EUROPEAN COMMISSION
DIRECTORATE-GENERAL ENVIRONMENT

Multi-stakeholder Working Group Reports
Soil Thematic Strategy

Working Group on Soil Erosion

Task Group III on Impacts of soil erosion

Final Report
May 2004

By

Luuk Dorren

Paolo Bazzoffi

Juan Sánchez Díaz

Arnold Arnoldussen, Renzo Barberis, Judit Berényi Üveges, Holger Böken

Victor Castillo, Olaf Düwel, Anton Imeson, Konrad Mollenhauer, Diego de la Rosa

Volker Prasuhn, Sid Theocharopoulos

Publisher: Commission européenne, BU9 3/173, B-1049 Bruxelles / Europese Commissie, BU9 3/173, B-1049 Brussel - Belgium. Telephone: (32-2) 29.91111, (32-2)29.69105. Fax: (32-2)29.68825.
Electronic address: env-soil@cec.eu.int
Internet: DG ENV Web: http://europa.eu.int/comm/environment/soil/index.htm
Internet: Soil CIRCA e-library: http://forum.europa.eu.int/Public/irc/env/Home/main

Soil Thematic Strategy: TWG Soil Erosion Task Group 3 - Impacts of soil erosion

Objectives

3.1 Definition of soil functions, soil quality and quality targets

The identification of soil functions, properties and processes which are affected by soil erosion is needed to evaluate the impacts of erosion on the soil system. Definition of soil loss tolerance according to soil types and environmental characteristics.

3.2 Development of criteria and indicators to assess soil sustainable use and soil protection measures

What are the impacts of soil erosion on soil functioning and soil quality? How does soil erosion affect environment health and security? The efficiency of soil protection and conservation measures must be evaluated by measuring the reduction of the soil erosion impacts.

3.3 Development of criteria and indicators to assess off-site impacts

What are the impacts of soil erosion in down slope or downstream areas, i.e. the off-site effects?

3.4 Development of studies of the economic impact of soil erosion.

Review and extract conclusion of existing studies. Development of specific studies on the social, health and economic impact of erosion.

Executive Summary

The concept of soil functions provide a sound basis for assessing soil resources.

The main soil functions can be classified into the following groups:

- *Food and other biomass production*
- *Storing, filtering and transformation*
- *Habitat and gene pool*
- *Physical and cultural environment for mankind*
- *Source of raw materials*

In addition, the soil has a communication function and it has an aesthetic, scientific and carrier function.

The fact that a soil can perform these functions means that the soil enables ecosystems to be resilient, to help for example forests to recover from fire and agricultural land from over-exploitation.

Soil quality is an intuitive concept that in simple terms could be explained as: "how well a soil does what we want it to do".

Soil quality cannot be measured directly, so we evaluate indicators. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. Indicators can be physical, chemical, and biological characteristics.

Soil erosion has also an impact on the soil itself. Examples of such impacts are loss of rooting depth for crops and reduced water holding capacity. Depletion of the soil's filter and buffer capacity and potential accumulation of pollutants by elevated concentrations of fertilizers and pesticides in local deposition areas. The severity of these impacts is indicative for the level of sustainable use of soil resources and for the efficacy of soil protection measures as well.

Soil quality indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions. With such indicators the impact of soil erosion on the soil itself could be estimated. The rate of erosion, which is dependent on many things and is variable in space and dynamic in time, is not a good indicator for this purpose.

A soil loss tolerance for specific sites could be useful. It should take into account the functions of the soil, soil properties, position of the site in the surrounding landscape, and potential off-site impacts. The points mentioned are to be investigated by an expert and individually for each specific site. Regional or nation-wide assessments would be inappropriate or misleading.

The concept of leptosolitation might be used as a general erosion impact indicator for a major group of soils. Leptolisation refers to soils that had a larger depth than currently is the case. This can only be assessed by a good soil resource inventory, whereby models can act as a supplementary source of information. However, the leptolisation concept needs to tested.

A distinct example of an offsite impact of erosion is sedimentation in neighbouring biotopes, discharge systems or other systems such as water reservoirs, which could lead to pollution, eutrophication, siltation and disruption of functions and hence significant damage to the environment.

Off-site damages relating to soil erosion by water can be, given the short-term economic consequences, far more important than the on-site damages. The off-site impacts of soil erosion are closely related to the processes of transport and sedimentation of soil particles by water and wind. One of the main impacts, which directly affects human health, is the pollution of drinking water sources.

Eutrophication, which is due to an increase in the rate of supply of organic matter to an ecosystem can be a result of soil erosion. Floods are also among the most important off-site impacts of soil erosion, which causes serious damage to public infrastructure and private property, as well as increased psychological stress for the affected population.

Two off-site impacts of erosion which have not been studied in detail refer to the changes in air quality due to the transport of particulate matter in air (e.g., by wind erosion) and the emission of green house gases into the atmosphere.

The off-site impacts of soil erosion could be assessed by the eutrophication of water bodies and by analysing the expenditures for removals of sediment deposits in built up areas (traffic routes, houses). These indicators are quite easy to measure.

The problem with many existing and often mentioned criteria and indicators is that they cannot be monitored intensively for larger areas or regions. Model based calculations of sedimentation from arable land, are not yet sufficiently advanced to permit their use as impact indicators.

There are no comprehensive, Europe-wide studies of the economic impact of erosion and available data suggest this is a major challenge. A detailed study of the economic impact of erosion at a European scale can probably only be done by collecting data obtained by local or regional studies, that are carried out by regional or provincial authorities, sometimes even at local community level.

About 17 % of the total land area in Europe is affected to some degree (source: EEA; average to be considered very carefully due to spatial variability). Yearly economic losses in affected agricultural areas in Europe are estimated at around 53 EUR per ha, while the costs of off-site effects on the surrounding civil public infrastructures, such as destruction of roads and siltation of dams, are estimated to cost 32 EUR per ha.

