REPORTS OF THE TECHNICAL WORKING GROUPS

ESTABLISHED UNDER THE THEMATIC STRATEGY FOR SOIL PROTECTION

VOLUME - II

EROSION

Editors

Lieve Van-Camp, Benilde Bujarrabal
Anna Rita Gentile, Robert J A Jones
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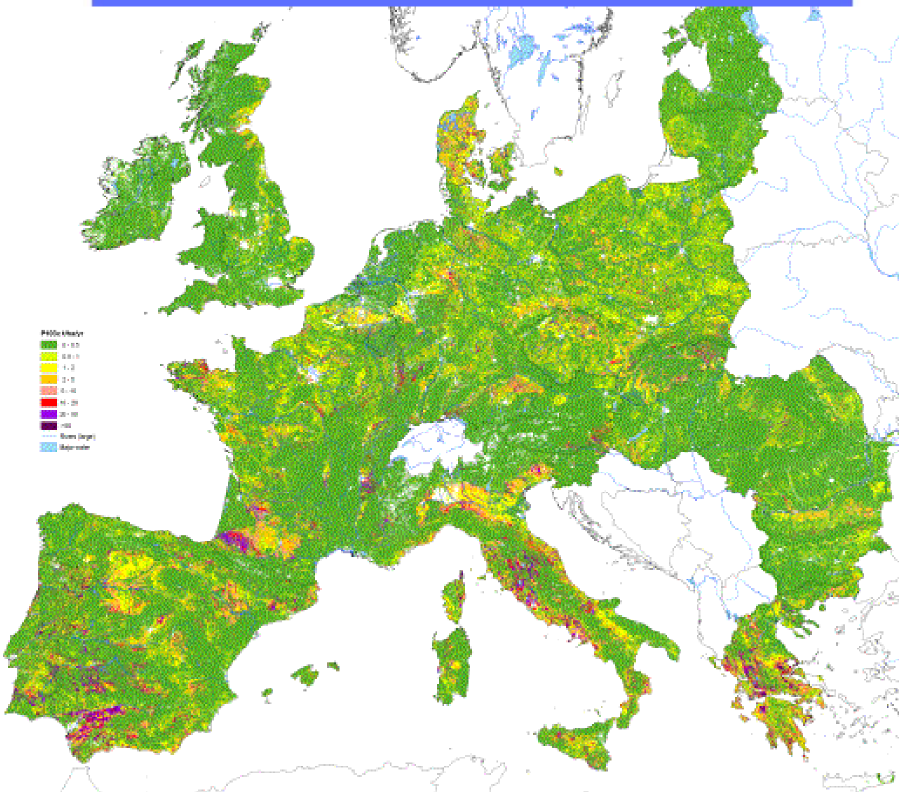

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SOIL EROSION

Task Group 1 on
PRESSURES & DRIVERS CAUSING SOIL EROSION

Jaume Fons Esteve, Anton Imeson, Rob Jarman, Renzo Barberis,
Bengt Rydell, Víctor Castillo Sánchez, Liesbeth Vandekerckhove

Executive Summary

Erosion is a natural process enhanced by human activities. Hence, soil erosion is driven by both natural and anthropogenic causes. The later increase the magnitude and frequency of the process.

Agriculture is the one of the main drivers of unnatural soil erosion, since many farming practices are soil-unfriendly and almost half of the European territory is intensively farmed, often in an unsustainable way. Farmer's management decisions are determined by market conditions, technological development, changes in the wider economy, particularly the rising relative cost of labour, and a range of structural changes. As a result, pressures on the environment increased by changes in land structure (land levelling or disappearing of landscape elements such as hedges, shelterbelts, etc.), changes in crop patterns and inappropriate agricultural practices.

In the more disadvantaged areas, land abandonment is the main driver, potentially leading to desertification if the soil productivity and erosion tolerance are low, and the bioclimatic conditions do not allow a speedy recovery of vegetation.

The increase of forest area in Europe, and in particular in the Mediterranean countries, can be considered as a positive driving force. However, a more detailed analysis is needed because changes in land structure may have impacts on the hydrogeological cycle and may increase wildfire risk. In addition, certain forestry practices may create the potential for negative impacts. Inappropriate practices prior to planting, and clear cuttings may have catastrophic effects. Poor design and maintenance of forest roads and bad drainage are of special concern.

Increasing urban population and tourism booss the demand for new land development and infrastructures. As a result, highly productive agricultural land in the floodplains has been transformed into residential areas, transferring or keeping agricultural activities in less productive areas, usually on the slopes of nearest hills where the erosion risk is higher. The development of urban and transport infrastructures may also have a direct effect on soil erosion during the construction phase. Tourism is especially impacting in coastal areas as well as in mountainous areas, where winter sports are attracting more people.

Coastal erosion is a complex process driven by a deficit in sediment load as a result of dams built upstream of the major rivers, mining activities, development of coastal infrastructures (e.g. harbours and protective breakwaters). Often, coastal defence measures are short sighted, solving a local problem but creating sediment shortage downstream. Other causes are pressure of tourism on fragile systems like sand dunes and the demand for new leisure infrastructures, disrupting sediment transport. Finally, see level rise and tidal inundation have a potentially a great impact at mid-long term.

Soil erosion affects large areas in the accession countries. The problem has been inherited, to a great extent, from the period prior to the economic and political changes (1980s and 1990s), and it remains significant today. Economic restructuring and lack of capital caused a sudden drop in agricultural investment in the 1990s, resulting in a lowering of pesticide and fertilizer input (with a consequent reduction of pollution), and the widespread abandonment of biodiversity-rich grassland systems. Reduced investment in measures to mitigate soil erosion mean that in the longer term, the renewed intensification of agriculture in more productive regions could intensify agricultural pressures on the environment to some degree. Although certain efforts have been made, greater investments in soil erosion mitigation measures are indispensable.

Natural events like droughts and wildfires reduce the vegetation cover, increasing the risk of erosion. Storms, flooding, bank erosion and landslides affect the most sensitive areas and may be quantitatively important. Climate change is expected to increase wind erosion in the drier periods and more erratic storms will increase water erosion. Sea level rise and increased frequency of storm surges will also have severe impact on coastal erosion.

Studies on the impact of existing policies on erosion are still scattered and incomplete. There is a need to improve the research in this area. Some causes are the lack or insufficient documentation on implemented policies, the absence of base level data, the need for an appropriate methodology to analyse the issue at different spatial scales, the time needed to detect the impact of a policy.

Several policies have been analysed at European level:

- Forestry. EU does not have a comprehensive common forestry policy since it relays on the principle of subsidiarity. However, there is an increasingly complex array of EU legislation and policy initiatives.
    - Afforestation regulation 2080/92. Available information suggests a positive impact, mainly when planting on slopes and arable land. However, some negative effects were observed regarding improper site preparation techniques and extensive afforestation of grasslands.
    - Council Regulation No 2158/92 of 23 July 1992 on protection of the Community's forests against fire (OJ L217, 31.7.1992). Direct impact on soil erosion is difficult to measure. However, the scheme has contributed to improve the efficiency of forest fire prevention and control systems.
    - Forestry measures within Rural Development Policy (Council Regulation (EC) No 1257/1999). These measures include afforestation of agricultural land, improvement of the multifunctional role of forestry and improvement of the protection value. However few data are still available. It needs to be assessed to what extent these measure are applied in areas under mid/high risk of soil erosion.
    - Natura 2000. Soil protection is one of the elements considered under habitat protection and taken into account in the delineation of the Natura 2000 network. In addition, in some countries, considerable part of the forests are included in Natura 2000.

