are discounted at a positive rate of 5 (8) percent, this threshold rises to 60 (200) years.

Apart from the choice of discount rate and planning horizon, a further issue in the intertemporal valuation relates to the identification of a baseline. In order to assess the economic impact of soil degradation, it is necessary to assess the benefits that soil would have produced if it had not been degraded. The cost of soil degradation is then measured as the difference between the scenarios with and without degradation. To establish the baseline as a first approximation, it is possible to simply extrapolate current yields (benefits), or the yields (benefits) in a specified pre-degradation year.

However, the productivity of soil also depends on the agricultural technologies and management methods applied, so that a part of the impact of soil degradation can be offset by improved technologies. Therefore, Lal (2001) argues that the impact of soil degradation should be assessed on the basis of the potential rather than the actual output. The potential output estimates the hypothetical benefits that could have been derived from the soil in its undegraded state, but using current, state-of-the-art technologies. This potential output should then be compared to the actual output (produced with degraded soils and current technologies), so that the difference between potential and actual output gives an estimate of the impact of soil degradation. The main challenge associated with this approach is to calculate the counterfactual baseline scenario for a state without soil degradation.

## 4.6 Methodology for the Economic Assessment of Soil Degradation

Based on the theoretical considerations elaborated above, the next step in the evaluation of soil degradation is to derive a damage function. This function expresses the economic impact of soil degradation (in monetary terms) as a function of the soil degradation processes themselves (expressed in environmental terms). As soil degradation is a multidimensional problem, it is necessary to identify a family of damage functions, where one function is established for each type of soil degradation. Once this set of damage functions has been estimated, it becomes possible to relate it in order to extrapolate these to other sites.

In principle, establishing a damage function proceeds in three steps:

1. Identify the impacts of soil degradation;
2. Quantify the identified impacts (including the selection of suitable indicators);
3. Estimate or derive coefficients (expressed in $^{€}/_{\text{unit of impact}}$) to value the impacts.

### 4.6.1 Identification of the impacts of soil degradation

As stated above, the impacts of soil degradation can be divided into different categories:

- the **on-site (private) costs of damage** suffered as a consequence of soil degradation. An example for this are the yield losses that farmers incur if the agricultural productivity of soil has been reduced through erosion, compaction or other degradation processes. These costs are denoted **PC**;
- the **on-site** (**private) cost of mitigation and repair measures** to restore degradation or to prevent further erosion. This includes, for example, the cost of additional fertiliser input to compensate for the impact of erosion, or the cost measures to restore the physical soil structure of compacted soils. This category is labelled **MC**;
- the **off-site (social) costs** of soil degradation, which are suffered by other parties. One example is the cost of damages caused by floods and landslides. It also includes the value of foregone ecosystem services, such as biodiversity maintenance or carbon sequestration, which are reduced through soil degradation. These costs are denoted **SC**;
- the **defensive costs** incurred in order to mitigate or limit the off-site impacts of soil degradation. This includes e.g. the cost of dredging canals in order to remove eroded sediment, or the cost of conservation measures to prevent landslides. These costs are abbreviated as **DC**;
- the **non-user costs** that accrue to the individuals that do not use the soil, but are nonetheless distressed by its degradation. This category measures the non-use values attached to soil, e.g. the patrimonial value of preserving soil for future generations. Where such values are affected by soil degradation, the cost are captured as **NC**;

Hence the total cost of soil degradation in the time period t can be expressed as the sum of these five cost components, as expressed in the following formula:

$$C_t = \sum_i \left( PC_{it} + MC_{it} + SC_{it} + DC_{it} + NC_{it} \right)$$

C represents the total cost. The subscripts (t) and (i) indicate the time period and the type of soil degradation, respectively. This means that each of the five impact categories has to be calculated and summed for each of the different types of soil degradation. Note that the types of soil degradation will be a marked by a different distribution of on-site and off-site costs: e.g., the cost of floods are by definition off-site costs of soil degradation. It should also be noted that while the cost components can be summed up in theory, it is likely that there will be overlaps between the components in practice. Also, as noted above, the combination of damage costs and damage avoidance costs is based on the assumption that the measures taken to prevent damage are planned and implemented efficiently. Finally, the use of mitigation costs should not be confused with an analysis of possible policy responses: mitigation cost are merely used as a proxy, based on the argument that the damage of avoided soil degradation is at least as big as the costs of restoration and conservation.

In relation to the theoretical impact categories discussed in section 4.3 and the cost categories explained in 4.4, the five cost components are visualised in Figure 5. As shown in the figure, the private on-site costs (PC) and the off-site social costs (SC) constitute the *damage costs* of soil degradation. By contrast, the on-site repair and mitigation costs (MC) together with the off-site defensive expenditure (DC) sum up to the *damage avoidance cost*. The non-user costs (NC) can fall into either category.

If added up differently, the private on-site costs (PC) and the repair and mitigation costs (MC) give the total private costs of soil degradation. The sum of off-site, social costs (SC), defensive costs (DC) and non-user costs (NC) yields the total social costs of soil degradation; in economic terms also referred to as the **external effects**.

Table 9 on page 57 provides examples of the different cost categories for the eight soil threats identified by the European Commission.

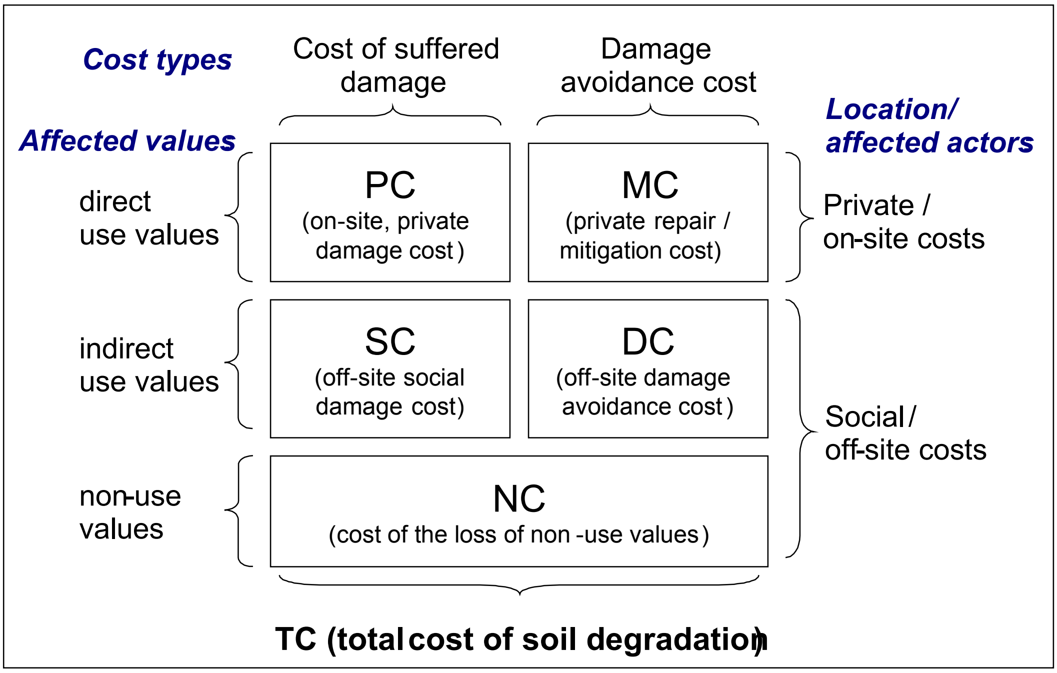

Figure 5: Overview of Different Cost Components

### 4.6.2 Quantification of the impacts

For each of the impact categories mentioned above (PC, MC, SC, DC and NC), it is necessary to establish a separate function, which quantifies the impact as a function of soil quality indicators. In order to ensure coherency of the underlying data, the soil impact indicators should ideally be the same for all impact categories. This leads to the following set of functions:

$$PC_{it} = \alpha_{it} * p_i(q_{it})$$

$$MC_{it} = \beta_{it} * m_i(q_{it})$$

$$SC_{it} = \gamma_{it} * s_i(q_{it})$$

$$DC_{it} = \delta_{it} * d_i(q_{it})$$

$$NC_{it} = \varepsilon_{it} * n_i(q_{it})$$

where $\alpha_{it}$, $\beta_{it}$, $\gamma_{it}$, $\delta_{it}$ and $\varepsilon_{it}$ are the value coefficients that quantify the impact in economic terms (see 4.6.4 below),

$p_i$, $m_i$, $s_i$, $d_i$ and $n_i$ are the functions that quantify the impact of soil quality on soil productivity for each type of soil degradation, and where

$q_{it}$ denotes the indicator(s) for soil quality at time t and with respect to the respective type of soil degradation (i).

In this context, the change of soil quality should ideally be measured with one aggregate indicator (or a representative *headline indicator*). Table 10 on page 59 gives an overview of possible soil quality indicators and related economic indicators.

## Table 9: Examples of Cost Categories and Degradation Types

| Cost category<br>Degradation | PC | MC | SC | DC | NC |
|---|---|---|---|---|---|
| Erosion | Yield losses from eroded agricultural soils | Cost of stabilisation and conservation measures (hedges etc.) | Cost of siltation of dams and canals (commercial and recreational uses) | Cost to prevent or clean up sedimentation of dams and canals | Impact on landscape values and biodiversity |
| OM decline | Yield losses associated with decline in OM<br>Resource cost of peat extraction | Measures to restore soil organic matter (where possible), cost of additional fertiliser applications | Suffered climate change impacts<br>Impact of peat extraction on biodiversity, climate | Defensive measures against climate change impacts | Cultural and heritage values of peatland |
| Contamination | Private monitoring costs, decline in property values | Private clean-up costs for contaminated soil | Health impacts due to soil and groundwater contamination, decline in adjacent property values | Cost for containment and remediation of contamination | Anxiety and uncertainty associated with contamination of soils and agricultural produce |
| Salinisation | Yield losses from salinisation, damage to irrigation infrastructure | Cost of de-salinisation measures | Increased salinity in aquifers and downstream rivers: impact on water uses and infrastructure | Cost of desalinisation for downstream water uses and groundwater treatment | Impact on landscape values and biodiversity |
| Biodiversity loss | Reduced agricultural productivity and reduced resilience | Need of plowing, pesticides and fertilisation to replace or substitute lost soil functions | Lost ecosystem services (i.e. bioremediation of chemicals, biocontrol of pests, waste recycling). | Cost of replacing lost ecosystem services (e.g. technical remediation vs. bioremediation) | Impact on patrimonial and bequest values from reduced soil resilience |
| Compaction | Yield losses from compaction | Cost of measures to restore the physical soil structure | Flooding through increased rainwater runoff, indirect impacts on biodiversity | Indirect cost of measures to keep back rainwater runoff | Impact on landscape values and biodiversity |

| Cost category<br>Degradation | PC | MC | SC | DC | NC |
|---|---|---|---|---|---|
| Sealing | Opportunity cost of alternative uses of land | Cost of de-sealing measures | Flooding through increased rainwater runoff, indirect impacts on biodiversity | Indirect cost of measures to keep back rainwater runoff | Impact on landscape and amenity values and on biodiversity |
| Floods & landsl. | Cost of damage from floods and landslides | Reconstruction cost of flood damage | Foregone production due to floods<br>Human lives lost through floods and landslides | Defensive expenditure for prevention of floods and landslides (dykes, soil stabilisation measures) | Anxiety and uncertainty associated with floods and landslides, impact on landscape values |

Note that the impacts and damage types in the table above are not exhaustive, but rather provide examples of the different cost types and impacts.