3.1 Definition of soil functions, soil quality and quality targets

Soil functions

The concept of soil functions provides a sound basis for assessing soil resources (García Álvarez et al., 2003). The soil performs all kinds of functions and many of these relate to the regulation of key processes that affect the storage and cycling of water and nutrients. When these functions are damaged, because the soil is eroded or degraded, the impacts are flooding, increased sedimentation in settlements, pollution and dissemination of polluted material. Similarly, the soil is the place where plants and crops or grown so that if the "production function" is damaged or lost through erosion then this leads to serious loss of productivity, production and income. Such losses are in practical terms often irreversible. Soils take thousands of years to evolve and in doing so they become complex acquiring additional or emergent qualities that enable them to support an enormous diversity of life. Nearly all organisms are dependent on soil at some moment or time so the soil is a prerequisite for protecting biodiversity. It provides a biological habitat and a genetic reserve for plants, animals and organisms. In addition the soil supports the buildings and at a larger scale, the soil functions as a resource that supports the needs of industry and people (raw materials, water, energy, recreation, food). In summary, the main soil functions can be classified into the following groups:

- *Food and other biomass production*
  Food and other agriculture production, essential for human survival, and 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 for drinking water, and releases CO_2, methane and other gases in the atmosphere.
- *Habitat and gene pool*
  Soil is the habitat for a huge amount and variety 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, sands, minerals and peat.

Furthermore, the soil has a communication function and it has an aesthetic, scientific and carrier function (e.g. it is an element of our cultural heritage).. It contains paleonthological and archaeological treasures that are important in order to understand the history of the earth and of mankind.

All these qualities mean that the soil enables ecosystems to be resilient. Whether erosion actually occurs depends on the resilience of the ecosystem, which is determined by ecosystem processes at different spatial and temporal scales. Resilience has two meanings in the ecological literature, both related to system state and disturbance. Engineering resilience is the time of return to a global equilibrium following a disturbance. Ecological resilience is the amount of disturbance that a system can absorb before it changes to an alternative stable state. A resilient ecosystem can withstand shocks and rebuild itself when necessary, to help for example forests to recover from fire and agricultural land from over-exploitation. (Dorren and Imeson, 2003). The alternative meanings of resilience have significant implications for application of the concept to understanding and managing complex systems (Gunderson and Holling, 2002). The challenge of sustainable land use is to make sure that all of the legitimate claims on the soil are equitably met. How does soil erosion affect the capacity of the soil to provide all of the functions upon which the different end-users depend?

Soil quality

Soil quality is an intuitive concept that, under different names, has been used for a long time to refer to the perception of how well a soil performs its production function. This was mainly interpreted in terms of agricultural and forest production capacity. More recent definitions of soil quality are closely linked to other soil functions as well. Among the most quoted definitions found in the literature, Doran's (2002) definition of soil quality is worth mentioning as "the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health". In simple terms could be stated that soil quality is how well a soil does what we want it to do.

In a report on environmental indicators for agriculture made by the OECD (2001), the concept of soil quality is considered from two points of view. Firstly, the inherent quality that results from the innate properties of soils, as determined by the factors that lead to soil formation. Secondly, the dynamic quality which results from the changing health or condition of soil properties influenced by agricultural use, forestry and other land management practices.

Strictly linked to the definition of soil quality is the need to evaluate it in a quantitative way. Soil quality cannot be measured directly, so we evaluate indicators. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. An indicator should be: easy to measure; able to measure changes in soil functions; encompass chemical, biological, and physical properties; accessible to many users and applicable to field conditions; sensitive to variations in climate and management.

It is widely accepted by the majority that the measure of soil quality can be established with adequate indicators, which would be surrogates of essential processes (physical, chemical and biological ones) that take place in soil. These indicators should be sensitive to the detection of space and time differences, establishing thus a clear cause-effect relation (Smyth and Dumansky, 1995; as cited by García Álvarez et al., 2003). A soil quality index (SQI) could then be obtained which would reflect the state of the soil.

The evaluation of soil quality has been the object of different proposals, which include different methodologies, indices and pedological parameters. Nevertheless, it seems that there is a consensus on the need to collect a minimum data set (MDS) that allows quantify soil quality. Table 1 collects the most used data and the relation that exists between the analysed variables and the soil functions they are associated with as indicators.

Table 1. Minimum data set (MDS) of physical, chemical and biological variables for soil quality determination (García Álvarez et al. 2003; modified from Doran and Parkin, 1994;

Larson and Pierce, 1994)

Soil quality indicators	Related soil functions and soil reactions
Physical properties	
Texture	Water/nutrient retention
Soil and rooting depth	Potential estimated production
Infiltration, porosity and bulk density	Potential leaching, erodibility
Field capacity and water retention	Transmission and erodibility
Chemical and physico-chemical properties	
Organic matter (total organic C and N)	Soil fertility and stability
Soil pH & electrical conductivity	Chemical and biological activity thresholds
Extractable N, P and K	Microbial and vegetation activity thresholds
Sodium content	Available nutrients for plants
Exchangeable cations, particularly Na, K, Ca, Mg	Assess the risk of dispersion and crusting
Biological properties	
Microbial biomass (C and N)	Potential microbial catalyst
Potential mineralisable N (anaerobic incubation)	Soil productivity
Soil respiration, water content and temperature	Microbial activity measure

The report by the OECD (2001) highlights the importance of using soil biodiversity indicators for assessing soil quality, as they can reflect the combined effects of many factors that would otherwise be too difficult, costly or time consuming to measure. According to the report, until recently, there have been few attempts to use soil biodiversity indicators to evaluate soil quality and a clear relationship between spoil organisms and soil quality has not yet been established. Many biological properties of soil are sensitive to changes in environmental conditions (e.g. temperature, moisture, organic mater inputs) that occur on relatively short time scales (days to months). The widespread use of soil biodiversity indicators for assessing soil quality will depend upon establishing justifiable optimum values, setting criteria for when and under what conditions the indicators should be measured and defining their confidence limits (Cameron et al., 1998; as cited by OECD, 2001).

The use of soil quality indicators would be very useful for researchers and policy makers for different purposes: e.g. setting research priorities, to document changes in the soil resource base, to monitor the implementation of policies, to predict how changes in soil quality affect water and air quality, as well as food safety, etc.