- Agriculture
    - Agri-environmental Regulation 2078/92. Area included in such programmes greatly varies from one country to another and its allocation does not necessarily coincide with those parts of Europe where the areas of either greatest nature conservation value or greatest agricultural pressures on the environment are found. This reflects different interests and also difficulties in designing and running incentive schemes for small-scale, traditional farming systems. Problems implementing the agri-environment schemes range from farmers perception to conflicting measures within the CAP. Good knowledge of local conditions is a

prerequisite to increase effectiveness of these measures.

- o CAP reform. Agenda 2000. It is particularly difficult to assess the impact of some of the more recent changes in the Agenda 2000 package because little monitoring or evaluation work has been completed. In general, it seems to slowly improve environmental issues already dealt under 1992 reform.

- Transport. The major environmental concern is on emissions, and, to a lesser extent biodiversity and protected areas. Hence, protection of soil against soil erosion is only a secondary issue, which is addressed indirectly through the protection of natural areas.

- Protection of specific areas: mountains and coast

- o Alpine Convention and related Protocol on Soil Protection. This is an important step forward integrating environmental issues, specifically soil protection, into sectoral policies. However, its slow implementation makes it still difficult to assess its impact on the area. The Convention and related protocols increased public awareness of the environmental problems, in particular to practices enhancing soil erosion.
- o The EU commission has agreed on a Communication regarding Integrated Coastal Zone Management (ICZM) COM(2000)547. ICZM is based on an integrated and broad “holistic” approach and could be an important instrument for land use planning of coastal areas. Best results have been obtained by combining different types of measures ('hard' and 'soft' measures), and taking into account non-local drivers. Furthermore, it is crucial to set clear measurable objectives (e.g. tolerated loss of land, beach carrying capacity) in order to optimise the long term effectiveness and social acceptability of coastal erosion measures, whereby multifunctional technical designs are the most acceptable and economically viable.

Identification of driving forces and pressures

The driving forces and pressures of soil erosion are social, economic, ecological and physical but they act in an integrated way. Soil erosion is directly driven by the forces of climate (energy of wind and rainfall), but it occurs when the vegetation and upper soil horizons have their storage and regulation functions impaired or diminished mainly under the influence of human actions. All kinds of pressures (e.g. pollution, cultivation and land levelling) can lead to the gradual or sudden loss of the (adaptive) capacity of the soil and its ecosystem to retain water and sediment on a slope.

Although erosion is directly triggered by the rain or wind that provides the energy for erosion and transport processes, the opportunity or propensity for erosion results from the effects of human actions which create erosive situations. These actions may be motivated by economic and financial incentives, as well as by social and psychological drivers but in addition there is a lack of awareness or ignorance about the medium and long-term impacts that they are having. If there was more awareness and concern about the consequences of soil erosion, in terms of the irreversible loss of capital and future opportunities for its productive use, these pressures could become less.

The pressures causing soil erosion in Europe now

There are many ways of identifying and analysing driving forces and pressures and for a representative analysis reference is made to background literature (SCAPE 2003). Identifying drivers and pressures requires answering the questions How, and Why is soil erosion occurring in Europe? In general this is quite well known to the soil erosion and conservation community who have during the last twenty years organised a succession of workshops and symposia dedicated to addressing specific problems (see http://www.zalf.de/essc/essc.htm and http://www.soilerosion.net/cost623/ web sites).

Bork (2003), reviewed the history of erosion in Europe since 1800 AD. He clearly explains the current context of soil erosion. He demonstrated that in all countries (e.g. The Netherlands, Germany, England and France) erosion became a problem following the intensification of agriculture between about 1960 and 1985 or when countries like Portugal and Norway expanded arable farming into marginal areas. Before 1970, soil erosion was not considered an issue in England and it mainly occurred when grasslands were converted to arable farmland. Large areas became have suffered erosion through the impact of grazing in mountain areas where rural development programmes made relatively fragile systems accessible to farmers or who could import feed and thus support larger herds that dramatically exceeded the carrying capacity.

In southern Europe, the situation is complex and varies from country to country. A common mistake is to think that the current impact of soil erosion is the most extreme in the driest regions. The greatest pressures from fire and grazing and cultivation are in the areas that produce the most biomass and which receive the most pressure (Imeson 1998). In the driest and coldest regions the greatest risks to erosion often result from land levelling and or afforestation. Semi-natural steppe vegetation, or matoral, adjusted to the prevailing conditions is with good intentions destroyed and being replaced with trees that have no hope of growing enough to protect the soil from erosion as the former vegetation did. At this moment in time there is a pressure to address these issues (Agenda 2000 and the work of the Soil Forum) and to integrate soil protection strategies and guidelines into other policies. If this is accomplished, pressure promoting erosion will disappear.

The above claims are supported by the following review which explains in more detail how these pressures have worked. For convenience they are considered under the following headings.

- Agriculture and forestry - rationalization and intensification in agriculture and forestry, inappropriate practices, related to intensification (e.g. overgrazing, land drainage in agriculture and forestry, road construction in forests, clear felling…) or extensification (e.g. agricultural land abandonment…) or for other reasons (e.g. stone removal for potato cultivation…).
- Land development and land cover changes;
- Human population and related factors as urban pressure, population density, transport and other infrastructure;
- Growing world economy, food security and changing consumption demands;
- Tourism;
- Natural events including climate change;
- Human activities leading to climate change, and the consequences increasing erosion risk (e.g. prolonged droughts and forest fires, erratic and high intensity rainfall events, windstorms, change in snow covered ground and permafrost).

1.1 Agriculture and forestry

Agriculture

Agricultural policies and practices greatly influence erosion, due to the fact that half of the European territory is used for agricultural production and agricultural practises can promote erosion (e.g. through soil compaction, reducing water holding capacity and increasing soil erodibility and influence on soil chemistry and (micro)biology, influence on the protective working of vegetation cover).

Agricultural policies enable agriculture to increase in extent so that poor quality land is used for production. It also enables the intensity of land use (the amount of non land inputs used per hectare) to increase. Production is not limited by land quality and the capital it generates.

Changes in market, need for increased productivity and technological improvements (mechanisation, inorganic fertilisers, irrigation systems…) have lead to intensification of agriculture in the last decades. Agricultural decisions have also been influenced by other factors like trade, transport, price agreements and economic factors at various scales.

Intensification has resulted in increased farm and field sizes, greater mechanisation, higher stock densities, changed crop sequences and crop types. Intensification has generally taken place on highly productive land, but not confined only to such situations. The slight decrease in the total agricultural area in Europe in the last decade does not reflect the real land use changes and regional differences in the process: some agricultural land has been taken for building and new agricultural areas have been developed in natural or semi natural areas.

A higher degree of agricultural intensity can be directly linked to greater water erosion in the high-risk areas, but sometimes the opposite can occur. When soil protection measures are used erosion can decrease under intensification. Both in northern and southern Europe, high erosion rates in the 1980's have become reduced as a result of adopting different cultivation and rotation practises.

As a result of these socio-economic changes, pressures on the environment increased, with an impact strongly dependent on local conditions:

- Changes in land structure.

  - Disappearing of shelterbelts and field margins with permanent vegetation that acted as effective windbreaks and controlled water runoff. Windbreaks play a key role preventing wind erosion occurring also in flat areas. Consequently, increased field sizes resulted in higher risks of water and wind erosion.
  - Surface modelling operations needed to facilitate the use of machinery cause important soil displacement, which is one of the most worrying erosion forms (tillage erosion). The mass displacements caused by levelling causes a local accumulation of incoherent material, which can be easily eroded. In these conditions, catastrophic erosion rates (beyond 500 t ha-1year-1) occur rather frequently. Levelling operations are often developed in crop techniques which highly increase the erosion risk, as it happens in the hilly vineyards where grape rows are located in a parallel way to the maximum slope direction.

- Crop patterns and agricultural practices.