### 4.6.3 Overview of proposed Soil Degradation Indicators

**Table 10: Overview of Indicators for Soil Degradation**

| Degradation type | Soil quality / degradation indicator | Unit | Economic indicator | Unit | Type* |
|---|---|---|---|---|---|
| Erosion | Area affected by erosion (agricultural and non-agricultural) | % | Crop yield losses, effect on land prices | € / % | PC |
| | Soil loss per year by erosion from agricultural land | t/ha/y | Off-site effects (siltation etc.) | € | SC |
| | Coastal erosion and progradation trends | | | | |
| | Area under risk of erosion | ha | Cost of stabilisation / conservation measures<br>Cost of additional fertiliser inputs | €<br>€ | MC<br>MC |
| Soil sealing | Built-up area as per cent of total land | % | Opportunity cost of alternative, potential uses | € | SC |
| | Per cent increase of built-up areas | % | (indirect effects through floods and landslides) | € / % | DC/SC |
| | Land consumed by urban sprawl | ha | (landscape / amenity values) | € / qual. | DC/SC |
| Floods and landslides | Area affected by floods (differentiated by intensity categories, where possible) | ha | Annual (reconstruction) cost of flooding events<br>Value of foregone production due to floods<br>Human lives lost through floods | €<br>€<br>€ | PC/SC<br>SC<br>SC |
| | | | Annual defensive expenditure for prevention of floods | (€) | DC |
| | Area affected by landslides (differentiated by intensity categories, where possible) | ha | Annual cost of landslides<br>Human lives lost through landslides | €<br>€ | PC/SC<br>SC |
| | Population number affected by natural hazards (including floods and landslides) | N$^{o}$ /y | Defensive expenditure for prevention of landslides | (€) | DC |

| Degradation type | Soil quality / degradation indicator | Unit | Economic indicator | Unit | Type* |
|---|---|---|---|---|---|
| Salinisation | Area of soil affected by salinisation (differentiated by intensity categories, where possible) | ha | Crop yield losses<br>Non-farm salinity impacts (shortened lifespan of infrastructures) | € / %<br>€ | PC<br>SC |
| | Salt content in soil (Ca, Mg, Na; Cl, $SO_4$, $HCO_3$) | mg/m$^3$ | Defensive expenditure for de-salinisation / irrigation | € | MC/DC |
| | Groundwater salinity | mg/m$^3$ | Groundwater treatment cost | € | SC |
| Contamination | Area affected by contamination (impact cat. 1-3) | ha | Expenditure for monitoring and inventories | € | PC/DC |
| | N$^o$ and av. Size of sites in different impact categories | N$^o$ | Abatement cost to avoid leakage and spills | € | PC/DC |
| | Risks of contamination of surface and groundwater from mining dump sites, industrial sites, waste landfill etc | | Insurance costs for hazardous activities | € | PC/DC |
| | Soil polluting activities from localised sources | % | Expenditure for clean-up of contaminated land | € | MC/SC |
| | Total concentrations of heavy metals in agricultural top-soils and sub-soils | mg/kg | Decline in property values | € / % | SC |
| | | | Health impact related to contamination | € | SC |
| | | | Indirect environmental damage cost | € | DC |
| Decline in organic matter | Organic matter content by volume / by mass (differentiated by intensities / quality categories) | % | Cost of conservation / mitigation measures<br>Cost of additional fertiliser input | € | MC |
| | Loss in organic matter in top soil calculated according to soil types and land use | t | Crop yield losses | € | PC |
| | Total carbon (C) contained in soil | t | (avoided) climate change effects,<br>sequestration or avoidance cost by alternative means | €<br>€ | SC |
| (Biodiversity) | Decline in number of species<br>(Decline in quality / composition of species) | % | Option value of biodiversity | (€) | SC |
| (Compaction) | Area affected by different degrees of compaction | ha | Crop and pasture losses | € | DC |
| | Density of the topsoil | kg/m$^3$ | (indirect effects through floods and landslides) | € / % | DC |

In order to keep the calculation of the impacts of soil degradation manageable, it is necessary to reduce the complexity of the concept of soil quality by aggregating the different aspects of soil quality. This is a considerable challenge, as it means that the impact on the various soil functions has to be quantified and expressed in comparable categories. Furthermore, there is considerable discussion on the exact linkages between soil quality and soil productivity[20] (see e.g. Lal 2001, Lal et al. 2003). For the off-site effects, the linkage between soil quality and degradation impacts is even more difficult to quantify.

In order to deal with these difficulties, it is necessary to identify and to account for the most important factors that influence soil quality and the productivity impact of soil degradation. The following factors are most significant in this context:

- First, it is necessary to account for the diversity of soil types and soil conditions (cf. chapter 2.1.2). Different soil types display a different resilience in dealing with the impact of soil degradation. For example, in the case of erosion, the extent of erosion can be measured as the volume ($m^3$) or the depth (cm) of eroded topsoil. However, it depends on the type of soil whether the first or last $m^3$ or cm of soil that is lost causes the greatest damage.[21] In the case of contamination, the vulnerability of the soil to contamination and its self-attenuation potential should be considered.
- Second, management practices have a sizeable impact on soil quality and productivity. Through careful management, soil resilience can be maintained and supported, while too intensive use can contribute to degradation. For agricultural uses, management practices such as ploughing, tillage, irrigation, use of machinery, cattle density, as well as the choice, timing and sequencing of crops would appear relevant.

This means that soil quality ($q_{it}$) will be calculated as a functional form:

$$q_{it} = f(\phi, \lambda)$$

where $q_{it}$ denotes soil quality,
$\phi$ stands for a vector of soil-specific parameters (soil functions, soil type and resilience, slope, chemical, physical and biological parameters),
$\lambda$ indicates the influence of management practices.

With respect to the productivity functions ($p_i$, $m_i$, $s_i$, $d_i$ and $n_i$), it is relevant to take account of the following difficulties and limitations:

- Soil productivity may not be a continuous function of soil quality. For some types of soil degradation, there are threshold levels beyond which soil functions are lost entirely and

---

[20] Note that productivity should be understood broadly here, i.e. including all soil functions and their uses by man. For example, the effect that soil contamination has on property values in the neighbourhood of a contaminated site is also a productivity effect, as the soil function of providing settlement space is impacted.

[21] Hopkins et al. (2001) argue that for tropical soils, the upper topsoil is most critical to productivity, consequently the first cm of soil erosion cause the biggest impact, whereas erosion of the deeper and poorer subsoil has less of an impact. By contrast, for many temperate soils, initial stages of erosion may be suffered without grave consequences, but the impact of erosion gradually increases as the rooting depth and the water-holding capacity of soil is affected.

irreversibly; by contrast, light forms of degradation can be suffered by healthy and resilient soils without serious productivity impacts. One way of dealing with this is to establish categories of degradation intensity (light / moderate / severe & irreversible) (cf. chapter 2.1.6), and to formulate separate productivity functions for these categories.

- A further reason why the impact of soil degradation may not be a continuous function of soil quality is that there are different, competing uses for soil, not all of which require the same soil quality levels. Thus, soil degradation may mean that a soil is no longer suited for crop cultivation, but can still be used for grazing of livestock. And while it may not be possible to use an area for residential use due to residual contamination, the same area may still be suitable for industrial uses. Thus, a sequence of uses may be identified, where further degradation leads to different uses with reduced productivity.
- Finally, due to the limited data availability, it may not be possible to estimate a productivity function for all damage categories and for all types of soil degradation. As discussed before (cf. chapter 3), the impact of certain types of soil degradation is understood only to a degree (e.g. in the case of soil biodiversity loss). Also, there is very little empirical evidence on certain damage categories, especially regarding the impact on indirect use-values (ecosystem services) and non-use values. Instead, the productivity impact can also be estimated using aggregated indicators, or by transferring results from previous investigations in other locations.

### 4.6.4 Assigning monetary values to the impacts

Once the impacts of soil degradation have been identified and quantified in environmental terms, it is necessary to assign monetary values to these impacts, in order to arrive at an economic evaluation of the impacts. In the impact functions explained above (4.6.2), these monetary coefficients are denoted $\alpha_{it}$, $\beta_{it}$, $\gamma_{it}$, $\delta_{it}$ and $\varepsilon_{it}$ (with one parameter for each of the cost types identified in 4.6.1).

These **monetary coefficients** should ideally be expressed in € / unit of soil degradation (e.g. € / ha of soil affected by erosion). The coefficients themselves depend on the prices of (lost) agricultural output, on the cost of conservation and mitigation measures, and on the valuation of other, non-traded benefits that soil provides. If a quantification of the impacts is not possible due to a lack of empirical data, a second-best alternative is to assess the economic impacts qualitatively, based on the physical impacts of soil degradation.

In order to reduce the substantial data requirements associated with the estimation of monetary coefficients, it can be helpful to transfer results from comparable studies that have previously been conducted in order to investigate the economic impact of soil degradation (for a brief overview of such studies, see section 4.7 below).[22] The transfer of empirical results to different temporal or spatial contexts has been discussed in the literature under the heading of **benefits transfer** (see e.g. van den Bergh and Button 1999, see also Box 8). This transfer is not unproblematic as it presumes a certain degree of coherence in the underlying data set and the economic methods used, as well as in the economic conditions under which the original results were derived. Thus, the underlying factors that influence the

---

[22] In this context, the results from the case studies carried out as part of this project will be of particular interest and relevance

valuation of soil degradation have to be identified correctly and measured in a comparable way. However, given the high (and often prohibitive) effort required to gather primary data of the economic impacts of soil degradation, benefits transfer so far appears to be the only feasible approach to estimating the costs on a spatially aggregated level.

As empirical data is very scarce for some types of soil degradation (e.g. compaction, biodiversity loss), it may also be necessary to consider whether a modified form of benefits transfer is possible between different types of soil degradation (e.g., whether extent and impact of soil biodiversity loss can be approximated via the organic matter content). Although methodologically contentious, such a transfer may be defensible as long as the economic impacts between different types of soil degradation do not differ too markedly.

The considerations and caveats mentioned above mean that any assessment of the economic impacts of soil degradation will be fraught with uncertainties, and will have to rely on a number of assumptions. However, if the assumptions and uncertainties are sufficiently explained and motivated, it is possible at least to indicate the order of magnitude of the impacts, if not the exact amounts.

### Box 8: Benefits Transfer to Assess Non-Use Values of Soil?

Judging by the terminology used in non-economic publications, there is some indication that soil as an essential but non-renewable resource should have a considerable non-use value. However, in a survey of valuation studies conducted in Europe, Navrud and Vågnes (2000) mention no study that has researched willingness to pay for the conservation of soil as such.

Therefore, estimates of the non-use values of soil can only be inferred from the valuation of other, related environmental goods and services. In the past, several studies have assessed how particular landscapes are valued by users and non-users (e.g. Bonnieux et al. 1998, Hackl 1997, DEFRA 1999). These studies could, in principle, serve as a first indication of the values attached to soil, as the valued landscape features would clearly be impacted by some types of soil degradation. However, there are some methodological problems that limit the applicability of such studies:

- Not all types of soil degradation also result in an impairment of landscape features: e.g. in the case of contamination, organic matter decline or biodiversity loss, soil degradation would have to become extreme before impacts on landscape features became visible.
- What is being valued is only the role of soil in supporting particular landscape features. Soil as such is not valued – therefore the transfer of such values would fail e.g. if applied to highly fertile soils in a landscape that is poor in scenic features.
- Consequently, it is only the instrumental value of soil that is considered: if people attach a value to soil over and above its ability to support a particular landscape and vegetation, it is not included in this way.
- By contrast, if there was a high valuation for harsh and rugged landscapes, caused by the *absence* of fertile soil, the transfer of values would be inappropriate. However, save for single exceptions, this phenomenon is not widely applicable.
- The empirical studies conducted assess not so much the value of a landscape as such, but rather the value that a change in land use would imply (e.g. moving from animal husbandry to more intensive farming practices). Therefore, the total value attached to the landscape may be omitted by the analysis. However, in order to infer the value of soil from a landscape value, the total value of a landscape is a more relevant starting point.