3.2 Development of criteria and indicators to assess soil sustainable use and soil protection measures

Apart from the impact of erosion and the caused damage off-site, for example sedimentation in streets, path ways, ditches and other infrastructure, which are quite well-known, erosion has also an impact on the soil itself. Examples of such impacts are: loss of rooting depth for crops and reduced water holding capacity, depletion of the soil's filter and buffer capacity, and potential accumulation of pollutants by elevated concentrations of fertilizers and pesticides in local deposition areas. The severity of these impacts is indicative for the level of sustainable use of soil resources and for the efficacy of soil protection measures as well. Especially, the second half of the twentieth century has seen increasing concern over the impacts of modern arable farming on agricultural ecosystems, and on the sustainability of arable systems themselves (Stoate et al., 2001). Inappropriate agricultural practices affect soil health and soil functions, in the way of altering the soil’s physical, chemical and biological properties and its related functions. Especially income support systems and subsidies within the European Union encouraged the simplification of cropping systems and an increase in effective slope length (field size). The aggravation of soil structure through soil compaction and declining values of soil organic matter have also contributed to higher levels of soil erosion (Evans, 1996; as cited by Stoate et al., 2001). In addition, overgrazing and the intensification of arable land-use of marginal land, some of which is linked in the European Union (EU) to the implementation of the common agricultural policy, has also accelerated the loss of soil through erosion (EEA, 2003).

The loss of fertile topsoil by the erosion process has serious effects on crop yields and the disruption of soil functions, as it reduces the plant rooting depth, removes nutrients and organic matter, reduces the infiltration rates and plant available water capacity, and, following extreme rainfall events, uproots plants and trees and originates rills and gullies that difficult access to the fields. Even more, the decrease in soil fertility and available water induces an increase of applied fertilisers, pesticides and irrigation water, which has serious consequences in downstream areas in terms of aquifer pollution and depletion, eutrophication, etc. Arable fields may also be damaged by erosion upstream through deposition of excessive stream sediment loads originating in eroding areas (EEA, 1995).

Decrease in soil biodiversity is another and very important on-site impact of soil erosion, as a report by the OECD on soil erosion and soil biodiversity highlights (OECD, 2003). Soil biota plays an important role in the formation and stabilisation of organo-mineral complexes. Decline in soil biodiversity affects soil turnover, decreases aggregation, increases crusting, reduces infiltration rates and exacerbates soil erosion. Thus, both processes have interactive effects on crop yield, as the impacts of soil erosion are accentuated by the reduction in soil biodiversity.

There are numerous reports regarding the on-site effects of erosion on productivity. On-site effects of erosion on agronomic productivity are assessed with a wide range of methods. Lal (1998) broadly groups them into three categories: economic assessment, agronomic/soil quality evaluation and knowledge surveys (when quantitative data is not available). The author also highlights the need to assess on-site impact of erosion in relation to soil loss tolerance, soil life, soil resilience or ease of restoration, and soil management options for sustainable use of soil and water resources.

The on-site impacts of soil erosion are usually assessed from an economic point of view, in terms of economic losses derived from decline in crop yield and changes in the overall input use efficiency. Decreases in crop yields due to erosion are not always clearly visible, but the costs of amelioration required to maintain yield levels could give a good indication of the damage done (Morgan, 1980; as cited by EEA, 1995). However, these costs (in terms of the quantity of fertilisers and manure required to replace the nutrients and organic matter lost with the removed topsoil) are difficult to assess and deserve more attention (EEA, 1995). Pimentel at al. (1995) also take into account the high energy costs derived from the use of fossil-based fertilisers and the pumping of ground water for irrigation to mask the damage of soil erosion.

Lately, with the introduction of the concept of soil quality, more attention is being paid to the assessment of the impacts of soil erosion on the ability of the soil to perform its ecological and human-related functions. The soil quality evaluation framework, identifying key soil quality attributes or indicators among the nearly infinite list of soil properties, and developing methods for evaluating and monitoring it with respect to the numerous soil functions is an evolving process (De la Rosa et al., 2003). Soil quality indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions.

Soil loss tolerance

Erosion is a natural process and if it is below a certain threshold value, it need not be of concern. But as we use the land rather intensively in Europe, soil erosion risk assessment is essential for sustainable land use. However, it is not scientifically shown where it would be appropriate to set values of different erosion categories (e.g. low risk, medium risk, high risk or very severe, severe, medium, low, and no erosion). It seems appropriate to use the term and limits of tolerable soil loss to define erosion risk categories and values for the results of conservation measures. In the USA early soil scientists compared rates of soil loss measured on agricultural fields with the depth of soil and calculated how many years this loss could be sustained. They made allowance for the addition of new soil material to the soil that resulted from weathering. They considered a tolerable rate of erosion, one that allowed this type of agriculture to persist for 50 to 100 years (2 to 5 tons per hectare). This approach is not useful because it makes no allowance for any process or causal factors that render this approach meaningless. In other words, what is tolerable has to be linked to all relevant functions. Thus, the rate of erosion, which is dependent on so many things and is variable in space and dynamic in time, is not a good indicator for this purpose. Management practices should minimize the risk of soil loss. Any unusually high rate of erosion might be a symptom that something is happening to the soil and water regulating function of the soil, but whether it is acceptable depends on other things.

A report on environmental indicators for agriculture by the OECD (2001) highlights the need to clearly establishing a definition of tolerable soil loss through soil erosion, in order to clarify the meaning of what is a “sustainable” use of soil resources by agriculture. However, accepting soil loss is not consistent with our long-term objective of sustainable land-use. Stating that 'tolerable soil loss' depends on soil depth, soil type, and agro-climatic zones (OECD, 2001) implies that the most fertile (deep) soils are accepted to be exposed at the highest soil loss rates! Soils in Europe should provide their services and functions for many generations to come. The consequence often asked for would be that the maximal soil loss tolerance should be similar to the level of natural soil formation, which – in central Europe – is lower than 1 t/ha yearly (= lower than 0.07 mm soil depth per year). Besides that, various other tolerance values are being discussed or already being used. But their suitability is questionable. We know that agricultural land-use inevitably means soil loss and that the losses vary from site to site and from situation to situation. The only possible thing to do is to minimise soil loss as far as possible. For instance, soil losses occurring under conservation tillage are often extremely lower than tolerance values usually given in different papers.

Instead of an implementation of general or regional tolerance values site specific assessments should be carried out. When assessing a site, the following questions are of interest:

- Does soil erosion take place?