  - Intensification of silvo-pastoral systems. Traditionally, these systems served multiple uses, with low energy and high labour input. Overexploitation by excessive cultivation and/or increased stocking densities reduced the pasture cover and its quality. In addition, soil compaction due to overgrazing lowered infiltration capacity, increasing water runoff. The problem is especially acute when overgrazing occurs in Mediterranean marginal areas, where unproductive fields have been abandoned, and erosion may lead to desertification. Overgrazing has also an impact on soil compaction. It is linked to the import of feed from northern Europe that enables stocking rates far exceeding the stocking capacity, and with the opening up of fragile mountain ecosystems to grazing through the construction of roads for rural development.
  - Conversion of silvo-pastoral systems to other crops (ploughing of permanent pastures). In many cases permanent grassland has been converted to intensively managed crops such as maize, or potatoes, where irrigation has increased the profitability.
  - Continuous arable cropping, increasing the exposure of soil to wind and water.
  - Late harvested spring-sown crops such as maize (increasingly planted as a silage crop), sugar beet, potatoes and other vegetables also increase exposure of soils to erosion.
  - Many rotations have been simplified so that the main crop, often wheat or maize, may be grown continuously without a break, which often requires higher applications of pesticides and increases the erosion risk.
  - The use of heavy machinery and frequent passes with cultivating equipment can cause soil compaction, increasing runoff at the soil surface and creating a soil pan within the soil. The latter inhibits drainage, causing water logging of crop plants on some soils and creating a physical barrier for their roots, making them more susceptible to drought in dry conditions. Soil compaction is a particular problem on soils with low organic matter. The worst effects of surface compaction can be rectified relatively easily by cultivation but once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate.
  - Harvesting roots and tubers.
  - Intensification of crops with lower cover density (e.g. olive and vineyards). The problem of erosion has been greatly exacerbated by changes in practices associated with mechanisation of tillage, to keep the soil of olive plantations bare of vegetation all the year round, by regular cultivation. Often, this tillage is carried out up and down the slope, rather than following the contours. The most severe erosion takes place with the arrival of the autumn rains on bare soils, which have been cultivated to a fine tilt by summer harrowing. Impediments to adopt conservation policies: lack of awareness and information, changing to a non-tillage system would require the purchase of new machinery in many cases, for applying herbicides or for mowing spontaneous vegetation.
  - Changes in vineyards to favour mechanisation: increasing the length of vine rows, removing terraces and use of tillage parallel to the maximum slope.
  - Inappropriate irrigation methods on slopes.

There are a number of factors that hampers the shift to appropriate agricultural practices to reduce soil erosion:

- Farmers react very quickly to changes in price incentives (e.g. sugar beet, linseed and potatoes) and world market. Local conditions and suitability are not enough taken into account.
- Low erosion rates and off-site impacts do not encourage farmers to invest in conservation. Off-farm costs of erosion are externalised to society and are considerably greater than on-farm costs incurred by farmers. In practice, it is difficult to internalise these costs due to the non point-source character of agricultural water pollution and other off-site impacts.
- Variety in the sizes of agricultural plots and unequal distribution of land. It is more difficult to apply effective erosion control methods in a small piece of land.
- There is a perception that practices to reduce soil erosion will not benefit farmers. Moreover, additional fertilisers, organic amendments and/or supplemental irrigation easily compensate short-term decline in yield.
- Lack of sufficient investment in the agricultural sector.

There are many indicators available to evaluate the crop intensity and, indirectly, the interaction risk with erosion, and they are almost all taken from agricultõral field statistics, such as fertiliser consumption, ratio between cultivated area and total area, average firm dimensions, ratio between intensive crop areas (arable and permanent crops), and the total agricultural area, product income per surface unit, number of animal and many others. The indicators weak point is that often data are available only for big extensions; more over they are not easily linked directly with the erosion risk.

Land abandonment

Land abandonment has been taking place mainly in the more disadvantaged areas, where the farming systems in general and livestock farms in particular, are often operating close to the margins of viability. This was originally a consequence of the difficulties associated with the adoption of modern farming systems and, later, as a result of the demographic exodus from these rural areas. First, the least economically desirable lands are abandoned and then, as the agricultural enterprise is transformed, further abandonment proceeds.

The process that follows land abandonment depends on the state of the land at the time of its abandonment, geomorphology and climate. A value of 40% vegetation cover is considered critical; below which accelerated erosion dominates on sloping land (Thornes, 1988). If the vegetation cover covers a greater area than 40%, then it will act as a factor of resilience or protection of the land. Soil depth is another important factor. A critical minimum soil depth of 25–30 cm has been measured in semi-arid landscapes below which the recovery of the natural perennial vegetation is very low and where the erosion processes may be very active, resulting in further degradation and desertification of the land (Kosmas et al., 2000).

Forestry

The total area of forest in Europe is increasing annually by about 0.1% (MCPFE Liaison Unit Vienna et al., 2003), with the largest increases in the Mediterranean region (Spain, France, Portugal, Italy and Greece), and the annual increment of growing stock has been larger than annual felling in nearly all countries (EEA, 2003). About 9% of forest and other wooded land in Europe is specifically designated to protect soil, water and ecosystem functions. Often, especially in Mediterranean Countries, the increase of forest areas is due to the abandonment of border low mountain zones, often accompanied by a minor control on the woods. This means that the simple increase of wood zones does not guarantee a better control of erosive phenomena, but it is often correlated to a worsening of the control of territorial hydro geological layout.

The implementation of certain forestry practices and techniques for wood production has created the potential for negative impacts:

- Forestry on steep slopes may increase the risk of landslides;
- Certain forest practices like ploughing prior to planting increase the risk of soil erosion if no countermeasures are taken (like vegetated buffer strips and sediment catchpits). On the other hand, keeping woody debris on the topsoil greatly reduces the risk of erosion.
- Clear-cutting of large areas increases the risk of erosion by reducing the vegetation cover and modifying the water runoff;
- Forest roads may be an important pathway for runoff leading to soil erosion. In some cases it is estimated that forest roads may account for 90% of the soil erosion taking place during forest operations. Effective design of a road network and maintaining an associated network of drains, culverts and sediment catchpits are crucial to minimise adverse effects on slope hydrology. Poorly maintained drainage systems in wet mountain roads can induce mass-wasting events large enough to destroy the road and affect adjacent forests and aquatic systems.

1.2 Human population

Population density

In highly populated areas, the competitiveness between the different possible uses definitely increased, and so are soil functions (means for edible productions, carrier of buildings and infrastructures support, provider of raw materials, including water, minerals and construction materials, part of the landscape and of the cultural heritage). Competitiveness increase can also be caused by improper planning choices, with soil uses often not matching the soil characteristics. So fertile lands are destined to housing, infrastructures and services, as leisure activities or waste storage, while less fertile and more vulnerable soils are left for crops.

The population density, although not directly related to erosion, can be an alarm bell, which suggests verifying for those areas the evolution of other more specific indicators, as soil use changes or the increase in impermeabilised grounds.

Urban pressure

Urban development may have a direct impact by exposing and removing bare soil for a certain period of time, especially if heavy storms occur. It has also an impact by increasing soil compaction. Increased urbanisation is particularly evident on the coastline. At the Mediterranean coast, tourism and urban development are competing with agriculture for extensive, flat lands, easily accessible by roads or waterways. Moreover, alluvial terraces and deltas are highly productive, with deep soils, best suited for agriculture. As a result, agricultural activities move or remain in less productive areas, usually on the slopes of the nearest hills where the risk of soil erosion is higher. The impervious area in the 10 km band from the coast increased by 13% on average during the period 1972-1992 with hot spots of 30% increase (Christensen & Perdigao, 2000).