The above considerations imply that the value attached to landscape features can only serve as a rough approximation for values attached to the underlying soil. More specifically, empirical studies of landscape values can only provide lower bounds for the value of soils. At the same time, soil values transferred from the valuation of landscapes can represent a highly useful addition to other, production-based valuation methods: while production-based methods focus mainly on the *goods* provided by soils (i.e. crops and timber), the values transferred from landscape valuation are more apt to measure the *services* that soils provide.

## 4.7 Quantitative Estimates

In the following, a brief overview will be given of studies that have assessed the economic impact of soil degradation. Of the empirical literature that has quantified the economic impact of soil degradation, most studies have focused on the yield losses associated with soil degradation. In addition, a number of studies have also considered the cost of replacing lost nutrients. By contrast, the costs of restoring soil are typically calculated only in the case of soil contamination, where there is much experience with remediation measures.

Likewise, the majority of empirical estimates have centred on the impact that soil degradation has on agriculture and forestry, and here concern the direct, on-site effects. The effect of soil deterioration on indirect uses of soil are less researched. In particular, the impact on ecosystem services has not been quantified systematically.

Of the different types of soil degradation that are identified by the Commission, erosion is the phenomenon that is covered most extensively in the empirical economic literature. For salinisation and contamination, as well as for floods and landslides, there is some evidence. However, the economic effects of compaction, biodiversity loss and loss of organic matter are covered only in occasional studies, or are not quantified at all.

In terms of the geographical distribution, the majority of studies comes from those countries where economic valuation has a longer tradition and is a well-established method (i.e. Australia and North America).[23] Furthermore, there is some evidence from regions where a substantial part of the economy depends on soil functions (i.e., developing countries and agricultural regions in developed countries). Generally, there is not a large amount of evidence from European countries. One exception here is the United Kingdom, where different studies have assessed the external effects of agriculture, including off-site costs of erosion (Evans 1996, Hartridge and Pearce 2001, Pretty et al. 2000, Riksen and De Graaff 2001). Van den Born et al. (2000) have assessed the cost of water erosion for the EU-15; however, their extrapolation is based only on the evidence from one Spanish study (ICONA 1991) and should therefore be interpreted with some caution.

---

[23] For Australia in particular, a large number of economic studies are collected in the ENVALUE database (http://www.epa.nsw.gov.au/envalue/).

## Table 11: Estimates of the Cost of Contamination

| Study | Region | Degradation type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Ecolas 2002 | Flanders, Belgium | Contamination | Remediation cost (clean-up of different contamination types) | SC | $\text{€}_{2002}$ 4,51 – 5,45 bn for 392 contaminated sites (hypothetical extrapolation) |
| Hirshfeld, Vesilind & Pas 1992 | USA | Contamination | Hedonic Pricing (Impact of waste site on property prices) | SC | 0.4 km: $\text{US\$}_{1989}$ 18,000 ($\text{€}_{1999}$ 24,465)<br>0.4-0.8 km: $\text{US\$}_{1989}$ 15,000 ($\text{€}_{1999}$ 20,388)<br>0.8-4.8 km: $\text{US\$}_{1989}$ 7,000 ($\text{€}_{1999}$ 9,514) |
| Jordi 2003 | Switzerland | Contamination | Remediation / containment cost | MC | CHF 5 bn over 20 yrs / 3000 sites.<br>80% of all sites cost < 1 m CHF |
| Ketkar 1992 | New Jersey, USA | Contamination | Hedonic Pricing (Impact of remediation on house prices) | SC | $\text{US\$}_{1980}$ 1,300 ($\text{€}_{199}$9 2,659) |
| Kohlhase 1991 | Houston, USA | Contamination | Hedonic Pricing (Impact of waste site on property prices) | SC | 1.6 km: $\text{US\$}_{1985}$ 4,259 ($\text{€}_{1999}$ 6,665)<br>3.2 km: $\text{US\$}_{1985}$ 3,476 ($\text{€}_{1999}$ 5,439)<br>4.8 km: $\text{US\$}_{1985}$ 2,606 ($\text{€}_{1999}$ 4,078) |
| Michaels and Smith 1989 | Boston, USA | Contamination | Hedonic Pricing (Impact of waste site on property prices) | SC | Per 1.6 km distance: $\text{US\$}_{1977}$ 115 ($\text{€}_{1999}$ 320) |

Notes: Studies from European countries are shaded light grey.

* for a detailed description of the measurement methods, please refer to sections 4.4.1 – 4.4.6

** PC = private damage cost; MC = private mitigation cost; SC = social cost; DC = defensive cost; NC = non-user cost. The cost categories are explained in detail in section 4.6.1

*** abbreviations: CHF = Swiss Frank; US$ = US Dollar; AU$ = Australian Dollar, CA$ = Canadian Dollar; NZ$ = New Zealand Dollar; ha = hectare; p.a. = per annum; m = million ($10^6$); bn = billion ($10^9$); t = tons. Subscripts after currency symbols (e.g. $\text{US\$}_{1986}$) indicate the original year in which prices are quoted; currency conversion was calculated using purchase power parity values.

## Table 12: Estimates of the Cost of Erosion

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Alcock 1980 in Yapp | Queensland, Australia | Erosion | Off-site replacement / repair cost (Cost of siltation and erosion of roads) | MC | AU$$_{1980}$ 1 /ha p.a. (€$_{1999}$ 2,04 / ha) |
| Barter 1986 in Yapp 1989 | NSW, Australia | Erosion | Replacement cost /repair cost (Cost of repairing erosion damage to public utilities) | MC | €$_{1999}$ 16.16 m p.a. |
| Bennett 1987 in Yapp 1989 | NSW, Australia | Erosion | Hedonic Prices / Off-site costs of erosion and sedimentation: | | |
| | | | (1) Losses to lakeside property | SC | AU$$_{1985}$ 347,000 (€$_{1999}$ 471,950) |
| | | | (2) Loss of recreation value | SC | AU$$_{1985}$ 152,000 (€$_{1999}$ 206,576) |
| Carder & Humphry 1980 in Yapp 1989 | Western Australia | Erosion | Replacement cost / repair cost (Cost of desilting roads) | MC | AUS$$_{1980}$ 40,000 p.a. (€$_{1999}$ 66,615 p a) |
| Clark, Haverkamp & Chapman 1985 in Clark 1985 | USA | Erosion | Repair cost / defensive cost; Off-site damages of erosion on: | | |
| | | | (1) Water storage | DC | US$$_{1980}$ 450 m (€$_{1999}$ 923 m); |
| | | | (2) Water treatment | DC | US$$_{1980}$ 50 m (€$_{1999}$ 103 m); |
| | | | (3) Navigation | DC | US$$_{1980}$ 420 m (€$_{1999}$ 862 m); |
| | | | (4) Flood damages | SC | US$$_{1980}$ 490 m (€$_{1999}$ 1005 m); |
| | | | (5) Recreation | SC | US$$_{1980}$ 950 m (€$_{1999}$ 1949 m) |
| Den Biggelaar et al. 2001 | USA | Erosion | Lost agricultural output (for maize, soybeans, wheat, cotton) | PC | US$$_{2000}$ 37.9 m p.a. (€$_{2000}$ 35 m p.a.) |
| Den Biggelaar et al. 2001 | Canada | Erosion | Lost agricultural output | PC | US$$_{2000}$ 3.3 m p.a. (€$_{2000}$ 3 m p.a.) |
| Dept of Environment, Housing & | Central Victoria, | Erosion | Hedonic Price Method, Difference in land price with and without soil | DC | AU$$_{1975}$ 225 / ha p.a. (€$_{1999}$ 757.50) |

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Community Development 1978 | Australia | | conservation measures | | |
| Dragovich 1990 | Sydney, Australia | Erosion | Contingent Valuation Method / WTP for bread produced with less erosive agricultural practices | NC | 8,4 ¢ per \$1.30 loaf of bread |
| Dragovich 1991 | Singleton, Australia | Erosion | Contingent Valuation Method / WTP for bread produced with less erosive agricultural practices | NC | 6,8 ¢ per \$1.30 loaf of bread |
| Eastwood, Krausse, and Alexander (2000) | New Zealand | Erosion | Replacement / repair cost | | Total: NZ\$$_{1998}$ 111.6 m p.a. (€$_{1999}$ 76.8 m p.a.) |
| | | | On-site cost: | | |
| | | | - lost output | PC | NZ\$$_{1998}$ 31.4 m p.a. (€$_{1999}$ 21.2 m p.a.) |
| | | | - farm infrastructure damage | PC | NZ\$$_{1998}$ 6.2 m p.a. (€$_{1999}$ 4.2 m p.a.) |
| | | | - residential property damage | PC | NZ\$$_{1998}$ 4.3 m p.a. (€$_{1999}$ 2.9 m p.a.) |
| | | | - road infrastructure damage | SC | NZ\$$_{1998}$ 18.2 m p.a. (€$_{1999}$ 12.5 m p.a.) |
| | | | Off-site cost: | | |
| | | | - increased flood severity | SC | NZ\$$_{1998}$ 14.0 m p.a. (€$_{1999}$ 9.6 m p.a.) |
| | | | - reduced water quality | SC | NZ\$$_{1998}$ 2.8 m p.a. (€$_{1999}$ 1.9 m p.a.) |
| | | | - dredging of ports and canals | DC | NZ\$$_{1998}$ 7.9 m p.a. (€$_{1999}$ 5.4 m p.a.) |
| | | | - public spending / erosion control | DC | NZ\$$_{1998}$ 26.0 m p.a. (€$_{1999}$ 17.9 m p.a.) |
| ESCC 1983 | Ontario, Canada | Erosion | Lost output / replacement cost | PC / MC | CAN\$ 89 m p.a. (€$_{1999}$ 32 m p.a.) |
| Evans 1996 | England and Wales | (Wind) Erosion | Lost Output | PC | GB£ 0.84 m p.a. (€$_{1998}$ 1.24 m) |
| | | | Off-site cost: property damage | SC | GB£ 2.45 m p.a. (€$_{1998}$ 3.62 m) |
| | | | Off-site cost: water industry | DC | GB£ 4.22 - 31.68 m p.a. (€$_{1998}$ 6.24 - 46.85 m) |
| FAO 1994 | India | (Water) erosion | Lost output | PC | 8% of cereal production, US\$ 2.3 bn |
| FAO 1994 | India | (Water) erosion | Nutrient replacement cost | MC | 16% of fertiliser purchases (US\$ 0.6 bn) |