- Is a reduction of soil erosion possible and using which measures?
- Does, in case of the desired land-use, an inevitable amount of soil loss remain and can it be accepted (both on-site and off-site)?

The last question leads to an individual tolerance of the particular site/soil and its use. To assess this kind of tolerance the following aspects are to be taken into account, e. g.:

- functions of the soil in its natural environment,
- functions of the soil with respect to its use,
- important site and soil properties (texture, depth, organic matter content, soil hydrology etc.) and those which lead to sheet, rill or gully erosion,
- rarity of the particular soil, natural monument, cultural or archaeological monument,
- position of the site in the surrounding landscape,
- sensitive neighbouring sites, especially surface waters, natural protection sites, or settlements and civil infrastructure, in relation to potential off-site impacts.

In any case, the long term sustainability with respect to the soil's functions should not be endangered. Furthermore, these questions may reveal that soil losses, which still might be acceptable for a given arable land-use, can be a disaster for an off-site-object like a surface water. The points mentioned are to be investigated by a soil expert and individually for the specific site/soil. Regional or nation-wide assessments would be inappropriate or misleading. However, there are some external effects which influence the type of land-use and the possibilities to introduce soil protection measures as provided in section 4.1.

Leptosolitation

The concept of leptosolitation can be used as a general erosion impact indicator for a major group of soils described by FAO Soil Keys. Leptolisation refers to soils that had a larger depth than currently is the case. Therefore, it does not address intermediate situations (e.g. soil truncation, loss of thickness of surface horizons, etc.), where the thickness of the combined organic and transformed horizons (A + B) is usually still sufficient for agricultural use. In general, where leptolisation takes place the soil might suffer of might have suffered soil loss. This can only be assessed by a good soil resource inventory, whereby models can act as a supplementary source of information. More information on the concept of Leptolisation is given by Ibáñez and Sánchez (1999).

3.3 Development of criteria and indicators to assess off-site impacts

Erosion by its nature implies the removal of soil material from where it is formed, or deposited in the past. Water erosion is always related to downslope deposition while wind erosion could transport soil particles to many different places. This paragraph presents the offsite effects of erosion both caused by water or wind erosion and their impacts on land, ground- and surface water, as well as the air. A distinct example of an offsite impact of erosion is sedimentation in neighbouring biotopes, discharge systems or other systems such as water reservoirs, which could lead to pollution, eutrophication, siltation and disruption of functions and hence significant damage to the environment.

Off-site damages relating to soil erosion by water can be, given the short-term economic consequences, far more important than the on-site damages (Verstraeten et al., 2003). Boardman et al. (2003) identify two aspects that complicate the issue: the difficulty in identifying the source of the sediment (and pollutants), and the fact that the impacts in downstream areas may take years before they manifest. For example, the impact on aquifers may be delayed for decades after application of fertilisers, due to the slow travel time through certain rocks (Foster, 2000; as cited by Boardman et al. 2003).

The off-site impacts of soil erosion are closely related to the processes of transport and sedimentation of soil particles by water and wind. One of the main impacts, which directly affects human health, is the pollution of drinking water sources. Nutrients (mainly in the form of nitrates and phosphates) and pesticides adhere to soil particles, which are detached by the erosive agents and transported from the fields into the water courses, causing pollution and eutrophication problems both in groundwater (aquifers) and surface water bodies (rivers, lakes and coastal areas). The report “Europe’s Environment: the Third Assessment” (EEA, 2003) recognises nitrate contamination as the most common problem identified from national reports regarding water resources, being agriculture the main source of nitrogen input to water bodies.

Ground and surface waters are also polluted through the downslope runoff water which carries apart from soil particles constituents either dissolved constituents like nitrates or in a colloidal state from soils upslope. Wind erosion is also contributing to the water pollution.

Eutrophication, which is due to an increase in the rate of supply of organic matter to an ecosystem can be a result of soil erosion. This is most commonly related to nutrient enrichment enhancing the primary production in the system (Nixon, 1995; as cited by EEA, 2003b). Eutrophication affects water supply (algae can block filters, stimulate bacterial growth, and give drinking water an unpleasant taste), irrigation, fisheries, navigation, water sports and angling (Mason, 1996; EA, 1998a; Withers & Jarvis, 1998; as cited by Boardman et al., 2003). Reservoirs may be affected by algal blooms and costly treatment costs are associated. A report on eutrophication of coastal areas carried out by the European Environment Agency (EEA, 2003b) identifies run-off from agricultural fields as the main source of nitrogen and phosphorous brought to the sea by rivers. The Agency reports that excessive growth of plankton algae increases the amount of organic matter settling to the bottom. Also harmful algal blooms may cause discoloration of the water, foam formation, oxygen depletion, death of benthic fauna and wild or caged fish, or shellfish poisoning of humans. Increased growth and dominance of fast growing filamentous macro-algae in shallow sheltered areas is yet another effect of nutrient overload which will change the coastal ecosystem, increase the risk of local oxygen depletion and reduce biodiversity and nurseries for fish.

Floods are also among the most important off-site impacts of soil erosion, which causes serious damage to public infrastructure and private property, as well as increased psychological stress for the affected population. Drainage ditches and sewage systems are often unable to cope with the increased run-off generated in upstream areas affected by soil erosion, which may lead to flooding of lowlands and populated areas. If there is pronounced soil erosion in the drainage basin, these floods can take the form of 'muddy floods', covering the streets and even floors inside houses with a blanket of mud (Verstraeten & Poesen, 1999). These events have very high associated costs, not only in the cleaning up and restoration works, but also in the prevention measures that governments may carry out. Verstraeten and Poesen (1999) classify these costs into direct and indirect costs. Direct costs include costs such as the cleaning up of road infrastructures, the repairing of damaged sewage pipes or the damages to private properties. Indirect costs include the construction and maintenance of retention ponds. Also the costs of government programmes for the rehabilitation of the upper parts of the catchment should be included (such as reforestation of burned areas, measures to control soil erosion in agricultural fields, etc.).

Siltation of reservoirs is another important impact originated by the sedimentation of the soil particles transported by water. It has important economic effects on the functioning of the reservoirs, as it reduces their water storage capacity, reducing their lifetime and increasing the maintenance costs, and undermines their ability to generate electrical power. Sediment deposition may also affect rivers and harbours, increasing the risk of flooding and affecting navigation. Siltation can also lead to the loss ecologically valued habitats, such as wetlands and riparian habitats.