Transport infrastructures

- Transport infrastructures have both direct and indirect impacts on soil erosion:
- Development and/or improvement of roads and highways has the potential to increase the pressure on the land by the potential increase of population density and urban sprawl around the new transport infrastructures. This has an indirect impact on soil erosion through modification of water flows and, in particular, increase of water runoff. In mountain areas, transit traffic is concentrated on a few main routes. In these "corridors", emissions from the vehicles damage trees reducing the protective effect of vegetation cover.
- Development of transport infrastructures may directly enhance soil erosion by exposing and removing bare soil, mainly on steep slopes. In addition, poor maintenance of drainage systems may modify water runoff and contribute to increase erosion risk.

Land use and development of coastal areas

Erosion of land on the coast inevitably leads to physical loss of soils – e.g. from land on top of eroding cliffs, or on lowland subject to tidal inundation and sea level rise. However, coastal erosion may also lead to losses of certain soil functions and their substitution by other functions. Thus, agriculture or freshwater aquifer functions may be lost due to salinisation, but biodiversity or sea defence functions may be gained.

Several factors are driving current coastal erosion trends, and are likely to aggravate these trends in the coming decades:

- Civil engineering structures - mainly dams - built upstream of the major rivers in Europe, which trap sediments before they reach the coast and therefore contribute to reduce the sediment budget available on the coast.
- The development of estuarine harbours and related dredging activities, which remove every year millions of tons of sediments from the riverbed. In parallel, protective breakwaters established at the entrance of coastal harbours may result in sediment deficit down-drift.

- Short-sightedness of coastal defence investments. In spite of significant budgets dedicated at the local level to coastal defence, the long term effectiveness of coastal defence strategies is in many cases questionable. By way of illustration, groynes, breakwaters, seawalls, and other engineered frontage designed to protect the assets invested along the coast disrupt sediment transport processes along the coast and create coastal erosion problems a few kilometres away.
- Mining activities - mainly sand and gravel extraction - result in a deficit of sediment, while oil extraction locally results in a vertical isostatic movement of the terrestrial crust which changes the relationship between land and sea surfaces and, therefore, the shoreline.

1.3 Growing world economy

Adaptation of EU agriculture to an increasingly competitive international context characterised by further moves towards trade liberalisation may reinforce productivity as a first priority. Free trade negotiations are increasing the pressure on the EU to change the present market intervention policy, because of the negative influence on the world food market.

Consumption demands

Increasing demand for products of organic farming has been reflected in an increased of 67% of its area during the period 1998-2000, although it only accounts for 3% of total agricultural area (DG AGRI). Consumption greatly varies from one country to another, to the extent that part of the Spanish production is exported to Germany. Organic farming is expected to decrease the risk of soil erosion by practices that improves soil protection and increases soil organic matter content.

On the other hand, the increasing demand of vegetables and potatoes by the retail industry, e.g. for deepfreezing, significantly increases the risk of soil erosion because most of these crops are highly sensitive to soil erosion, and the economic incentive related to their production tends to extend it into the more erodible areas.

Accession countries and enlargement

Currently soil erosion and degradation affect large areas in central and eastern Europe, although there are significant differences between countries regarding its extent and intensity. Areas affected range from 5% to 39% of the total surface. The situation is the most severe in Romania (6.7 million ha), Bulgaria (4.8 million ha, affecting 72% of the arable land), Poland and Hungary (4.7 and 3.8 million ha). In Turkey, approximately three quarters of the 27 million ha of arable land are affected.

Soil erosion was already a problem in the accession countries prior to the changes in the agricultural sector during the 1980s and 1990s, and it remains significant today. Since the Second World War soil erosion has gradually increased as a result of inappropriate land use in combination with natural vulnerability factors. Land consolidation, field enlargement, the use of inappropriate machinery and tillage practices are the most important factors involved.

Agriculture's share of the total national land area varies considerably between the Accession Countries ranging from 30-60%. Average farm size is small compared to EU15, but considerable regional differences exist. Very small and very large farms exist alongside each other. Most of these rely on outdated machinery and socialist era buildings. The political changes have affected agricultural development profoundly. Economic restructuring and lack of capital caused a sudden drop in agricultural investment in the 1990s, resulting in a lowering of pesticide and fertiliser input (with a consequent reduction of pollution), and in most countries the widespread abandonment of biodiversity-rich grassland systems. Reduced investment in measures to mitigate erosion and in manure storage facilities mean that in the longer term the renewed intensification of agriculture in more productive regions could intensify agricultural pressures on the environment to some degree. This seems a potential risk in central European countries in particular.

The economic climate during the 1990s has not allowed much investment in appropriate landscape planning, including windbreaks and other erosion mitigation features. Some areas of grassland have been ploughed up for conversion to arable land, increasing erosion risk and causing biodiversity loss. Investment in erosion mitigation measures is essential to ensure that this major agri-environmental issue does not worsen in the future

Some extensification and expansion of arable land is expected. If this is accompanied by improved management of fertilisers and pesticides – a likely possibility – consequences for soil and water resources may be limited. Conversion of grassland to arable is, however, detrimental to biodiversity, particularly where semi-natural grasslands are concerned. Conversion of grassland, multi-annual fodder crops or long-term fallow to arable cultivation will also increase soil erosion risk, in particular if this would occur on erosion prone soils, such as on slopes. The impact of the increased soil erosion risk can be reduced if appropriate standards of Good Farming Practice, farmer advice and other mitigating measures are implemented.

Although certain efforts have been made to fight erosion in several countries, most particularly in Hungary, Slovakia, Estonia, the Czech Republic and Turkey, the extent of the problem and the lack of proper incentives for farmers to improve their practices now requires comprehensive and concerted action to tackle the issue. It is possible that the abandonment of some agricultural areas and the subsequent encroachment of scrub are reducing erosion in some areas. However, these unintended erosion mitigation measures are no substitute for the carefully planned building of windbreaks and other features that will help to combat the problem in a more effective manner.

1.4 Tourism

Tourism is an important driver of land use changes causing a direct impact in both soil sealing, compaction and erosion. Two areas are of special concern related to environmental impact of tourism: mountain areas and the coast.

Booming of coastal tourism is the principal cause of the urbanisation of European coasts as stated before. There is a direct impact on soil erosion by removing or exposing bare soil during the development of infrastructures. Moreover, deficient land planning may change watercourses increasing the risk of floods. In addition, tourism has a strong impact on coastal erosion:

- Increased pressure on fragile systems like sand dunes
- Demand for new leisure infrastructures like ports and other coastal defences (e.g. groynes, breakwaters and seawalls) disrupt sediment transport processes along the coast and create coastal erosion problems a few kilometres away, especially in wave-dominated coasts with important sediment transport drift.

Mountain areas are also of great concern because its morphology is prone to erosion. Ski and other winter sports are those with a higher impact on erosion. The development of ski-runs and lifts for downhill skiing leads to a reduction of vegetation cover and topsoil loss, resulting in soil erosion and extended needle-ice solifluction. Moreover, disturbances due to the shearing effect of skis is repeated year for year on the same site and leads to complete destruction of the upper layer of soil. Overheating, desiccation and erosion during the summer impair the edaphic conditions still further.

Tourist concentration may lead to a rapid drop in livestock farming (abandonment of cultivated land, decrease in livestock population and farms) because of the competition of tourism for labour and fertile land, which are essential to the maintenance of extensive livestock farming. Low use of pasture resources leads to their progressive loss, owing to the advance of plant succession (substitution of pastures by shrubs), decreasing landscape diversity, and increased fire hazard and soil erosion as has been described in Central Pyrenees (Marin-Yaseli and Martinez, 2003).

Another effect of tourism pressure in the Alps has been the damage caused to trees by emissions from the vehicles that bring visitors to the slopes, reducing the protective effect of vegetation cover on soil erosion.