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Fox and Dickson 1988, 1990 | Ontario, Canada | Erosion | Off-site costs from sediment | SC / DC | CAN$ 25 – 100 / ha p.a. (€$_{1999}$ 43 – 173) |
| Hartridge and Pearce 2001 | England and Wales | (Water) Erosion | Lost agricultural output | PC | GB£$_{1998}$ 5.40 present value / ha (€$_{1998}$ 8,00)<br>GB£$_{1998}$ 12.97 m p.a. (€$_{1998}$ 19.18 m p.a.) |
| Hopkins et al. 2001 | USA | Erosion | Lost agricultural output | PC | US$ 0.01 – 3.85 / ha p.a. / inch of soil eroded, depending on soil type |
| Huszar and Piper 1985 | New Mexico, USA | (Wind) erosion | Replacement / repair cost (off-site wind erosion costs, related mainly to road maintenance) | | |
| | | | - Off-site household cost | SC | US$$_{1985}$ 457 m p.a.(€$_{1999}$ 717.2 m p a) |
| | | | - Off-site business cost | SC | US$$_{1985}$ 7.57 m p.a.(€$_{1999}$ 11.86 m p a) |
| | | | - Off-site cost for public bodies | SC | US$$_{1985}$ 0.11 m p.a.(€$_{1999}$ 0.16 m p a) |
| King and Sinden 1988 | NSW, Australia | Erosion | Hedonic Price Method (Increase in land values per dollar invested in soil conservation works) | MC | AU$$_{1984}$ 2.28 / ha (€$_{1999}$ 3.31 / ha) |
| ICONA 1991 | Spain | (Water) Erosion | Lost output, damage to dams | PC / SC | €$_{1991}$ 280 m p.a. |
| | | | Mitigation and repair cost | MC | €$_{1991}$ 2.000 m for 15 – 20 years |
| Mallawaarachchi 1993 | NSW, Australia | Erosion | Lost agricultural output | | |
| | | | Net agricultural income loss per ha | PC | AU$$_{1989/90}$ 5.64 / ha (€$_{1999}$ 5.62 / ha) |
| | | | Total net agricultural income loss | PC | AU$$_{1989/90}$ 0.41 m (€$_{1999}$ 0.41 m) |
| | | | Gross external value of income loss per ha (social cost) | SC | AU$$_{1989/90}$ 2.11 / ha (€$_{1999}$ 2.10 / ha) |
| | | | Gross external value of income loss in total (social cost) | SC | AU$$_{1989/90}$ 0.15 m (€$_{1999}$ 0.15 m) |
| Miranowski and Hames 1984 | Iowa, | Erosion | Hedonic Price Method | | |

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| | USA | | (1) Marginal price of topsoil (effect on agricultural land prices) | PC | (1) $\text{US\$}_{1978}$ 4.65 / cm (€$_{1999}$ 12.04 / cm) |
| | | | (2) Reduction in potential erosivity (effect on agricultural land prices) | MC | (2) $\text{US\$}_{1978}$ 15.12 / t*ha (€$_{1999}$ 39.10 / t*ha) |
| Niskanen 1998 | Thailand | Erosion | Replacement/Repair Cost | | |
| | | | Cost of replacing nutrient value of eroded soil | MC | $\text{US\$}_{1997}$ 1.20 / t soil eroded (€$_{1999}$ 1.26 / t) |
| Osborn & Shulstad 1983 | Arkansas, USA | Erosion | Travel Cost Method | | |
| | | | Lost recreation value of a dam affected by siltation | SC | $\text{US\$}_{1980}$ 186.15 / party*visit (€$_{1999}$ 381.26 / party*visit) |
| Palmquist and Danielson 1989 | North Carolina, USA | Erosion | Hedonic Price Method (Effect of erosion on agricultural land prices) | | |
| | | | (1) Unit increase in erosion | PC | (1) $\text{US\$}_{1980}$ 7.86 (€$_{1999}$ 15.51) |
| | | | (2) 1 t/ha p.a. reduction in erosion | MC | (2) $\text{US\$}_{1980}$ 16.85 (€$_{1999}$ 34.56) |
| Piper and Huszar 1989 | New Mexico, USA | Erosion | Off-site replacement / repair cost, mainly infrastructure maintenance | DC | US\$ 260 m – 466 m p.a. (€$_{1999}$ 284 m - 509 m) |
| Pretty et al. 2000 | UK | Erosion | Off-site costs: | | |
| | | | Damage to infrastructure, waterways etc. | SC | GB£ 14 m p.a. (€$_{2000}$ 23 m p.a.) |
| | | | Loss of organic matter | SC | GB£ 82,3 m p.a. (€$_{2000}$ 135,2 m p.a.) |
| | | | Cost of removing P and soil from drinking water | DC | GB£ 52,3 m p.a. (€$_{2000}$ 86 m p.a.) |
| Rennie 1986 | Western Canada | Erosion | Lost output / replacement cost | PC / MC | CAN\$ 430 m p.a. (€$_{1999}$ 221 m p.a.) |
| Ribaudo 1989 | USA | Erosion | Off-site costs | DC | ∅ US\$ 9 bn p.a. (ranging from US\$ 5 – 18 bn) |

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| | | | | | of which 39% due to agriculture |
| Riksen and De Graaff 2001 | Barnham, UK | (Wind) Erosion | Lost agricultural output for different crop types / on-site costs | PC<br>PC / MC | € 61 / ha without conservation (ranging from € 8 - 175 / ha, depending on crop type)<br>€ 36 / ha with conservation measures (ranging from € 8 – 98 / ha, depending on crop type) |
| Science Council of Canada, 1986 | Canada | Erosion | Lost agricultural output | PC | CAN$$_{1986}$ 20 – 15 / ha p.a. €$_{1999}$ 10,27 – 7,70) |
| Sinden 1987 | NSW, AUS | Erosion | Contingent Valuation Method WTP for bread produced with less erosive agricultural practices | | |
| | | | (1) cents extra per $1 loaf of bread | NC | (1) 10.60 ¢ 1 AU$ loaf of bread |
| | | | (2) $ per household p.a. | NC | (2) AU$$_{1985}$ 15.00 p.a. (€$_{1999}$ 20.40 / ha) |
| Sinden and Yap, 1987 | New South Wales / AUS | Erosion | Lost agricultural output | PC | AU$$_{1987}$ 50 m (€$_{1999}$ 68m) |
| Van den Born et al. 2000 (based on ICONA 1991) | Austria | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 76 m p.a.<br>€$_{1991}$ 818 m for 15 – 20 years |
| Van den Born et al. 2000 (based on ICONA 1991) | Finland | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 53 m p.a.<br>€$_{1991}$ 563 m for 15 – 20 years |
| Van den Born et al. 2000 (based on ICONA 1991) | France | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 194 m p.a.<br>€$_{1991}$ 2078 m for 15 – 20 years |
| Van den Born et al. 2000 (based on ICONA 1991) | Germany | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 13 m p.a.<br>€$_{1991}$ 134 m for 15 – 20 years |
| Van den Born et al. 2000 (based on ICONA 1991) | Greece | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 79 m p.a.<br>€$_{1991}$ 845 m for 15 – 20 years |

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Van den Born et al. 2000 (based on ICONA 1991) | Italy | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 195 m p.a.<br>€$_{1991}$ 2086 m for 15 – 20 years |
| Van den Born et al. 2000 (based on ICONA 1991) | Portugal | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 46 m p.a.<br>€$_{1991}$ 491 m for 15 – 20 years |
| Van den Born et al. 2000 (based on ICONA 1991) | Sweden | (Water) erosion | Lost output, damage to dams<br>Mitigation and repair cost | PC / SC<br>MC | €$_{1991}$ 20 m p.a.<br>€$_{1991}$ 210 m for 15 – 20 years |
| Walpole 1994 | NSW, Australia | (Gully) Erosion | Lost agricultural output (mainly wheat and sheep) | | |
| | | | (1) Range of present value of opportunity costs of degradation | PC | (1) AU$$_{1988}$ 155.40 / ha (€$_{1999}$ 166.96 / ha) |
| | | | (2) Average present value of opportunity cost of degradation | PC | (2) AU$$_{1988}$ 860.80 / ha (€$_{1999}$ 924.82 / ha) |
| Walpole, Sinden & Yapp 1992 | NSW, Australia | (Gully, sheet and rill) Erosion | Increase in agricultural output from reducing erosion to negligible level | | |
| | | | (1) Gully erosion | PC | (1) AU$$_{1990}$ 405.00 m (€$_{1999}$ 377.04 m) |
| | | | (2) Sheet and rill erosion | PC | (2) AU$$_{1990}$ 1069.00 m (€$_{1999}$ 995.18 m) |
| | | | (3) Acidity | PC | (3) AU$$_{1990}$ 63.50 m (€$_{1999}$ 59.11 m) |
| Walpole, Sinden & Yapp 1996 | NSW, Australia | (Gully, sheet and rill) Erosion | Lost agricultural output / output increases if soil degradation is reduced to a negligible level | | |
| | | | (1) gully erosion p ha | PC | (1) AU$$_{1988}$ 10.00 (€$_{1999}$ 10.74) |
| | | | (2) sheet and rill erosion p ha | PC | (2) AU$$_{1988}$ 9.00 (€$_{1999}$ 9.67) |
| Williams and Tanaka 1996 | North Central USA | Erosion | Lost agricultural output (without mitigation measures) | PC | US$$_{1996}$ 1.28 – 1.98 per cm of eroded soil (€$_{1999}$ 1.06 – 1.65 per cm of eroded soil) |
| Xu and Prato 1995 | Missouri, USA | Erosion | Lost agricultural output | PC | US$ 3.55 – 8.91 / ha over 25 years |

| Study | Region | Erosion type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Yapp, Young & Sinden (1991 | Sydney AUS | Erosion | Contingent Valuation Method WTP for bread produced with less erosive agricultural practices | NC | AU$$_{1990}$ 20.60 cents per loaf of bread purchased (€$_{1999}$ 19.18) |
| Zvirbulis 1994 | NSW, AUS | Erosion | Replacement/Repair Cost: Maintenance dredging costs to remove eroded sediment | SC | AU$$_{1990}$ 5.55 - 15.71 /$m^3$ (€$_{1999}$ 5.17 - 14.63/$m^3$) |

Notes: Studies from European countries are shaded light grey.

* for a detailed description of the measurement methods, please refer to sections 4.4.1 – 4.4.6

** PC = private damage cost; MC = private mitigation cost; SC = social cost; DC = defensive cost; NC = non-user cost. The cost categories are explained in detail in section 4.6.1

*** abbreviations: CHF = Swiss Frank; US$ = US Dollar; AU$ = Australian Dollar, CA$ = Canadian Dollar; NZ$ = New Zealand Dollar; ha = hectare; Mha = megahectare ($10^6$ ha); p.a. = per annum; m = million ($10^6$); bn = billion ($10^9$); t = tons. Subscripts after currency symbols (e.g. US$$_{1986}$) indicate the original year in which prices are quoted; currency conversion was calculated using purchase power parity values.