Two off-site impacts of erosion which have not been studied in detail refer to the changes in air quality due to the transport of particulate matter in air (e.g., by wind erosion) and the emission of green house gases into the atmosphere. The emission of green house gases may be exacerbated by change in soil biodiversity, especially the process of methanogenesis and denitrification (OECD, 2003), by adding uncontrolled eroded material downslope.

Aerial deposition of particles causes contamination/degradation since through wind erosion it is possible to have pesticide, heavy metal and organic toxic constituents to other sites due to the movements of fine particles through air and affecting air soil, and water quality.

The amount of material which is eroded from an agricultural field is normally, or very often, not identical to the amount reaching a off-site object due to infiltration of overland flow and sedimentation. However, there are remarkable differences in sedimentation and continuing transport between different components of eroded material. Some are deposited very rapidly, while other particles with the same size are still transported.

An off-site object can not only be damaged by sediments, nutrients or pollutants, but also by gully formation, piping (gully formation underground). Therefore, a certain amount of eroded material, which cannot be considered as an important loss for an arable field during one event, can nevertheless have a substantial impact on an off-site object. As a result, a big difference could exist between the requirements to protect the soil on arable field and the requirement to protect a particular object.

Criteria and indicators for offsite impacts of soil erosion

Many criteria and indicators are known to assess the off site effects of rain and wind soil erosion. These criteria could be based on the induced changes, while the indicators should be generally accepted throughout Europe and should be easily to determine using a standardized methodology. The off-site impacts in Germany are mainly assessed by the eutrophication of water bodies. Between 1993 and 1997 1.8 to 2.8 of the diffuse nitrogen input into the Danube, Rhine and Elbe result from soil erosion. The fraction of the diffuse phosphorous loads by soil erosion is estimated to 40.3 % for the Danube, 21.5 % for the Rhine and 25 % for the river Elbe (UBA-Texte 75/99). Another criteria is the amount of deposited sediment after soil erosion events, which could be estimated by analysing the expenditures for removals of sediment deposits in built up areas (traffic routes, houses). These indicators are quite easy to measure. The problem with many existing and often mentioned criteria and indicators is that they cannot be monitored intensively for larger areas or regions. Offsite impacts from soil erosion through water is still hard to describe with appropriate methods. Methodical approaches for measuring sediment loads in rivers and streams do exist, but monitoring results are not really suitable as impact indicators for soil erosion, because the monitored sediment provides no indication of its agricultural origin or the size of the catchment area. Besides soil erosion in the agriculturally used part of the drainage basin, sources of sediment in surface waters may also include river bed erosion, bank erosion, and a removal of soil material from the flood plain due to flooding. Hence, it is difficult to link sediment loads of rivers to actual soil erosion on agricultural fields in the drainage basin. Model based calculations of sedimentation from arable land, are not yet sufficiently advanced to permit their use as impact indicators

3.4 Development of studies of the economic impact of soil erosion

In the soil communication (CEC, 2002) the CEC already indicates that there are no comprehensive studies of the economic impact of erosion and that available data suggest this is a major challenge. Accelerated soil erosion adversely affects agronomic productivity on-site and environmental quality off-site. The economical consequences of both on- and off farm consequences are often complex and little accurate and comprehensive data are available. Crosson (1997) estimated for the USA the annual on- farm costs, in terms of losses of net farm income, roughly at $100 million per year (about $0,60 per ha). Other studies came up with both higher and lower numbers (Crosson, 2003). The differences are caused by different approaches. In Europe the loss of income should be comparable with that in the USA or even less (Boardman 1998, Crosson 2003). Robinson (1999) states that erosion hazard in Britain is one of the factors influencing land- use decision-making but it is of minor influence compared to market prices and EU policy. However relatively small soil losses over a long period can lead to larger damage, especially when thresholds are passed. Even with relative small soil losses the soil loss can exceed the natural soil renewal and we may speak about a non- sustainable situation. (don't agree with this)

Robinson (1999) states that the low priority for soil erosion measures accorded the erosion hazard appears the result from its lack of short term economic consequence for the farmer. The chance of severe erosion affecting any individual farm is low, and the direct costs of land restoration and reduced yields are relatively small. In the case of (more) extreme circumstances and land- abandonment the economical losses are much larger and should be translated in the costs necessary to repair the damage and to restore the soil quality. More research is needed to find out the on- farm costs of erosion, both at national and European level. It is important that a farmer gains knowledge about the own financial interest he has on the short and long term to reduce erosion.

The economical costs for off farm damage may be divided in the following posts:

- Damage on infrastructure (roads, rivers). Roads can be covered by sediment or rivers can be filled with sediment. Costs need to be made for cleaning and dredging.

- Damage to lakes needed for water- supply and electrical power. Lakes can be filled up and large costs need to be made for restoration or the lakes can even become useless.
- Damage to water quality so that damage is done to recreation and fishing grounds
- The eutrophication causes the development of populations of blue- algae poisoning biological life. Costs need to be made to monitor shells and muscles used for consumption.
- The eutrophication makes it impossible to use the water for producing drinking water or large costs have to be made to clean the water.

Clark et al. (1985) made a rough estimation of the total off- farm costs in USA and concluded that this was in the range between $3 billion and $13 billion per year with a best guess of $6 billion. Soil erosion and land degradation do have also impact on the local population. Farmers close down their farm if the surroundings are getting severely degraded and unemployment rates are increasing. Often many other driving forces are playing here at the same time, so it is difficult to estimate the social costs caused by erosion. Local people living under circumstances of severe land degradation are often fully aware of the process and are often getting depressed (Haaften and Van de Vijver, 1996a; Haaften and Van de Vijver, 1996b).

A study in Spain carried out in 1991 estimated the direct costs of impacts of erosion at ECU 280 m per year, including the loss of agricultural production, impairment of water reservoirs and damage due to flooding. In addition the cost of attempts to fight erosion and restore the soil were estimated at about ECU 3,000 m over a period of 15 to 20 years. Comparable studies at a European scale that analyse the cost and benefits of erosion do not exist. One of the reasons is that problems are encountered at assessing the extent of the European area that suffers from erosion. There are estimates of the amount of ha suffering from erosion based on non-standardized data and on predictive modelling. The output of this modelling is still highly uncertain for many cases (CEC, 2002).