1.5 Natural events

Storms
Impact of the storms is dependent on vegetation cover and soil properties. For this reason they have a major impact on sub humid and semi-arid Mediterranean areas, with fine sand and silt soils.

Droughts
Droughts are affecting most of the European continent with a higher impact in the Mediterranean areas, increasing the risk of soil erosion. Decreased water availability diminishes the capacity of the system to support certain vegetation cover; hence the probability of bare soil being exposed to erosion increases. If a period of drought is followed by heavy storms, erosion is triggered by surface run-off. As an indirect effect droughts increase the risk of forest fires.

Forest fires
Forest fires remove the plant cover and litter layer which play a major role in the prevention of soil erosion caused by raindrop impact and wind velocity. Fire can also affect several of the physical and chemical soil properties related to erodibility. As a consequence, burned lands are especially sensitive to erosive agents, and important soil losses can be generated while an effective soil cover is absent. The risk of soil degradation is very high immediately after a fire and decreases exponentially with time as the plant cover regenerates. In recent years, the number and frequency of fires have increased as a result of more homogenous landscapes and more people accessing the forests for leisure activities. Recurrent fires can affect vegetation recovery, leading to desertification in most extreme cases.

Windstorms
Windstorms have a direct impact increasing the risk of wind erosion. Damage caused to forests may result in a temporal decrease of vegetation cover. In addition, felled trees may expose bare soil.

Flooding
As a consequence of storm surges, flooding of low-lying coastal plains, reduces the ability of natural habitats - including dunes, flats and marshes - to act as buffer zones between lowlands and the sea. Coastal erosion is potentially exposing millions of people to the risk of flooding.

Sea level rise
Climate change - including accelerated sea-level rise and an increased frequency of storm surge occurrence - is also expected to impact coastal erosion processes significantly. In some specific areas sea level rises at a pace, which makes it impossible for coastal wetlands to adapt to these changes. They finally collapse and recede. In other locations the average period between two consecutive storms has so much decreased that damaged dunes or beaches cannot restore themselves completely in-between.

Bank erosion
Bank erosion occurs in river valleys and along lakeshores and can be exacerbated by rapid runoff after heavy rainfall. An increased volume of water raises the water level and increases the speed of flow. This can quickly under cut banks causing soil losses by landslides. Furthermore, sediments will be transported along the river and causing damages off-site. In periods with normal runoff there will be erosion and scouring along the bank sides of the streams.

1.6 Human activities leading to climate change

There is a link between climate change and soil erosion. Human activities leading to a decrease of soil organic mater, and a release of C to atmosphere, have also an impact on soil erosion, namely:

- Deforestation. Conversion of forest or semi natural areas to agricultural land results in a decrease of vegetation cover and soil organic matter; topsoil is exposed or even removed. All these process combined increases the soil erosion risk.
- Agricultural practices which result in a decrease of soil organic matter. It has a direct effect on soil structure increasing the risk of soil erosion.
- Increased fuel consumption and other activities releasing $CO2$ and other greenhouse gasses in the atmosphere, by industry, traffic, settlements, agriculture… . In agriculture, fuel consumption is high due to increased mechanisation, and increased production in greenhouses. Furthermore, ruminants are also an important source of greenhouse gasses.

Increased temperatures and reduced moisture contents are likely to reduce vegetation cover and loss of carbon causing soils to be more probable to erode. Longer droughts will enhance wind erosion. In addition, changes in rainfall patterns will increase the probability of storms after long dry periods, with a direct impact on water erosion.

Increased temperatures may also affect the snow cover and snow melt patterns. Presently, in northern countries a high amount of annual precipitation comes as snow, which causes a high runoff peak in spring. Due to climate projections, this peak will almost completely disappear, but a high increase in runoff during all winter months is expected with the associated particle loss (Lundekvam, 2001).

2 Impact of existing policies

2.1 Forestry

The Treaties on European Union make no provision for a comprehensive common forestry policy. However, there is an increasingly complex array of EU legislation and policy initiatives within different EU sectoral policies which considerably influences the forest policies of the Member States. An EU Forestry Strategy was therefore adopted in 1998, which puts forward as its overall principles the application of sustainable forest management and the multifunctional role of forests. In line with the principle of subsidiarity, this Strategy seeks to establish a coherent framework of forest-related actions at EU level. It also aims to improve the linkages and co-ordination between different policy areas as well as the coherence with the forest policies of the Member States. EU actions under existing responsibilities are based on the following:

- With their many functions, forests are essential to rural areas and constitute a major component of an integrated rural development policy, particularly because of their contribution to income and employment and their ecological and social value;
- Forests and their structural and biological diversity are an important part of the European natural environment. Their protection and conservation falls within the scope of a number of EU policies, and is the subject in particular of specific environmental measures, such as the EU Biodiversity Strategy and Action Plans and the Natura 2000 network of protected areas;
- Forests play an important role in climate change mitigation and forest-related actions are foreseen in the context of the European Climate Change Programme;
- For forest products, and in particular wood (as well as cork and resins), the rules of the Internal Market apply, including the normal EU competition rules on state aids, mergers and cartels.

Thus, a number of important EU policies have a considerable impact on forests. In the next sections the most relevant ones are analysed more in depth.

Afforestation Regulation 2080/92

In 1992, measures accompanying the reform of the common agricultural policy (CAP) were adopted to benefit the environment, early retirement and forestry. These measures aimed to support the expected processes of change, and to mitigate some of the effects deemed to be to the disadvantage of farmers. Falling under one of the basic options for the reform of the CAP (temporarily leaving land to lie fallow or use land for afforestation of non-food production), Council Regulation No 2080/92 therefore introduced a system of Community aid for forestry measures in agriculture with the following objectives

- To accompany the changes planned in the context of the common market organisations,
- To contribute to a long-term improvement in forestry resources,
- To help to manage the countryside in a way which is more compatible with the balance of the environment,
- To fight against the greenhouse effect and absorb carbon dioxide.
- The evaluation of the impact of this policy is limited by the following constraints
- The lack of information on the location of the wooded areas compared with fragile areas (no maps of the plots planted were available)
- The absence of bases of reference and specific measures, which makes it difficult to carry out any quantitative and precise evaluation of this impact.
- In spite of the sound arguments sometimes put forward by the Member States in their national programmes, protection of the natural resources did not really give rise to the setting of really specific objectives over the period 1994-1999 (except for the Spanish and Portuguese programmes).

However, some conclusions can be taken from the available information (Picard and Giry, 2001):

- Afforestation has been mainly done on the least productive agricultural plots. This may have a positive impact tempering land abandonment.
- In Portugal, most of the plantings were in hilly regions in the south of the country.
- Afforestation is beneficial against erosion when it takes place on arable land. More than 50% of afforested area has been done on previous arable land in Denmark, Germany, Greece and Italy. However, there is a concern where afforestation has been on grassland, which is more resilient. Spain has afforested 50% of grassland and 22% of arable land.
- In Spain and in Portugal, soil preparation before planting, which was often carried out by public works companies which had turned to forestry, involved the use of heavy machinery and techniques which sometimes accelerated erosion in the first few years, where the land sloped steeply.

Council Regulation No 2158/92 of 23 July 1992 on protection of the Community's forests against fire (OJ L217, 31.7.1992)
Regulation No 2158/92 was established in 1992 and ran until 2002. The objective was to underpin the efforts of the Member States to prevent forest fires, while ensuring at the same time that forestry measures, with support from other sources, such as rural development in areas subject to fire risk, are linked with protection systems through the implementation of global forest fire protection plans. During the period 1992–2002 the EU financial contribution provided to Member States (France, Germany, Greece, Italy, Portugal and Spain) amounted to EUR 124 million and focused on the following measures:

- Measures to identify the causes of forest fires and means of combating them, in particular:
  - studies to identify the causes of fires and to devise proposals to eliminate such causes;
  - campaigns to inform and educate the public on the risks and consequences of forest fires.