**Table 13: Estimates of the Costs of Other Types of Degradation**

| Study | Region | Degradation type | Measurement method* | Cost cat** | Amount*** |
|---|---|---|---|---|---|
| Scrimgeour 1995 | New Zealand | Compaction | Willingness to pay f. protection<br>Lost output | PC | NZ$$_{1995}$ 37 - 185 /ha p.a. (€$_{1995}$ 19 - 94)<br>NZ$$_{1995}$ 250 - 750 /ha p.a. (€$_{1995}$ 127 - 381) |
| Munich Re 2002 | Rhone River, France | Floods | Damage cost (September 2002 floods) | SC | € 1.2 bn (soil-related share of the damage not quantified) |
| Munich Re 2002 | Danube & Elbe, A/CZ/D | Floods | Damage cost (August 2002 floods | SC | € 18.5 bn (soil-related share of the damage not quantified) |
| Munich Re 2003 | Rhone River, France | Floods | Damage cost (December 2003 floods) | SC | € 1.5 bn (soil-related share of the damage not quantified) |
| Pretty et al. 2000 | UK | Organic matter / $CO_2$ losses | Lost output | PC | GB£ 82 m p.a. (€$_{2000}$ 131 m p.a.) |
| Ahmad and Kutscher 1992 | Pakistan | Salinisation | Lost output | PC | 25% of cotton and rice production,<br>US$ 2.5 bn |
| Ahmad and Kutscher 1992 | Pakistan | Salinisation | Mitigation cost (reclamation) | MC | US$ 9 bn (hyp.) / 3.3 Mha, US$ 500 / ha |
| FAO 1994 | India | Salinisation | Lost output | PC | US$ 0.6 bn |
| NDSP 1998 | Australia | Salinisation | Lost output<br>Infrastructure damage | PC<br>SC | AUS$$_{1998}$ 130 m p.a. (€$_{1998}$ 71,4 m) (2.5 m ha)<br>AUS$$_{1998}$ 100 m p.a. (€$_{1998}$ 54,9) |
| FAO 1994 | India | Soil fertility decline | Lost output / replacement cost | PC / MC | US$ 0.6 – 1.2 bn (for each method)<br>(US$ 30/ha) |
| Repetto et al., 1989<br>Magrath and Arens, 1989 | Indonesia | Soil fertility decline | Lost output | PC | 4% of crop production |

Notes: see Table 12 above.

## 4.8 Overview of the Availability of Economic Data

Based on the evidence presented in the tables above, some preliminary conclusions can be drawn with a view to the availability of economic data and the possibilities for a Europe-wide extrapolation of the costs of soil degradation. Table 14 below provides an overview of the available evidence on different cost categories and different types of soil degradation. The table distinguishes between such cases where monetary information is available, between cases where there is quantitative but not monetary information (e.g. surface area affected by degradation), and between the cases where economic impacts can only be assessed qualitatively.

### Table 14: Overview of Available Economic Data

| | Erosion | OM decline | Contamination | Salinisation | Biodiv. loss | Compaction | Sealing | Floods & landslides | Σ |
|---|---|---|---|---|---|---|---|---|---|
| **PC** | € | ⊕ | € | € | ≈ | ⊕ | ≈ | € | € |
| **MC** | € | ⊕ | € | ? | – | ? | – | ⊕ | € |
| **SC** | € | ⊕ | ⊕ | ≈ | ? | (⊕) | (⊕) | € | ? |
| **DC** | € | ? | ⊕ | – | – | – | – | € | **?** |
| **NC** | ≈ | ≈ | – | – | ≈ | – | ≈ | – | ≈ |
| **Σ** | € | ⊕ | € | ⊕ | ≈ | ≈ | ≈ | € | **?** |

With € = monetary assessment
⊕ = quantitative assessment
(⊕) = for compaction and sealing, indirect social costs arise through the effect on floods and landslides
≈ = qualitative assessment
? = availability of data uncertain or incomplete
– = no data available / only preliminary qualitative assessment

It should be noted that:

- The table above only identifies whether any economic or quantitative information is generally available. It does not indicate the quality of this information, the number of studies on which it can be based, or the spatial coverage of the information. Therefore it is only a very tentative indication of whether an extrapolation is possible in principle. While the table indicates where economic data can be found, it is possible that this information would only provide a rough, lower-bound estimate, or that the information is only applicable under particular circumstances. At any rate, the extrapolation of this data to other spatial contexts would require a number of strong assumptions.
- The horizontal and vertical sums should be viewed with some caution, as they require an aggregation of data that is presented in different forms and in different contexts. This includes monetarised, quantitative and qualitative information, as well as data of different origin, quality, and robustness, leading to more assumptions in the aggregation process.

- For the aggregation of different cost types, the results will therefore take the form of cost ranges, with a quantitative (or, where possible, monetary) lower bound estimating the effects where hard data is available, and an upper bound, which includes all major effects in a qualitative form. This applies in particular to cases such as erosion and contamination, where different types of costs estimates are available. In cases where little or no empirical estimates are available, such as biodiversity loss or sealing, the result will be presented mainly in a qualitative way, supported by quantitative evidence where available.
- In the case of floods and landslides, while it is possible to quantify the damage costs of floods in monetary terms, it is far more difficult to quantify how much of the cost can actually be related to soil degradation through changed runoff dynamics in the catchment area of a river.

# 5 Conclusions

In order to prepare an economic assessment of soil degradation in Europe, this paper provides a review of the main concepts, methods and issues that are discussed in the soil-scientific and economic literature. The following main aspects were emphasised:

- Derivation and description of a **typology of soil degradation**, including basic concepts to describe the dynamics of soil degradation processes, as well as the identification and description of the most important types of soil degradation;
- Description of possible **indicators** to describe soil degradation processes and their impacts (both environmental and socio-economic), as well as an overview of possible **data sources**;
- Derivation and description of the **methodology for assessing the economic impacts** of soil degradation trends in Europe, including the identification of relevant cost categories and methods to estimate the impacts and related costs;
- Overview of existing **empirical estimates** assessing the costs of soil degradation, which includes mainly agronomic and other economic studies from European and other industrialised countries;

Based on these preliminary results, the project “Assessing the Economic Impacts of Soil Degradation” (Study Contract ENV.B.1/ETU/2003/0024) an empirical assessment of the cost of soil degradation in Europe was carried out (Volume III of this report), based on the methodology described, the overview of empirical estimates and five case studies from different European regions (Volume II of this report).

The following preliminary findings can be derived from the methodological papers and the empirical estimates surveyed in this study:

- In general, the data availability is far too limited to give a comprehensive and reliable estimate of the costs of soil degradation. Based on the available evidence, this is only possible on a local scale. However, it is possible to identify the most relevant types and impacts of soil degradation, and to give a broad estimate of their relative significance, and possibly also their order of magnitude.
- Apart from the number of studies, the empirical findings are also limited in their focus: a majority of studies focuses on the cost of erosion, whereas other aspects of soil degradation receive less attention. Geographically, a large part of the available evidence stems from North America and Australia, with comparatively few European studies. Finally, most studies investigate the impacts of soil degradation in relation to agriculture, either the impacts soil degradation *suffered by* agriculture, or the impacts *caused by* agriculture.
- Several studies provide evidence that the total cost of soil degradation is indeed significant. Estimates of the total, nation-wide or state-wide cost from Australia, Canada, New Mexico and Spain have produced results between € 200 million and € 1.9 billion per year (expressed in 1999 €). While these numbers should not be compared directly, they

illustrate that the potential economic impact of soil degradation can reach a significant order of magnitude, even if viewed on a macroeconomic scale.

- In the case of soil erosion, the off-site (or social) costs represent a significant part of the total costs, even exceeding the on-site impact through reduced yield losses. For the UK, estimates of these impacts range from € 50 million to € 224 million per annum. For the US, single estimates range as high as US$ 9 billion per annum.
- Some of the biggest uncertainties in the economic valuation of soil degradation are related to the ecosystem services that soil provides. One reason for this is that the interactions with other environmental media are only partly understood. Whereas the interactions between soil and hydrosphere are sufficiently well researched, there is more uncertainty regarding the linkages between soil and the climate system. Regarding the connection between soil quality and above-soil biodiversity, there is only very limited, inconclusive evidence. Above all, even where there is a sufficient understanding of these ecosystem services in theory, there is hardly any quantitative data that would allow an economic valuation of such services on an aggregated level.
- The evidence is also fairly weak concerning the non-use values of soil. This appears to be a serious deficiency, given the fact that soil would generally be seen as a good with a high patrimonial value, not least through the cultural and spiritual functions it performs.
- Finally, academic discussion revolves around the appropriate approach to dealing with the temporal dimension of soil degradation. As soil is essentially a non-renewable resource, and as it is of fundamental value for human survival, it may appear questionable to apply standard economic discounting procedures. However, the decision not to discount future costs and benefits will have a great impact on the appropriate policy response to soil degrading activities.

By way of a preliminary conclusion, it should be underlined that the methodology described in chapter 4.6 should only be regarded as a first approximation, based on theoretic considerations. Although it provides a solid basis for the future work, it remains to be adapted for practical implementation. The described methodology aims to meet the challenge posed by the economic evaluation of soil degradation: to adequately represent the different facets and impacts of soil degradation, while at the same time reducing complexity in order to make an extrapolation possible. Through the identification of the major cost categories and the proposal of feasible indicators, this study suggests a possible compromise between the two conflicting targets.

For some types of soil degradation in particular, the lack of reliable, quantitative indicators will limit the applicability of the proposed methodology. Standard economic assessment methods are associated with high data requirements if they are to deliver scientifically robust results. If such data is not available in sufficient quantity and quality, the robustness of the results will decrease, while the uncertainty will increase.

# 6 Literature

Ahmad, M., and Kutcher, G.P. 1992: Irrigation planning with environmental considerations: a case study of Pakistan's Indus basin. World Bank Technical Paper. Washington DC.

Alcock, B.S. 1980: “The Cost of Soil Erosion.” Miscellaneous Bulletin No.11. Economic Services Branch, Department of Primary Industries,Toowoomba.

Anderson, Jock R. and Jesuthason Thampapillai 1990: Soil Conservation in Developing Countries. No. PRS 8. Washington: World Bank.

Arnalds, O., and B.H. Barkarson 2003: Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. Environmental Science and Policy 6 (2003): 105-13.

Balmford, Andrew, et al. 2002: “Economic Reasons for Conserving Wild Nature.” Science, Vol. 297, No. 9 August 2002, 950-953.

Baltic Environmental Forum, 2001: 2nd Baltic state of the environment report: The Baltic environmental indicators set .Baltic Environmental Forum, Riga. http://www.bef.lv/baltic/baltic2/content.htm.

Barter, S.A. 1986: An Economic Analysis of Soil Erosion Damage to Public Utilities. Report No.9 of the project 'Estimation of Unpriced and Social Benefits of Soil Conservation'

Batjes, N. H. and Bridges, E. M., 1991: Mapping of Soil and Terrain Vulnerability to Specified Chemical Compounds in Europe at a Scale of 1:5 m. Proceedings of an International Workshop held at Wageningen, the Netherlands – ISRIC, Wageningen.

Beinat, E. and P. Nijkamp 1997: Environmental Rehabilitation: Efficiency and Effectiveness in Soil Remediation. Vrije Universiteit Amsterdam: Serie Research Memoranda (1997-62).

Bennett, R.J. 1987: Soil Erosion Damage Costs to Community Assets. Final Report No.3, in the project 'Estimation of Unpriced and Social Benefits of Soil Conservation'.

Bishop, Joshua 1992: Economic Analysis of Soil Degradation. Gatekeeper Series. London: International Institute for Environment and Development.

Blum, W.E.H., 1988: Problems of soil conservation – Nature and Environment Series No. 40, Council of Europe, Strasbourg.

Blum, W.E.H. 1990: The Challenge of Soil Protecion in Europe. Environmental Conservation, No. 17, 724.

Blum, W.E.H. 1998: Soil degradation caused by industrialisation and urbanisation. In: Blume H.-P., H. Eger, E. Fleischhauer, A. Hebel, C. Reij, K.G. Steiner (Eds.): Towards Sustainable Land Use, Vol. I, 755-766, Advances in Geoecology 31, Reiskirchen: Catena

Blume, H.-P., 1992: Handbuch des Bodenschutzes: Bodenökologie und –belastung Vorbeugende und abwehrende Schutzmaßnahmen, p.p. 129– 494, Ecomed (2. Ed.).

Blume, H.-P., et al. (ed.) 1998: Towards Sustainable Land Use: furthering cooperation between people and institutions. Acvances in Geology 31. Reiskirchen: Catena.