A detailed study of the economic impact of erosion at a European scale can probably only be done by collecting data obtained by local or regional studies, that are carried out by regional or provincial authorities, sometimes even at local community level. Trimble and Crosson (2000) already mentioned that the problem of resource or environmental management can only be rationally addressed if its true space and time dimensions are known. In Europe, as in other parts of the world, the limitations of modelling are such that we are not perfectly able to know how much soil erosion is occurring. According to the EEA (2003), about 17 % of the total land area in Europe is affected to some degree. Soil erosion has a major economic impact. Yearly economic losses in affected agricultural areas in Europe are estimated at around 53 EUR per ha, while the costs of off-site effects on the surrounding civil public infrastructures, such as destruction of roads and siltation of dams, are estimated to cost 32 EUR. Even though a considerable amount of money has already been spent on contamination remediation activities, the share compared to the total estimated remediation costs is relatively low (up to 8 %).

Trimble and Crosson (2000) further stated that “average annual U.S. cropland soil erosion losses have been given from 2 billion to 6.8 billion tons. Increases in spending for soil conservation have been many billion dollars. It is remarkable that this discussion is based mostly on models and little physical, field-based evidence has been offered to verify the high estimates. The uncritical use of models is unacceptable as science and unacceptable as a basis for national policy. A comprehensive national system of monitoring soil erosion and consequent downstream sediment movement and/or blowing dust is critical. The costs would be significant; nevertheless, they would reflect efforts better focused on achieving better management of the country's land and water resources.” This accounts for the U.S., but the same applies for Europe if we aim to assess the costs of the impacts of erosion at a European scale. However, as mentioned before, the monitoring of soil erosion has to be carried out at a feasible scale, i.e. local to regional scale, based on standardised European monitoring guidelines. There are already some examples of good attempts to evaluate the economic impacts of soil erosion, e.g. the earlier mentioned study carried out in Spain. Another example is described by Pretty and al. (2000) who published an assessment of the total external costs of UK agriculture and they specified the costs of soil erosion as well. Although they acknowledge that soil erosion causes both on- and off-farm problems, they do not include internal costs, even though loss of soil fertility represents a loss of public good in the long-run. Examples of off-site costs that are taken into account are costs that arise when soil carried off farms, by water or wind, blocks ditches and roads, damages property, induces traffic accidents, increases the risk of floods, and pollutes water through sediments and associated nitrate, phosphate and pesticides. They cite Evans (1996), who used data from local authorities, and estimated that the national external costs to property and roads alone to be £13.77 m (£4 m for damage to roads and property; £0.1 m for traffic accidents; £1.19 m for footpath loss; £8.47 for channel degradation), but not counting water company costs or losses to fisheries.

After an extensive search for studies of social and economic impacts of soil erosion within the soil and environment science related journals no other studies were found that investigated the real costs due to the on- and offsite impacts of soil erosion. There are however many studies that describe the socio-economic impacts of soil erosion and that give some ideas for mitigating the effect of soil erosion via policies or socio-economic instruments. One example is the study of Ananda and Herath (2003) in which they reveal that negative impacts of technical change, inappropriate government policies and poor institutions are largely responsible for the continued soil erosion in developing countries. They also state that the potential for market-based approaches to mitigate the problem is also low due to the negative externalities involved. In Europe, problems to mitigate the effects of soil erosion exist as well, but they are different however. Problems encountered in Europe are described by Boardman et al. (2003). According to them agriculturally marginal areas are easy to deal with in terms of offering economic incentives for combating erosion. The real challenge is to reduce erosion on high value agricultural land. This is more difficult because farmers have little incentive to change land use or practices that are economical successful in the short-term economic evaluation. Socio-economic drivers may be used to discourage over-exploitation of soils in situations where alternative land uses are economically viable and socially desirable. In areas with high value crops on fertile soils there will be little incentive to conserve soils. In some areas, soils have become almost irrelevant to farming with wholesale remodelling of landscapes to create flat, soil-less terraces and climate and water provision are the only issues with regard to successful agricultural production (see Faulkner et al., 2003). The emphasis may then shift to costs of inputs (water, labour, fertilisers), and outputs (polluted water and soil). Here, policies which provide pressures for change can play an important role.

Riksen et al. (2003) studied the effect of 'Code of Good Farming Practice'. At present, they stated, there are no direct policy measures at a European level to control soil erosion, and few measures exist in individual Member States. In Germany the “Soil Protection Law” of 1999 (§ 17) demands from the farmers provision measures against soil erosion by Good Farming Practice. Specifications of this duty and practical details are explained in a guidance edited by the federal ministry concerned (see: Frielinghaus et al., 2001). Agricultural or environmental EC policies offer different tools to approach wind erosion problems related to agricultural practices. Tools like subsidies for the re-afforestation of arable land can help regional policy makers with the implementation of wind erosion control measures. They showed that regional differences result in different control measures that fits best given the physical, social and economic context. The formulation of the practical details of such code should therefore remain a task of the local or regional government. The main objectives of a Code of Good Farming Practice could be formulated at national or European level.

Souchere et al. (2003) mention that the agri-environment regulations accompanying the 1992 CAP reform were a major, but insufficient step to reduce all the environmental impacts of CAP. One of the foci of the coming battle is to preserve as long as possible the remaining permanent grassland, or even to introduce new grassland. Like the location of agri-environmental measures, the location of these new grassland must be carefully designed within catchments.

Hediger (2003) propose an 'agricultural Hartwick rule' which addresses both on-farm and off-farm effects of soil erosion and sustains the level of farm income. First, it requires the investment of the soil rents into alternative capital. Second, additional measures are required to comply with an ambient quality target. A charge-subsidy scheme proves the most adequate from a perspective of cost-effectiveness and sustainability, if effluent charge revenues are earmarked to subsidize cropland retirement at the watershed scale. In combination with the investment of soil rents this enables to maintain the level of farm income constant over time while respecting the ambient quality target. Altogether, this fulfils the requirements of efficiency and sustainability.