- Measures to set up or improve systems of prevention, with particular emphasis on the launching of protective infrastructures such as forest paths, tracks, water supply points, firebreaks, and preventive forestry measures within the framework of a global strategy for the protection of forested land against fire;
- Measures to set up or improve forest monitoring systems;
- Training of highly specialised personnel and analytical studies and pilot projects on new methods, techniques and technologies to boost the effectiveness of the scheme.

It is difficult to assess the direct impact of these measures on soil erosion. However, at qualitative level, it can be said that the scheme has contributed to improve the efficiency of forest fire prevention and control systems over the years. Co-operation between Member States and the establishment of an EU forest information system, increased public awareness of the risks and consequences of fires and the development of preventive silvicultural methods have been also key factors in reducing the extent of forest fires.

Forestry measures within Rural Development Policy (Council Regulation (EC) No 1257/1999).

The EU's rural development policy – the second pillar of the common agricultural policy (CAP) – seeks to establish a coherent and sustainable framework for the future of these rural areas by bringing together economic, social and environmental objectives into a coherent package of voluntary measures and thus giving added value to the implementation of forest programmes
of the Member States in their regions. The forestry measures of the rural development programmes are at the same time seeking to contribute to more global issues such as climate change and biodiversity. In broad terms, the integration of forestry aspects in the Rural Development Policy follows three pathways, in particular for privately owned and municipality forests:

- afforestation of agricultural land (article 31);
- investments to improve the multifunctional role of forestry (article 30);
- improvement of the forest protection values (article 32).

All these measures are expected to have some impact reducing the risk of erosion. However, low availability of data make it still difficult to assess its actual magnitude. A crucial issue is to know the share of the area where these measures are implemented under mid/high risk of soil erosion.

Natura 2000

The adoption of the Habitats Directive in 1992 led to the creation of an EU-wide network of Species Areas of Conservation (SACs), Natura 2000. It is expected that, ultimately, two thirds of the designated sites will be located in forests or will have forests elements. Soil protection is one of the elements of habitat protection. In some countries considerable part of the forests are included in Natura 2000 (e.g. 30% of forests in Greece, Luxembourg and Netherlands; 25% in Spain). However, only a minor part of total EU forest area will belong to Natura 2000 (less than 10%).

2.2 Agriculture

Measurement and evaluation of policy effects directly based on environmental characteristics pose serious difficulties. The main limitations are the lack of linearity and immediacy (effects may very well lag behind the source of disturbance), unequivocal causality (effects are subject to a multitude of influences of which the policy to be evaluated is only one) and high cost of measurement (Peco et al., 1999). A brief analysis is presented below related to environmental requirements included within the EU Common Agricultural Policy.

Agri-environmental Regulation 2078/92.

Agri-environmental schemes were introduced in Europe in the 1980s as a separate policy domain accompanying the Common Agricultural Policy and with clear links to nature conservation. As part of the 1992 reform it became obligatory for the Member States to implement Reg. EC/2078/92, which was the legal framework until 2000. The central objectives are a) to contribute to providing an appropriate income for farmers, and b) to promote agricultural production methods compatible with environmental protection of nature and landscape.
Member States were asked to design five-year programs in which these measures were implemented with horizontal or zonal approaches. Although implementation is compulsory (but not for all measures), the Regulation gives the Member States the freedom to adapt it to their own political, social and environmental idiosyncrasies, applying the subsidiary principle with the only compulsory requirement of having to establish clear environmental objectives.

Some of these measures might be used to counter soil erosion. The measures must be linked to agricultural activities that provide environmental benefits. Several objectives are eligible for funding (CEC, 1992). Those relevant for combating soil erosion are indicated in bold:

(a) Substantial reduction in the use of fertilisers and/or pesticides, to maintain the existing reduction, or to introduce or continue organic farming methods.

(b) By other means than those in (a), to change to more extensive forms of crop and forage production, to maintain extensive production methods introduced in the past, or to convert arable land into extensive grasslands.

(c) To reduce the proportion of sheep and cattle per forage area.

(d) To use other farming practices compatible with environment and natural resource protection or countryside and landscape maintenance, or to rear local animal breeds in danger of extinction.

(e) To ensure the upkeep of abandoned farmland or woodlands.

(f) To set aside farmland for at least 20 years for environment-related purposes, in particular for the establishment of biotope reserves or nature parks or for the protection of hydrological systems.

(g) To manage land for public access and leisure activities.

(h) Farmer training for environment-compatible agricultural or forestry practices.

Currently over 20% of EU farmland is included in such programmes (Buller, 2000), going far beyond the target set in the 5th Environmental Action Programme of 15% area coverage by 2000. However, its allocation does not necessarily coincide with those parts of Europe where the areas of either greatest nature conservation value or greatest agricultural pressures on the environment are to be found. For example, there are very large areas of high nature value agricultural land in Spain and Greece but both the level of expenditure and the area of land enrolled have been considerably below the EU average. This reflects in part a lack of strong national traditions of explicit environmental management of agricultural land, as well as the difficulties in designing and running incentive schemes for small-scale, traditional farming systems.

Main problems encountered implementing the agri-environment schemes are

- Inadequate funding. Funding for certain crops or management practices may be higher, and more profitable, than agro-environment provisions.
- Resistance to long-term obligations.
- Reluctance to abandon traditional practices.
- Efficiency of these measures is strongly dependent on good knowledge of local conditions. A study conducted in Upper Normandy, France, showed that converting 1% of existing arable land to grassland will reduce runoff volume up to 45% if the grassland is located on major runoff pathways. However, the same area randomly located will result only in a reduction of 15% (Souchère et al., 2003).
- Need of transfer of knowledge. A survey among farmers in central Belgium found out that fields with higher chance to be taken out of production as a consequence of the EU-CAP policy where those with higher risk of erosion: steep fields with a sandy or clay soil and a bad drainage (Van Rompaey et al, 2001). This case illustrated a good perception of the problem by farmers.
- Measures to prevent pollution or erosion sometime conflict. For example, to reduce the amount of bare soil in winter, farmers receive a subsidy to buy cover crop seeds. However, this is offset by grass chopping rather than by a chemical destruction with herbicide because of the worry about possible pollution by pesticide. Grass chopping carried out with only 3m cutter width and bad climatic conditions will damage the field soil structure, thus producing runoff.
- The limited success of the measure that promotes organic agriculture can be partly attributed to sociological and cultural factors that prevent farmers from effectively modifying their production methods and the traditional approach to the solution of agronomic problems. Further, it is quite difficult to commercialise and distribute organic products, since they are seldom recognised by the market as quality products (INEA, 1999).
- Application of long-term set-aside has been high in some areas of the Mediterranean area. However, a study in the Agri Basin (Italy) showed that a large number of requests for the set-aside measure came from young farmers. There is a risk that the willingness to set aside their land is only a first step towards abandoning the agricultural activity altogether on the part of these young farmers (INEA, 1999).

CAP reform: Agenda 2000

The Agenda 2000 reform package was agreed in Berlin in March 1999 and implemented from July 2000. By proposing to deepen and extend the reform of 1992, further shift from the price support system to direct payments was planned. In addition, an important element of the package was the strengthening of a rural development policy to be integrated and become the "second pillar" of the CAP, next to the market support system, considered to be the "first pillar".

The Agenda 2000 reform pursued environmental integration in many respects: it established the general obligation on the Member States to introduce appropriate environmental measures for a range of commodity regimes, while leaving a wide degree of freedom as to how Member States can fulfil their obligation. Environmental clauses have been introduced into both market policies and rural development programming. Agri-environmental measures were consolidated as compulsory parts of rural development programmes.