Boardman, Joan, Jean Posen and Robert Evans 2003: “Socio-economic factors in soil erosion and conservation.” Environmental Science and Policy, Vol. 6, 1-6.

Botschek, J., A. Skowronek and N. Jayakody 1998: “Soil Degradation, Soil Assessment and Soil Rehabilitation in a Former Tea-Growing Area of Sri Lanka.” Applied Geography and Development, Vol. 51, 94-105.

Brouwer, F., M. Riksen and J. De Graaff 2002: "Soil Conservation Policy Measures to Control Wind Erosion in Northwestern Europe," in: Andrew Warren (ed.): Wind Erosion on European Light Soils (WEELS). London: University College London.

Brouwer, F.M., Thomas, A.J. and M.J. Chadwick (eds.) 1991: Land Use Changes in Europe, Processes of Change, Environmental Transformation and Future Pattern – Kluwer Academic Publisher, Dordrecht.

Bryant, Kelly J. 1998: Economic Results of Conservation Tillage in Cotton. Little Rock: University of Arkansas.

Carder, D.J., & Humphry, M.G. 1983: “The Costs of Land Degradation.” Journal of Agriculture, Vol. 24, No. 2, 50-53.

Cavigelli, M.A., S.R. Deming, L.K. Probyn and R.R. Harwood (eds). 1998: Michigan Field Crop Ecology: managing biological processes for productivity and environmental quality, Michigan State University, Extension Bulletin E-2646, United States.

Chadwick, M.J. and J.C.I. Kuylenstierna 1990: The Relative Sensitivity of Ecosystems in Europe to Acidic Depositions. A Preliminary Assessment of the Sensitivity of Aquatic and Terrestrial Ecosystems. York: SEI.

Clark, E.H. 1985: “The Off-site Costs of Soil Erosion.” Journal of Soil and Water Conservation, Vol. 40, No. 1, 19-22.

Clark, E.H., H.J. Haverkamp and W. Chapman 1985: Eroding Soils: The Off-Farm Impacts. Washington DC: The Conservation Foundation.

Coalition Clean Baltic (CCB) 2002: Baltic Sea Hot Spots - Hazards and Possibilities for the Baltic Sea Region. CCB, www.sll.fi/tiedotus/pressreleases/CCBHotSpots.html.

CORINE, 1992: Soil erosion risk and important land resources in the southern regions of the European Community. EUR 13233. Commission of the European Communities, Luxembourg.

Council of Europe, 1990: European Conservation Strategy. Recommendation for the 6th European Ministerial Conference on the Environment. Council of Europe, Strasbourg.

Coxhead, Ian 1995: Economic Modelling of Land Degradation in Developing Countries. University of Madison-Wisconsin, Agricultural and Applied Economics Staff Paper Series, Vol. 385.

Crosson, P. 1986: Soil Erosion and Policy Issues, in: T. Phillips, P. Crosson and K. Price (ed.): Agriculture and the Environment. Washington, DC: Resources for the Future.

Crosson, P.R. and A.T. Stout 1983: Productivity Effects of Cropland Erosion in the United States. Washington: Resources for the Future.

Cuffaro, Nadia, and Frank Heins 1998: Population Growth, Food Production and the Environmental Resource Base in Poor Countries. World Congress of Environmental and Resource Economics, June 25-27 1998. Venice.

Daily, Gretchen C., et al. 1997: “Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems.” Issues in Ecology, Vol. 2, No. Spring 1997, 1-18.

De Graaff, J., and L.A.A.J. Eppink 1999: “Olive oil prouction and soil conservation in Southern Spain, in relation ot EU subsidy policies.” Land Use Policy, Vol. 16, 259-267.

DEFRA 1999: Estimating the Value of Environmental Features. London: Institute of Ecology and Resource Management at the University of Edinburgh and Scottish Agricultural College, Edinburgh.

den Biggelaar, Christoffel, Rattan Lal, Keith Wiebe and Vince Breneman 2001: “Impact of Soil Erosion on Crop Yields in North America.” Advances in Agronomy, Vol. 72 (2001), 1-52.

Department of Environment, Housing & Community Development 1978: Economic Evaluation of Eppalock Soil Conservation Project, Victoria. Canberra: AGPS.

Desaules, A., 1991: The Soil Vulnerability Mapping Project Group for Europe (SOVEUR): Methodological considerations with reference to conditions in Switzerland. In: Batjes, N H and Bridges, E M (Eds) Mapping of soil and terrain vulnerability to specified chemical compounds in Europe at a scale of 1:5M, pp 23-8. Proceedings of an International Workshop held at Wageningen, The Netherlands (20-23 March 1991) ISRIC, Wageningen.

Doran, J.W., M. Sarrantonio, and M.A. Liebig. 1996. Soil health and sustainability. P. 1-54. In: D.L. Sparks (ed.) Advances in Agronomy, vol. 56. Academic Press, San Diego, CA.

Dragovich, D. 1990: “Does Soil Erosion Matter to People in Metropolitan Sydney?” Australian Journal of Soil and Water Conservation, Vol. 3, No. 1, 29-32.

Dragovich, D. 1991: “Who Should Pay for Soil Conservation? - Community Attitudes about Financial Responsibility for Land Repair.” Australian Journal of Soil and Water Conservation, Vol. 4, No. 1, 4-7.

Eastwood, C., Krausse, M. and Alexander, R. 2000: Muddied Waters: Estimating the National Economic Cost of Soil Erosion and Sedimentation in New Zealand. 44th Conference of the Australian Agricultural and Resource Economics Society. Sydney.

Ecolas 2002: Financiële behoeftenraming mbt bodemsanering. Mechelen: Openbare Afvalstoffenmaatschappij voor het Vlaamse Gewest (OVAM).

EEA (European Environment Agency), 1995: Chapter 7: Soil, in: Europe's Environment: the Dobris Assessment. p.p. 146-171, EEA, Copenhagen.

EEA (European Environment Agency), 1998: Multiannual work programme 1999–2003, available on the Internet (http://org.eea.eu.int/documents/mawp1999-2003/index.html).

EEA (European Environment Agency), 1999: Environment in the European Union at the turn of the century. Environmental assessment report No 2. Office for Official Publications of the European Communities, Luxembourg.

EEA (European Environment Agency), 2000a: Are we moving in the right direction? Environmental Issues Series No 12.Office for Official Publications of the European Communities, Luxembourg.

EEA (European Environment Agency), 2000b: Down to Earth: Soil Degradation and Sustainable Development in Europe. Environmental issue series No 16. European Environment Agency.

EEA (European Environment Agency), 2001a: Proposal for a European Soil Monitoring and Assessment Framework. Technical Report No 61. Copenhagen, Denmark. http://reports.eea.eu.int/Technical_report_No_61/en.

EEA (European Environment Agency), 2001b: European Soil Monitoring and Assessment Framework. Technical Report No. 67. Copenhagen, Denmark. http://reports.eea.eu.int/technical_report_2001_67/en.

EEA (European Environment Agency), 2001c: Environmental signals 2001. Environmental assessment report No 8.Office for Official Publications of the European Communities, Luxembourg.

EEA (European Environment Agency), 2001d: Towards spatial and territorial Indicators using land cover data. Technical Report 59. European Environment Agency.

EEA (European Environment Agency), 2003a: EEA Core Set of Indicators. Revised version April 2003, Technical Report. Copenhagen, Denmark..

EEA (European Environment Agency), 2003b: Chapter 9: Soil Degradation in Europe's Environment: the Third Assessment. p.p. 198-212, Copenhagen.

EEA (European Environment Agency), 2003c: Assessment and reporting on soil erosion. Technical report No 94. EEA, Copenhagen.

EEA-UNEP, 2000: Down to earth: Soil degradation and sustainable development in Europe. A challenge for the 21st century. Environmental issues Series No 6.EEA, UNEP, Luxembourg.

European Commission 1992: Soil Erosion Risk and Important Land Resources in the Southern Regions of the European Community. Brussels: Commission of the European Communities.

European Commission 1994: Communication from the Commission to the Council and the European Parliament on "Directions for the EU on Environmental Indicators and Green National Accounting", COM (94) 670 final, 21.12.94, Brussels.

European Commission, 2000: The environmental impacts of irrigation in the European Union. Report to DG Environment prepared by Institute for European Environmental Policy, London, Polytechnical University of Madrid, University of Athens. EC, Brussels.

European Commission 2002: “Towards a Thematic Strategy for Soil Protection”, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions, COM (2002) 179 final, 16.4.2002, Brussels.

Eurostat, 2001: Environmental pressure indicators for the EU. European Commission.

Evans, R. 1996: Soil Erosion and its Impacts in England and Wales. London: Friends of the Earth UK.

FAO (undated). Soil Biodiversity Portal. http://www.fao.org/ag/agl/agll/soilbiod/default.stm

FAO 1990: Soilless Culture for Horticultural Crop Production. Rome: FAO.

FAO 1994: Land Degradation in South Asia: Its Severity, Causes, and Effects upon the People. World Soil Resources Report. Rome.

FAO 1996: Report of the FAO Regional Conference for Europe.20th Session, Tel Aviv, 29 April – 3 May 1996. ERC/96/REP. FAO, Rome.

Feodoroff, N., 1987: The production potential of soils – Part 1: Sensitivity of principal soil types to intensive agriculture in NW Europe. In: H. Barth and D. L’Hermite (eds.): Scientific basis for Soil Protection in the European Community, p. 65-85 – Elsevier Applied Science, London, N.Y.

Follet, R.F. and Stewart, B.A. (Eds), 1985: Soil erosion and crop productivity. ASA, CSSA, SSSA, Madison (USA).

Fons-Esteve J., 2003: State on the soil issues: Indicator development within the reporting system. Technical Workshop on Indicators regarding Soil Threats for Balkan Countries. 29-30 September 2003, Belgrade. http://terrestrial.eionet.eu.int/Soil/Balkan.

Fox, G., and E.J. Dickson 1988: What's economic about the costs of soil erosion to Canadian farmers? Discussion paper. Guelph: University of Guelph.

Fox, G., and E.J. Dickson 1990: “The economics of erosion and sediment control on southwestern Ontario.” Canadian Journal of Agricultural Economics, Vol.  38, No. (1), 23-44.

Fraters, D., 1994: Generalised soil map of Europe: Aggregation of the FAO-Unesco soil units based on the characteristics determining the vulnerability to soil degradation processes. Report 71240300, RIVM, Bilthoven, The Netherlands.

Furtan, W.H., and S.S. Hosseini 1997: Economic and Institutional Considerations for Soil Depletion. CSALE occational papers: University of Saskatchewan.

García, A.; Ibáñez, J.J. & Bello, A. 2003: Soil functions, soil quality or soil health. Scientific, metaphorical or utilitarian concepts in soil sciences. In: Lobo, M.C. & Ibáñez, J.J. (Eds.). Preserving soil quality and soil biodiversity. The role of surrogates indicators. Instituto Madrileño de Investigación Agraria y Alimentaria. Centro de CC. Medioambientales. Madrid.

García-Torres, L. et. al., 2001: Conservation agriculture in Europe: Current status and perspectives. In: Conservation agriculture, a world-wide challenge. I World Congress on Conservation Agriculture. Madrid,1–5 October 2001 .ECAF, FAO, Córdoba, Spain.

Gardner, G.,1997: Preserving global cropland. In: State of the World 1997 (Brown, L. et. al., ed.). W. W. Norton, New York.

Goebel. J.J., M.J. Mausbach and D.L. Karlen 1997: Using the National resource inventory as a framework to assess soil erosion, soil conservation, and soil quality. Papers presented to the 23rd Study Group on Food and Agricultural Statistics in Europe, UNECE/FAO/Eurostat/OECD, 2-3 July, Geneva, Switzerland.