Back to the question how to study the economic impacts of soil erosion. As in any economic study both the costs and the benefits of soil erosion have to be assessed. In addition, simple rules have to be applied since not all the costs/benefits related to soil erosion could be assessed. TEMA (The Turkish Foundation for Combating Soil Erosion, for Reforestation and the Protection of Natural Habitats) estimated the value of nutrients in the soil that are lost annually in Turkey and calculated the equivalent value of fertilizers. This was worth 640 million dollars. If the amount of lost nutrients would be known this would be a simple guideline. More complex costs due to soil erosion are described in the following example given by TEMA. Between the years 1984-1993, the decrease in agricultural output has been 39 percent for wheat and 25.4 percent for rice. A steady decline has continued since then. TEMA links the decrease of agricultural output in recent years to soil erosion and could thus be calculated as a direct cost of soil erosion.

TEMA also mentions that soil erosion leads to loss of vegetation and forests and this results in floods and avalanches. Every year many lives are thus lost and property destroyed. Water retention capacity of the soil is reduced, making droughts more likely. This loss of water diminishes one of the most vital resources of the country. Further they mention the decrease in agricultural incomes in recent years, which is the causes of rapid migration from rural areas to urban centres, causing financial problems there. These costs are very hard to calculate.

Sedimentation due to soil erosion reduces the life span of the reservoirs and hydroelectric dams. According to a survey conducted by METU (Middle East Technical University in Ankara), 16 dams have already been identified as unproductive. And the newly built dams of the South East Anatolia Project are likely to be filled with sediment long before their designated life spans.

The Botany Department at the University of the Western Cape in South Africa mentions at their website that annual soil loss in South Africa is estimated at 300 - 400 million tonnes. Replacing the soil nutrients carried out to sea by rivers each year, with fertilizer, would cost 118 million Euro.

These examples show that it has to be defined to which degree the costs of effects of soil erosion are taken into account, because some costs cannot be assessed while others provide excellent possibilities for a cost/benefit analysis. The Management of Soil Erosion Consortium (MSEC) that was established through the Soil, Water and Nutrient Management initiative of the Consultative Group on International Agricultural Research (CGIAR, http://www.iwmi.cgiar.org/) already started to develop methods to trace the impact of soil erosion from the farmers' field to the sea. Their idea is also to present these impacts in economic terms.

The first steps of studying the economic impacts of soil erosion are thus being taken at present, but ready to use concepts have to be developed still. Following Trimble and Crosson (2000), such methods only make sense if the true space and time dimensions of soil erosion are known. A comprehensive system of monitoring soil erosion and consequent downstream sediment movement and/or blowing dust is therefore critical. As this is currently being discussed in Europe, economists and consortia such as the MSEC have to be consulted to develop useful methods to assess the economic impacts of soil erosion, as well as the economic impacts of combating soil erosion.

A remaining problem with the economical assessment of soil erosion impact is that it misleads policy makers by implying that damage is replaceable. In fact soil erosion (hence the loss of fertile top soil) is irreversible. As soil degrades over time, yield and income losses build up. Linking the market opportunity to conservation practices is however vital, as the introduction of income generating opportunities without any links to conservation, have exacerbated resource degradation (Thrupp, 1993). This is specially important in mountain areas, as pointed out by the Final Resolution of the 23rd Session of the European Forestry Commission. In fact in the EU-15 54 million people live in mountains and mountainous areas account for 38.8 % of the total EU 15 land area. Mountainous areas provide employment, transit zones, water reservoirs, landscape, wilderness, natural parks and reserves, recreational and sport areas, open spaces or simply nature. Mountain forests provide a wide range of goods and services and are necessary for human settlements in many areas. Employment linked to all these activities is important, not only for the regional economy, but also to prevent out-migration from mountain areas. Therefore, sound management and protection of mountain forests is of vital importance to the sustainable development of many mountain areas and the services that mountain forests provide to the public should be fairly compensated through appropriate financial mechanisms at regional and international levels. But mountainous areas are also fragile and particularly vulnerable. They suffer from the adverse impacts of soil erosion, forest fires, air pollution and other phenomenon, as well as the impact of climate change. The 23rd session of the Working Party on the Management of Mountain Watersheds considers that the concept and practice of integrated watershed management are necessary for sustainable development in the mountain areas of Europe. To ensure sustainable development in mountainous areas it is essential to pay simultaneous consideration to agriculture, forestry, land-use planning, transport, trade, tourism, conservation of nature, landscape and cultural heritage, water management, and protection from and prevention of natural hazards. Cross-sectoral approaches are required, and therefore, land use planning should be integrated rather than sector-based.

References

Ananda, J. and Herath, G., 2003. Soil erosion in developing countries: a socio-economic appraisal. Journal of Environmental Management, 68(4): 343-353.

Boardman, J., 1998. An average soil erosion rate for Europe: Myth or reality?. Journal of Soil and Water Conservation 53 (1): 46-50.

Boardman, J., Poesen, J. and Evans, R., 2003. Socio-economic factors in soil erosion and conservation. Environmental Science & Policy, 6(1): 1-6.

Burnham, C.P. and G.M. Mutter, 1993: The depth and productivity of chalk soils. Soil Use and Management, 9 (1), 1-8.

Clark, E. II, J. Haverkamp, and W. Chapman. 1985. Eroding Soils: The Off-farm Impacts. The Conservation Foundation, Washington, D.C.

Crosson P., 1995. Soil Erosion and Its On-farm Productivity Consequences: What Do We Know, Resources for the Future Discussion Paper 95-29, Washington, D.C.

Crosson, P. 1997: The On- farm Economic Costs of Soil Erosion. In: R. Lal, W. Blum, C Valentine and B. Steward (eds): Methods for Assessment of Soil Degradation, CRC Press, Boca Raton, Florida.

Crosson, P. 2003: The economics of Soil Erosion and Maintaining Soil Biodiversity. OECD Conference on Agricultural Soil Erosion and Soil Biodiversity Indicators, Rome, 25 – 28 March 2003.

De la Rosa, D.; Diaz-Pereira, E. & Mayol, F., 2003. Restrictions of agricultural zones and identification of soil protection practices by using soil quality decision support tools, with special reference to the Mediterranean region. SCAPE Workshop, Alicante (14 – 16 June 2003).