The most relevant measures were:

- Regulation (EC) 1259/1999,
  - Article 3:
    - "general mandatory environmental requirements"
    - "specific environmental requirements constituting a condition for direct payments" (cross-compliance)
- Regulation (EC) 1257/1999,
  - Chapter V, VI: Less Favoured Areas and Agri-Environmental Programmes: "usual good farming practices"
  - Chapter I, II, VII: (investment, young farmers, processing and marketing): "minimum standards regarding the environment"

It is particularly difficult to assess the impact of some of the more recent changes in the Agenda 2000 package because little monitoring or evaluation work has been completed. The environmental consequences of the shift from headage to area payments for the LFA compensatory system, for example, are not yet apparent (Baldock et al., 2002). Another problem is that good farming practices (GFP) defined by the Member States and regions for the implementation of the Rural Development Regulation (EC) 1257/1999 varies between comprehensive catalogues of criteria and few, but operational verifiable standards. As some catalogues contain recommendations without clarifying whether these codes are subject to control and punishments, and only a little information on control, compliance and punishments is available, comparisons remain difficult.

It is clear that some of the new options made available to Member States under Agenda 2000 have the potential to support environmental goals but that these have not yet been widely used for that purpose. For example, national envelopes in the beef regime offer Member States considerable flexibility and scope for targeting support, but do not appear to have been used to target specific environmental concerns or experiment with more decoupled payments. Few countries seem to have introduced new environmental standards under Article 3 of Regulation 1259/1999 through cross-compliance for example. Only few Member States have chosen significantly to expand expenditure on agri-environment and other accompanying measures, through the use of modulation. On the other side, some countries have taken a more integrated approach, such as the application of various measures under Regulation 1257/1999 to support the implementation of Natura 2000.

Considering the impact of agri-environment measures included under Regulation (EC) 1259/1999, they seemed to be successful in reducing the input of fertilisers or pesticides. However, few specific measures target soils and land management specifically. Moreover, there is a need to target at vulnerable areas.

2.3 Transport

Decisions on transport infrastructure are still made mainly in response to problems of traffic bottlenecks. This reactive approach favours the extension of road infrastructure. The development of the trans-European transport network (TEN) aims at improving intermodality and the shares of combined (high-speed) rail and inland waterways transport. However, TEN investments are still biased towards motorways, which is supposed to have a greater environmental impact than railroads.

Integration of environmental requirements in transport related policies have been developed recently by different mechanisms:

- The European Council at the Cardiff Summit (1998) urged the Commission and the transport ministers to develop and implement integrated transport policies and to report regularly (using indicators) on progress.
- Strategic Environmental assessment (SEA) is considered by the Commission to be a key instrument to promote integration of the environment into sectoral policies (Commission Communication on Integration, 1998). According to the SEA directive (Directive 2001/42/EC) — to be implemented by EU Member States by 2003 — transport plans and programmes should be subject to environmental assessment prior to their adoption. UNECE is developing a protocol on SEA. This would also require countries to establish mechanisms for SEA at international, national, regional and local levels as well as in transboundary and non-transboundary contexts.
- The Convention on access to information, public participation in decision-making and access to justice in environment matters calls for better environmental education and awareness.

However, there are several bottlenecks integrating environmental policies in transport:

- Few Member States are yet implementing integrated transport and environment strategies. Eight countries are in the course of developing such strategies, but in most cases they still need to be fully adopted, funded and implemented.
- Few countries (lead by Austria and Finland) have set up indicator reporting mechanisms. The Cardiff Process should provide a greater impetus to report on progress with integration at the sectoral level.
- Although the transport sector is more advanced in developing SEA than other sectors, SEA is still seldom used to assess transport policies or plans at a sufficiently early stage of development. SEA is beginning to be put into practice in several countries (driven by pioneering initiatives in the Nordic Member States, the Netherlands and France), but there is seldom a proper link with decision-making. The main reason for this is the lack of legal frameworks and the persistence of institutional barriers, which hamper its acceptance and application. In addition to the necessary legal requirements, practical implementation also requires sufficient administrative capacity to perform the SEA, which is often not present. Moreover, to be effective, the findings of SEAs should also be taken into account in decision-making, which is as yet rarely the case — in the EU as well as in the accession countries.
- At the company level, the transport sector is increasingly adopting environmental management systems (notably ISO 14001 and EMAS) as a cost-effective means of improving environmental performance. Such management tools can provide more cost-effective solutions than end-of-pipe measures.
- Even where integration strategies and policies are being developed, most have yet to be fully approved, funded and implemented. National policies vary in substance, but have common elements, such as the acknowledgement of the need for demand management (for road and air transport), for the promotion of cleaner transport modes, and for changes in life style and driving behavior.

The major environmental concern is on emissions, and, to a lesser extent biodiversity and protected areas. Hence, protection of soil against soil erosion is only a secondary issue, which is addressed indirectly through the protection of natural areas.

2.4 Protection of specific areas: mountains and coast.

Convention on the Protection of the Alps (Alpine Convention)

The Alpine Convention is a framework agreement for the protection and sustainable ecological development of the Alpine region. It was signed on 7 November 1991 in Salzburg (Austria) by the seven countries of the Alps (Austria, France, Germany, Italy, Liechtenstein and Switzerland) and the European Community. Slovenia signed the convention on 29 March 1993. The Convention entered into force on 6 March 1995. The goal of the Alpine Convention is a holistic policy for the conservation and protection of the Alps involving the circumspect and sustainable use of resources taking due account of the principles of prevention, polluter-pays and co-operation. It is also designed to strengthen cross-border co-operation in and for the Alpine region. The framework convention relates to the following sectors: people and culture, land use planning, air quality, soil protection, water regimes, environmental protection and landscape management, mountain agriculture, mountain forests, tourism and leisure activities, transport, energy and waste management.

The implementation of the Convention is defined in protocols with a greater policy content. Several thematic protocols have been signed: transport; tourism; energy; nature protection and landscape management; mountain agriculture; mountain forests; regional planning and sustainable development; and soil protection.

The protocol on Soil Protection was signed in 1998. Several actions are specified in order to protect the soils:

- Soil protection should be considered in land planning. Specially for urban development (art. 7).
- Limitation of sealing by urban sprawl, promoting the reuse of land.
- Mapping the areas at risk and taking appropriate measures to combat soil erosion and landslides. It is also recognised the need to integrate environmental issues, and particular soil erosion, in other sectoral policies like agriculture, forestry and tourism (art. 11).
- Restoration of vegetation in areas heavily impacted by tourism (art. 14).

One of the bottlenecks of the Convention and related protocols has been the slow implementation and the difficulty to evaluate its success due to the complexity and interconnexion between several policies. It has been recognised that one of the greatest success has been its contribution to widespread awareness that the Alps are a region with distinct environmental and cultural characteristics, and of considerable European importance. Within the Alps, it has led to recognition that many issues cannot be solved only through national legislation; co-ordinated regional approaches and initiatives are essential.

Integrated Coastal Zone Management COM (2000)

The EC Coastal Strategy highlights the importance of coastal zones acknowledging, “our coastal zones are facing serious problems of habitat destruction, water contamination, coastal erosion and resource depletion” but also recognising that an important factor is affecting coastal zones can be identified in socio-economic and cultural problems that include damage to property due to erosion.

The Commission states:

“The basic bio-physical problem in the coastal zones is that development is not kept within the limits of the local environmental carrying capacity. Some of the most common manifestations of this problem are:

- Widespread coastal erosion, often exacerbated by inappropriate human infrastructure and development too close to the shoreline
- Loss of property and development options, as the coast erodes; Coastal erosion is locally perceived as the most significant threat to maintaining income in many areas that live from tourism.”