Hardin, G. 1968: The Tragedy of the Commons. Science 162: 1243-48.

Hartridge, Olivia, and David Pearce 2001: Is UK Agriculture Sustainable? Environmentally Adjusted Economic Accounts for UK Agriculture. London: CSERGE-Economics, University College London.

Hébert, J., 1982: About the problems of structure in relation to soil degradation. In: Soil degradation (Boels, D., Davies, D. and Johnston, A.E., eds.). A.A. Balkema, Rotterdam.

Hopkins, J.W., R. Lal, K.D. Wiebe and L.G. Tweeten 2001: “Dynamic Economic Management of Soil Erosion, Nutrient Depletion, and Productivity in the North Central USA.” Land Degradation and Development, Vol. 12, 305-318.

Husznar, P.C. and S.L. Piper 1986: “Estimating the Off-site Costs of Wind Erosion in New Mexiko.” Journal of Soil and Water Conservation, Nov-Dec, 414-416.

ICONA, Instituto Nacional para la Conservación de la Naturaleza 1991: Plan Nacional de lucha contra la erosión. Madrid: Ministerio de Agricultura, Pesca y Alimentación.

Jansson, M.B., 1988: A global survey of sediment yield. Geografiska Annaler 70 A (1-2), 86.

Joosten, H., and Donal Clarke (2002). Wise Use Of Mires And Peatlands: A Framework for Decision-making. Draft version, 16 May 2002 Greifswald: International Mire Conservation Group.

Jordi, Beat 2003: Teure Aufräumaktion zum Schutz der Gesundheit. Umwelt (Zeitschrift der schweiz. Bundesamt für Umwelt, Wald und Landschaft), Vol. 3/2003, 6-10.

Karavayeva, N.A., Nefedova, T.G. and Targulian, V.O., 1991: Historical land use changes and soil degradation on the Russian Plain. In: Brouwer, F M, Thomas, A J and Chadwick, M J (Eds) Land use changes in Europe: processes of change, environmental transformations and future patterns, p.p. 351-77. Kluwer Academic Publishers, Dordrecht, the Netherlands.

King, D.A. and J.A. Sinden 1088: “Influence of Soil Conservation on Farm Land and Values.” Land Economics, Vol. 64, No. 3, 242-255.

Kraemer, R. Andreas; Tanja Dräger; Ruta Landgrebe and Keya Choudhury (eds.) 2003: EU: CAP and Enlargement - An Opportunity for Nature and Environment. BfN-Skripten: Bundesamt für Naturschutz (BfN).

Lal, R. 1999: “Soil management and restoration for carbon sequestration to mitigate the accelerated greenhouse effect.” Progress in Environmental Science, Vol. 1, 307-326.

Lal, R., 2000: Soil conservation and restoration to sequester carbon and mitigate the greenhouse effect. III International Congress European Society for Soil Conservation, Valencia.

Lal, R. 2001: “Soil Degradation by Erosion.” Land Degradation & Development, No. 12, 519-539.

Lal, R., C. den Biggelar and K.D. Wiebe 2003: Measuring On-Site and Off-Site Effects of Soil Erosion on Productivity and Environmental Quality. OECD Expert Meeting on Soil Organic Carbon Indicators for Agricultural Land - October 2002. Rome.

Larson, W.E. and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. P. 37-51. In: J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.), Defining Soil Quality for a Sustainable Environment. SSSA Special Pub. No. 35. ASA, CSSA, and SSSA, Madison, WI.

Lutz, E., S. Pagiola and C. Reiche (ed.) 1994: Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Carribean. World Bank Environment Paper No. 8. Washington, DC: The World Bank.

Magrath, W., and P. Arens 1989: The Costs of Soil Erosion on Java: A Natural Resource Accounting Approach. Washington DC: World Bank Environment Department Working Paper.

Mallawaarachchi, T. 1993: Economic Costs of Cropland Erosion: An Application of GIS-based Resource Accounting Approach. 37th Annual Conference of the Australian Agricultural Economics Society, University of Sydney. Sydney.

Malthus, T. 1798: “Essai sur le Principe de Population.” Presse Universitaire de France, Paris.

Miranowski 1984: “Implicit Prices of Soil Charakteristics for Farmland in Iowa.” American Journal of Agricultural Economics, Vol. 66, 745-749.

MMA (Ministerio de Medio Ambiente), 2001: Programa de Acción Nacional Contra la Desertificación (Borrador de Trabajo). Ministerio de Medio Ambiente. Madrid, Marzo.

Moen, J.E.T. and Brugman, W.J.K., 1987: Soil Protection Programmes and Strategies: examples from the Netherlands. In: H. Barth and D. L’Herite (eds.): Scientific basis for Soil Protection in the European Community, p. 429-446 – Elsevier Applied Science, London, N.Y.

Morgan, R.P.C. (Ed), 1986: Soil erosion and conservation. Longman, Harlow (UK).

Morgan, R.P.C., 1987: Sensitivity of European soils to ultimate physical degradation. In: H. Barth and D.L.’Hermite (eds.): Scientific basis for Soil protection in the European Community, p. 147-157 – Elsevier Applied Science, London, N.Y.

Munich Re 2002: Analysis of natural catastrophes in 2002. Munich: Münchner Rück AG.

Munich Re 2003: Analysis of natural catastrophes in 2003. Munich: Münchner Rück AG.

National Dryland Salinity Program, NDSP 1998: Management Plan 1998-2003. Canberra: Land and Water Resources Research and Development Corporation.

Navrud, Stale, and Mette Vagnes 2000: Assessment of Environmental Valuation Reference Inventory (EVRI) and the expansion of its coverage to the EU. Lysaker, Norway: ENCO Environmental Consultants AS.

Niskanen, A. 1998: “Value of external environmental impacts of reforestation in Thailand.” Ecological Economics, Vol. 26, 287-297.

OECD, 1997: Environmental Indicators for Agriculture, Volume 1: Concepts and Framework, Paris, France.

OECD, 1999: Environmental Indicators for Agriculture, Volume 2: Issues and Design. The York Workshop, Paris, France.

OECD, 2001a: Environmental Indicators for Agriculture, Volume 3: Methods and Results, Paris, France.

OECD, 2001b: OECD Environmental Indicators: Towards Sustainable Development, Paris, France.

OECD, 2003: Report and recommendations of the expert meeting on agricultural soil erosion and soil biodiversity indicators (Rome, 25-28 March 2003). Joint working party on agriculture and the environment. Paris, 16-18 June 2003. Directorate for Food, Agriculture and Fisheries and Environment Directorate, COM/AGR/CA/ENV/EPOC(2003)24.

Oldeman, L.R., Hakkeling, R.T.A. and Sombroek, W.G. 1991: World Map of the Status of Human-Induced Soil Degradation, with Explanatory Note (second revised edition) - ISRIC, Wageningen; UNEP, Nairobi.

Osborn, C.T. and R.N. Shulstad 1983: “Controlling Agricultural Soil Los in Arkansas' North Lake Chicot watershed: analysis of benefits.” Journal of Soil and Water Conservation, 509-512.

Pagiola, Stefano 1999: The Global Environmental Benefits of Land Degradation Control on Agricultural Land. World Bank Environment Paper Number 16. Washington, D.C.: The World Bank.

Palmquist, R.B. and L.E. Danielson 1989: “A Hedonic Study of the Effects of Erosion Control and Drainage on Farmland Values.” American Journal of Agricultural Economics, Vol. 71, No. 1, 55-62.

Pankhurst, C.E., B.M. Doube, and V.V.S.R. Gupta, 1997: Biological indicators of soil health. CAB Int., Wallingford, UK.

Pearce, D.W., and A. Howarth 2000: Technical Report on Methodology: Cost Benefit Analysis and Policy Responses. RIVM report 481505020. Bilthoven: Rijksinstituut voor Volksgezondheit en Milieu (RIVM).

Perrings, C. 1996: “Economics, Ecology and the Global Biodiversity Assessment.” Trends in Ecology and Evolution, Vol. 11, No. 6, 270.

PIK (Potsdam Institute for Climate Impact Research), 2000: Proceedings of the European conference on advances in flood research. Potsdam, November 2000. PIK Report 65. PIK.

Pimentel, D. (1997). “Economic and Environmental Benefits of Biodiversity.” BioScience 47(11): 747-758.

Pretty, J.N., Brett, C., Gee, D., Hine, R.E., Mason, C.F., Morison, J.I.L., Raven, H., Rayment, M.D., van der Bijl, G. 2000: “ An assessment of the total external costs of UK agriculture.” Agricultural Systems, Vol. 65, 113–136.

Rennie, D.A. 1986: “Soil degradation: a western perspective.” Canadian Jornal of Agricultural Economics, Vol. 33, No. June 1986, 19-29.

Ribaudo, M.O. 1989: Water Quality Benefits from the Conservation Reserve Program. No. AER-606. Washington, DC: US Department of Agriculture.

Riksen, M.J., and J. De Graaff 2001: “On-Site and Off-Site Effects of Wind Erosion on European Light Soils.” Land-Degradation and Development, Vol. 12, 1-11.

Sandler, T. 1993: “Tropical deforestation: markets and market failures.” Land economics, Vol. 69, 225-233.

Sauerborn, P. et al., 1999: Future rainfall erosivity derived from large-scale climate models — methods and scenarios for a humid region. Geoderma 93:269 –276.

Schramek, J., 2002: Development of national Indicators for soil protection in Germany – use of international indicator frameworks on national level and related data needs. Summary of Final Report. Frankfurt/M., 25.01.2002.

Science Council of Canada 1986: A Growing Canadian Concern: Soil Degradation in Canada. Ottawa: Science Council of Canada.

Scrimgeour, Frank 1995: The Economics of Soil Compaction: A Case Study from the Manawatu. 2nd Annual Conference, New Zealand Agricultural Economics Society. Blenheim, NZ: University of Waikato.

Secrétariat d'Etat auprès du Premier Ministre, Chargé de l'Environnement, 1988: L'observatoire de la qualité des sols. Neuilly-sur-Seine, France.

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers. 1998. Quantification of soil quality. p. 387-404. In: R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (eds.) Soil processes and the carbon cycle. CRC Press, BocaRaton.

Shortle, James S., and David G. Abler 1999: "Agriculture and the Environment," in: J. van den Bergh (ed.): Handbook of Environmental and Resource Economics, 159-176. Cheltenham: Edward Elgar.

Sinden, J.A. 1987: “Community Support for Soil Conservation.” Search, Vol. 18, No. 4, 188-194.

Sinden, J.A. 1990: "The Costs of Soil Degradation on the Northwest Slopes of New South Wales," in: J.A. Dixon; D.E. James and P.B. Sherman (eds.): Dryland Management: Economic Case Studies. London: Earthscan Publication Ltd.

State Committee of the Republic of Uzbekistan, 2000: State of environment in Uzbekistan .State Committee of the Republic of Uzbekistan, Department for managing of ecological information and prognostification. http://www.grida.no/ enrin/htmls/uzbek/soe2/english/ index.htm.

Stocking, M.A., and N. Murnaghan 2001: Handbook for the Field Assessment of Land Degradation. London: Earthscan.

Stolbovoi, V. and Fischer,G., 1997: A new digital georeferenced database of soil degradation in Russia .Interim Repo rt IR-97-084/ November. IIASA, Laxenburg, Austria.