De la Rosa, D.; Moreno, J.A.; Mayol, F. & Bonsón, T., 2000. Assessment of soil erosion vulnerability in western Europe and potential impact on crop productivity due to loss of soil depth using the ImpelERO model. Agriculture, Ecosystems and Environment 81: 179–190.

den Biggelaar, C., Lal, R., Wiebe, K., Eswaran, H. and Breneman, V. 2003b. The global impact of soil erosion on productivity. II. Effects on crop yields and production over time. Adv. Agron. (in press).

Doran, J.W., 2002. Soil health and global sustainability: translating science into practice. Agriculture, Ecosystems and Environment 88: 119–127.

Dorren, L. and Imeson, A., 2003. Soil erosion and the adaptive cycle metaphor. In: Boix Fayos, C., Dorren, L. and Imeson, A. (Eds). Briefing Papers of the first SCAPE workshop in Alicante (ES), 14-16 June 2003, [www.scape.org]: pp. 31-40.

EEA, 1995. Europe's Environment: The Dobris Assessment. European Environment Agency.

EEA, 1998. Europe's Environment: the Second Assessment. Environment Agency. Office for Official Publications of the European Communities.

EEA, 2003. Europe's Environment: the Third Assessment. Environmental Assessment Report No 10. European Environment Agency. Office for Official Publications of the European Communities.

EEA, 2003b. Eutrophication in Europe's coastal waters. Topic report 7. EEA, Copenhagen.

Erhard, M.; Böken, H. and Glante, F.: The Assessment of the Actual Soil Erosion Risk in Germany, Based on CORINE Land-Cover and Statistical Data from the Main Representative Survey of Land Use. OECD expert meeting on soil erosion and soil biodiversity indicators, Rome 25-28 March 2003

Evans, R., 1996. Soil erosion and its impacts in England and Wales. Friends of the Earth, London, 121 pp.

Frielinghaus, Mo.; Brandhuber, R.; Gullich, P. and Schmidt, W.-A., 2001. Gute fachliche Praxis zur Vorsorge gegen Bodenschadverdichtungen und Bodenerosion. Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft (BMVEL) (Editor), Bonn, 105 p.

García Álvarez, 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.

Haaften, E.H. Van and F.J.R. Van de Vijver, 1996a: Psychological stress and marganilization as indicators of human carrying capacity in deforesting areas. International Journal for Sustainable Development and World Ecology 3: 32 – 42.

Haaften, E.H. Van and F.J.R. Van de Vijver, 1996b: Psychological Consequences of Environmental Degradation. Journal of Health Psychology 1(4): 411-429.

Hediger, W., 2003. Sustainable farm income in the presence of soil erosion: an agricultural Hartwick rule. Ecological Economics 45(2): 221-236.

Ibáñez, J.J. & Sánchez, J., 1999. From soil map to soil resources map. A proposal for the implementation of the ESB 1:1.000.000 and 1:250.000 soil databases. Meeting of the ESB Working Group 1:250.000. 30th September and 1st October 1999, Ispra, Italy.

Lal, R., 1998. Soil Erosion Impact on Agronomic Productivity and Environment Quality. Critical Reviews in Plant Sciences. Volume 17, Issue 4: pp. 319-464.

Lal, R. and Stewart, B.A. (eds), 1994. Soil Processes and Water Quality. CRC/Lewis Publishers, Boca Raton, FL, 398 pp.

Lal, R., Biggelaar den, C. and Wiebe, K.D., 2003. Measuring on-site and off-site effects of soil erosion on productivity and environment quality. OECD expert meeting on soil erosion and soil biodiversity indicators, Rome 25-28 March 2003.

Larson, W.E., and F. J. Pierce. 1991. Conservation and Enhancement of Soil Quality. In: Evaluation for Sustainable Land Management in the Developing World, pp. 175-203.

Mosimann, Th., 1995. Schätzung der Bodenerosion in der Praxis und Beurteilung der Gefährdung der Bodenfruchtbarkeit durch Bodenabtrag. In: Rosenkranz, D., Bacjmann, G., Einsele, G., Har-Reß, H.-M., Bodenschutz. Kennziffer 4070, Erich Schmidt Verlag, Berlin

OECD, 2001. Environmental indicators for agriculture; methods and results. Volume 3. Organisation for Economic Co-operation and Development. Paris.

OECD, 2003. Report on the OECD expert meeting on soil erosion and soil biodiversity indicators: summary and recommendations.

Oldeman, R. 1994. The Global Extent of Soil Degradation. In: D. Greenland and Szabolics (eds.). Soil Resilience and Sustainable Land Use, CAB International, U.K.

Pimentel, D. et al. 1995. Environmental and Economic Costs of Soil Erosion and Conservation Benefits. Science 267 (24 Feb 1995): pp. 1117-1123.

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, 65(2): 113-136.

Riksen, M., Brouwer, F. and de Graaff, J., 2003. Soil conservation policy measures to control wind erosion in northwestern Europe. CATENA, 52(3-4): 309-326.

Robinson, D.A. 1999: Agricultural practice, climate change and the soil erosion hazard in parts of southeast England.

Souchere, V., King, C., Dubreuil, N., Lecomte-Morel, V., Le Bissonnais, Y., Chalat, M., et al., 2003. Grassland and crop trends: role of the European Union Common

Agricultural Policy and consequences for runoff and soil erosion. Environmental Science & Policy, 6(1): 7-16.

Stoate, C.; Boatman, N.D.; Borralho, R.J.; Rio Carvalho, C.; de Snoo, G.R. & Eden, P., 2001. Ecological impacts of arable intensification in Europe. Journal of Environmental Management 63: 337-365.

Thrupp,L.A., 1993, Political ecology of sustainable rural development: dynamics of social and natural resource degradation, In Food for the Future: Condictions and Contraditions of Sustainability, Edited by Allen,P., pp47-74, John Wiley & Sons, New York, 328p

Trimble, S.W. and Crosson, P., 2000. U.S. soil erosion rates - myth and reality. Science, 289(5477): 248-250.

Verstraeten, G. and Poesen, J., 1999. The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium. Geomorphology 29: 275–292.