Szabolcs, I., 1991: Salinisation potential of European soils. In: Brouwer, F. M., Thomas, A. J. and Chadwick, M. J. (Eds) Land use changes in Europe: processes of change, environmental transformations and future patterns, Warsaw, 5-9 Sept 1988, p.p. 293-315. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Turner, R. Kerry, et al. 2000: “Ecological-economic analysis of wetlands: scientific integration for management and policy.” Ecological Economics, Vol. 35 (2000), 7–23.

Umali, Dina 1993: Irrigation-induced salinity: A growing problem for development and the environment. World Bank Technical Paper No. 215. Washington, DC: The World Bank.

UNECE (United Nations Economic Commission for Europe), 2000: Environmental Performance Review of Armenia. UNECE, Geneva.

UNECE (United Nations Economic Commission for Europe), 2000b: Meeting of the Parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes. The Hague, the Netherlands, 23-25 March 2000.

UNECE (United Nations Economic Commission for Europe), 2001: Assessment of Progress in Sustainable Development since Rio 1992 for Member States of the United Nations Economic Commission for Europe. CEP/AC.12/3. UNECE, Geneva.

UNEP, 2000: Guidelines for erosion and desertification control management. United Nations Environment Programme.

United Nations 2000: Integrated Environmental and Economic Accounting. An Operational Manual. No. ST/ESA/STAT/SER.F/78. New York: United Nations.

United States Department of Agriculture (USDA), 2001: Guidelines for Soil Quality Assessment in Conservation Planning. United States Department of Agriculture. Natural Resources Conservation Service, Soil Quality Institute.

van den Bergh, J. C. J. M. (1999). Handbook of Environmental & Resource Economics Cheltenham: Edward Elgar.

van den Bergh, Jeroen C.J.M., and Kenneth J. Button 1999: "Meta-analysis, economic valuation and environmental economics," in: Jeroen C.J.M. van den Bergh (ed.): Handbook of Environmental and Resource Economics, 796-808. Cheltenham: Edward Elgar.

van den Born, G.J., B.J. de Haan, D.W. Pearce and A. Howarth 2000: Technical Report on Soil Degradation. RIVM report 481505018. Bilthoven: Rijksinstituut voor Volksgezondheit en Milieu (RIVM).

Van Lynden, G.W.J. 1994: The European soil resource: Current status of soil degradation in Europe: causes, impacts and need for action. ISRIC, Wageningen. Council of Europe, Strasbourg.

Van Lynden, G.W.J. 1995: European Soil Resources: Current status of soil degradation, causes, impacts and need for action. Nature and Environment, No. 71. Council of Europe Press. ISRIC, Wageningen. Council of Europe, Strasbourg.

Van Lynden, G.W.J. 2000: Guidelines for the Assessment of Soil Degradation in Central and Eastern Europe. Report 97/08b (Revised edition). Food and Agriculture Organisation of the United Nations and International Soil Reference and Information Centre.

Walpole, S.C. 1994: “Estimation of Regional, Local and Site-specific Profitability of Soil Conservation for the Wheat-Sheep Zone of NSW, Australia.” Journal of Environmental Management, Vol. 41, 349-364.

Walpole, S.; J. Sinden and T. Yapp 1996: "Land Quality as an Input to Production: The Case of Land Degradation and Agricultural Output." Economic Analysis and Policy, Vol. 26, No. 2, 207, 185.

WG on Erosion (Working Group on Erosion), 2003: European Commission Soil Thematic Strategy: Working Group on Erosion, Interim Report, Executive Summary. (Vandekerckhove, L., V. C. Sanches, et al.). October 2003. European Commission.

WG on Contamination (Working Group on Contamination), 2003: European Commission Soil Thematic Strategy: Working Group on Contamination, Task Group on Contaminated Land Management, Interim Report. (Dries, V.). October 2003. European Commission.

WG on Organic Matter (Working Group on Organic Matter), 2003: European Commission Soil Thematic Strategy: Working Group on Organic Matter, Interim Report, Executive Summary. (Robert, M., S. Nortcliff, et al.). October 2003. European Commission.

WG on Research TG 1 (Working Group on Research, Task Group 1), 2003: European Commission Soil Thematic Strategy: Working Group on Research, Task Group 1 on erosion, compaction, floods and landslides, Interim Report. (Imeson, A. and C. Ritsema). October 2003. European Commission.

WG on Research TG 3 (Working Group on Research, Task Group 3), 2003: European Commission Soil Thematic Strategy: Working Group on Research, Task Group 3 on organic matter, biodiversity, Interim Report. (Kottwitz-Erdödy, A., A. Benedetti, et al.). October 2003. European Commission.

WG on Research TG 5 (Working Group on Research, Task Group 5), 2003: European Commission Soil Thematic Strategy: Working Group on Research, Task Group 5 on sealing, urban soils, land use, land use planning, 2nd Interim Report. (Nerger, M., W. Burghardt, et al.). December 15, 2003. European Commission.

WG on Research TG 9 (Working Group on Research, Task Group 9), 2003: European Commission Soil Thematic Strategy: Working Group on Research, Task Group 9 on good status, soil/water system, soil quality/soil health, Interim Report. (Diels, L., I. Schoeters, et al.). October 2003. European Commission.

Williams, Jeffrey R., and Donald L. Tanaka 1996: "Economic evaluation of topsoil oss in spring wheat reduction in the northern Great Plains, USA." Soil & Tillage Research, Vol. 37, 95 - 112.

Xu, Feng, and Tony Prato 1995: "Onsite erosion damages in Missouri corn production." Journal of Soil and Water Conservation, Vol. 50, No. 3, 312-316.

Yapp, T. 1989: "The Costs of Degradation to the Community: Issues and Estimates." Australian Journal of Soil and Water Conservation, Vol. 2, No. 3, 32-36.

Yapp, T.P., Young, L.J. & Sinden, J.A. 1991: Trends in Community Support for Soil Conservation. 35th Annual Conference of the Australian Agricultural Economics Society. Armidale: University of New England.

Yassoglou, N.J. 1987: The production potential of soils – Part II: Sensitivity of the soil systems in Southern Europe to degrading influxes. In: H. Barth and D.L.'Hermite (eds.): Scientific basis for Soil protection in the European Community, p. 87-122 – Elsevier Applied Science, London, N.Y.

Young, Anthony 1998: Land Resources: now and for the future. Cambridge: Cambridge University Press.

Zvirbulis, E., Public Works Department, personal communication, 1993: (cited from ENVALUE database, http://www.epa.nsw.gov.au/envalue/.

# 7 Annex

### Table 15: Soils of Europe, adapted from EEA 1995[24] (FAO 1981;[25] Fraters 1994[26])

| Soil classes | Soil category | FAO classification | % of European land area | Part of the Europe | Countries covered | Land use type | Use characteristics | Limitations | Sensitive to a specific degradation |
|---|---|---|---|---|---|---|---|---|---|
| Well drained soils | Black earths | *chernozems* | 9 | Continental climate zone of the Central European plain, the steppe, in a belt extending from Poland to Urals |  | Agriculture, arable farming; (in Russian Federation and Ukraine, black earth are notable for extensive cereal production) | Thick humus-rich topsoil, suitable for arable farming | Erratic rainfall often limits yields |  |
|  | Sandy soils | *podzols* | 9 | Northern Europe (under forest), Western Europe |  | Forest, intensive agriculture with the application of fertilisers to overcome |  |  |  |

---

[24] European Environment Agency 1995: Europe's Environment - The Dobris Assessment - Chapter 7. EEA, Copenhagen.

[25] FAO (1981) Europe, FAO/Unesco soil map of the world, scale 1:5 000 000. Volume V, UNESCO, Paris.

[26] Fraters, D (1994) Generalized soil map of Europe: Aggregation of the FAO-Unesco soil units based on the characteristics determining the vulnerability to soil degradation processes. Report 71240300, RIVM, Bilthoven, The Netherlands.

| Soil classes | Soil category | FAO classification | % of European land area | Part of the Europe | Countries covered | Land use type | Use characteristics | Limitations | Sensitive to a specific degradation |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | the inherent low fertility | | | |
| | | *arenosols* | | | Areas in Poland, Spain, UK | | | | |
| | Acid loamy soils | *podzoluvisols* | 14 | Cold continental conditions of the central taiga of the north and the centre of the Russian Federation | | Forestry in the northern latitudes, grassland and crops in the more central area | | Low fertility and a short growing season are limitations to production | |
| | Non-acid loamy soils | *orthic luvisols* | 8 | Widespread in Western and Central Europe | | | Most productive agricultural areas | | |
| | | *cambisols* | | In more northern latitudes of Western and Central Europe | Ireland, Sweden | Livestock production | | | |
| | | *haplic* and *luvic phaeozems* | | In more northern latitudes of Western and Central Europe | Ireland, Sweden | | | | |

| **Soil classes** | **Soil category** | **FAO classification** | **% of European land area** | **Part of the Europe** | **Countries covered** | **Land use type** | **Use characteristics** | **Limitations** | **Sensitive to a specific degradation** |
|---|---|---|---|---|---|---|---|---|---|
| | Clayey soils (red and reddish-brown soils) | *chromic cambisols*<br>*chromic luvisols* | 4 | In the Mediterranean countries | | *luvisols* are used for vineyards, olives and citrus | Fertile | Fertile, but present management problems because of their unfavourable physical properties | *luvisols* are sensitive to erosion |
| | Heavy dark clay soils | *Vertisols* are associated with the *cambisols* and *luvisols* | | | | Production of cereals | | | |
| Shallow and stony soils | | *lithosols, cambisols* and *rendzinas* | 30 | Predominant in the major mountain and hill ranges of Europe, such as the Pyrenees, the French Massif Central, the Alps, the Apennines, the Carpathians, the Scandinavian | | Used mainly for non-intensive grazing and wood production | | Occur on steep slopes;<br>These soils are not suitable for intensive arable farming and use of | The acid shallow and stony soils (occur in Scandinavia and Germany) are more vulnerable to acidification |

| **Soil classes** | **Soil category** | **FAO classification** | **% of European land area** | **Part of the Europe** | **Countries covered** | **Land use type** | **Use characteristics** | **Limitations** | **Sensitive to a specific degradation** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | mountain ranges and the Caucasus | | | | heavy machinery | than the non-acid shallow and stony soils (for example in France, Greece, Italy and Spain) |
| Semi-arid and salt-affected soils | | *solonchaks* with excess of salts, or<br>*solonetz* with excess of sodium | 9 | The eastern part of Southern Europe, mostly in the southern part of the Russian Federation, Ukraine and Romania | | | | The lack of rainfall combined with the excess of salt or sodium permits only non-intensive agriculture | |
| | | *xerosols* and *kastanozems* (semi-arid soils) | | | | | | Have potential for more intensive agriculture, with irrigation | |

| **Soil classes** | **Soil category** | **FAO classification** | **% of European land area** | **Part of the Europe** | **Countries covered** | **Land use type** | **Use characteristics** | **Limitations** | **Sensitive to a specific degradation** |
|---|---|---|---|---|---|---|---|---|---|
| Imperfectly drained soils | | *gleyic luvisols* and *planosols* due to surface water stagnation or *gleysols* and *fluvisols* (due to fluctuating groundwater) | 17 | Very widespread in the northern part of Europe (the Russian Federation, Scotland and Ireland) – with high groundwater tables;<br>widespread in England and Germany – due to surface waterlogging | | The dominant feature of these soils is their prolonged waterlogging, which strongly influences their use and management. Depending on the climate under which they occur, they are used either for extensive wood production and/or grazing (such as in the boreal parts of the Russian Federation and Finland), or, after reclamation (drainage), for arable cropping, dairy farming or horticulture (in Western Europe). | | | |