Based on this, the European Commission has adopted a Communication document (COM (2000)547) on Integrated Coastal Zone Management (ICZM). The strategy has a starting point in eight principles of good coastal zone management:

- *A Broad “Holistic” Perspective (Thematic and Geographic)*

This principle highlights the fact that in order to manage coastal zones it has to take into consideration the entirety of the numerous inter-related systems and pressures that can exercise an influence on them e.g. hydrological, geomorphological, socio-economic, administrative institutional and cultural systems.
Furthermore the principle suggests that for an effective management, initiatives should include both the seaward and the landward portion of the coastal zone.

- *A Long Term Perspective*

“The needs of both present and future generations must be considered concurrently and equally, ensuring that decisions respect the ‘precautionary principle’, and do not foreclose future options.” Adaptive Management (responding to new information and conditions) During a Gradual Process
This principle advocates the need for a flexible management of the coastal zone due to uncertainty of future conditions.

- *Adaptive Management (responding to new information and conditions) During a Gradual Process*

This principle advocates the need for a flexible management of the coastal zone due to uncertainty of future conditions.

- *Local Specificity*
  Local circumstances and need must be take into account in order to achieve good coastal zone management therefore it must be developed an understanding of the specific characteristics of the area in question.

- *Working with Natural Processes*
  This principle is supporting the idea that successful coastal management can be achieved through an understanding of natural processes rather than through actions against them. Working with natural processes is seen as increasing long-term options.

- *Participatory Planning*
  Participatory planning is aiming to reduce conflict and develop consensus in coastal zone management.
  Participatory Planning is building the different opinions and perspectives of all the relevant stakeholders into the planning process through collaborative involvement that it will lead to commitment and shared responsibility.

- *Support and Involvement of all Relevant Administrative Bodies*
  “Almost all of the Demonstration Programme project leaders have affirmed that coastal zone management is not effective if it is not supported by all levels of administration as well as by all of the relevant branches of administration concerned with the target coastal area.”

- *Use of Combination of Instruments*
  The use of multiple instruments (law, economic instruments, voluntary agreements, information provision, technological solutions, research and education) has been seen to be the only way to succeed in coastal zone management. The choice of the specific instruments to use depends on the problems that arise in the area that is being dealt with.

Past measures to manage coastal erosion have generally been designed from a local perspective: they have ignored the influence of non-local forcing agents and have disregarded the sediment transport processes within the larger coastal system. As a consequence, they have locally aggravated coastal erosion problems, and have triggered new erosion problems in other places. They still influence the design of present measures. As an attempt to better respond locally to non-local causes of coastal erosion and to anticipate the impact of erosion management measures, a number of cases mainly in Northern Europe have built their coastal erosion management strategies upon the concept of “sediment cell” as well as on a better understanding of sediment transport patterns within this sediment cell. Such approaches require a strong co-operation between regions which share a same sediment cell.

There is no single best solution. Best results have been achieved by combining different types of coastal defence including hard (e.g. breakwater, gabion, seawall) and soft solutions (such as beach nourishment), taking advantage of their respective benefits though mitigating their respective drawbacks.

Assignment of clear and measurable objectives to coastal erosion management solutions - expressed for example in terms of accepted level of risk, tolerated loss of land, or beach/dune carrying capacity - optimises their long-term cost-effectiveness and their social acceptability. This has been facilitated by the decrease of costs related to monitoring tools.

Multi-functional technical designs, i.e. which fulfils social and economical functions in addition to coastal protection, are more easily accepted by local population and more viable economically. Though critical for decision-making, the balance of coastal defence costs and their associated benefits is - in general - poorly addressed in Europe. This may lead to expenses, which are at the long run unacceptable for the society compared to the benefits.

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SOIL EROSION

Task Group 2 on
NATURE AND EXTENT OF SOIL EROSION IN EUROPE

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Objectives WP2:

To appraise the current situation with respect to soil erosion using existing data, information systems and models; To establish harmonised criteria and guidelines for the development and use of indicators assessing the present soil erosion risk or state as well as trends in soil erosion over time.

Description of the work:

2.1 Identify different forms of soil erosion processes or mechanisms causing mass movements and consequent soil loss, as well as their relevance in different Member States (MS) and their inclusion in current soil erosion methodologies

- Water erosion
  - Rills and inter-rill erosion
  - Gully erosion
  - Snowmelt erosion
  - Bank erosion in rivers and lakes
- Disturbance or translocation erosion
  - Tillage erosion
  - Land levelling
  - Erosion due to harvesting of root crops
  - Erosion by trampling and burrowing animals
- Wind erosion
- Coastal erosion
- Landslides and debris flows
- Internal erosion provoked by groundwater flows

2.2 Review and analyse existing soil erosion assessment methodologies at European and national scales (including soil erosion indicators)

Analyse the results obtained in terms of erosion rates, potential and actual erosion risk, vulnerability areas. Compare the result and check possible inconsistencies.

2.3 Synthesis report of extent of soil erosion in Europe

Based on the information derived from the task 2.2 and, after a critical review, a synthesis report on the nature and extent of soil erosion should be delivered by the workgroup. This report might include the weak points and uncertainties, which have been pointed out in task 2.2.

2.4 Definition of benchmarks and soil erosion indicators

Assessment of existing soil erosion indicator systems: applicability at European and national level. Establish harmonised criteria and guidelines to develop a European soil erosion indicator system.

2.5 Secondary Threats

- Compaction: report on likely geographical extent, particularly in subsoils, in Europe and the links with erosion.
- Salinisation: report on nature and extent in Europe.

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Summary

1. Soil erosion is a natural process, occurring over geological time, and indeed it is a process that is essential for soil formation in the first place.
2. With respect to soil degradation, most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activity.
3. Soil erosion by water is a widespread problem throughout Europe.
4. The processes of soil erosion involve detachment of material by two processes, raindrop impact and flow traction; and transported either by saltation through the air or by overland water flow.
5. Combinations of these detachment and transport processes give rise to the main processes of ‘Rainsplash’, ‘Rainwash’, ‘Rillwash’, and Sheet wash.
6. Runoff by rainfall and from snowmelt is the most important direct driver of severe soil erosion by water and therefore processes that influence runoff play an important role in any analysis of soil erosion intensity. Measures that reduce runoff are critical to effective soil conservation.
7. The most dominant effect is the loss of topsoil, which is often not conspicuous but nevertheless potentially very damaging.
8. Physical factors like climate, topography and soil characteristics are important in the process of soil erosion.
9. The Mediterranean region is particularly prone to erosion because it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils.
10. This contrasts with NW Europe where soil erosion is less, because rain falling on mainly gentle slopes is evenly distributed throughout the year and consequently, the area affected by erosion is less extensive than in southern Europe.
11. However, erosion is still a serious problem in NW and central Europe, and is on the increase.
12. In parts of the Mediterranean region, erosion has reached a stage of irreversibility and in some places erosion has practically ceased because there is no more soil left.
13. With a very slow rate of soil formation, any soil loss of more than 1 t $ha^{-1}yr^{-1}$ can be considered as irreversible within a time span of 50-100 years.
14. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t ha^{-1} in extreme events.
15. The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing, forest fires and construction activities.
16. The identification of areas that are vulnerable to soil erosion can be helpful for improving our knowledge about the extent of the areas affected and, ultimately, for developing measures to control the problem.
17. For assessing soil erosion risk, various approaches can be adopted that distinguish between *expert*-based and *model*-based methods.
18. The CORINE programme, an example of an expert-based approach, assessed the risk of soil erosion in Mediterranean Europe by overlaying soil, climate and topography using GIS technology.
19. Another example of an expert-based approach is GLASOD – Global Assessment of Soil Degradation. The GLASOD map identifies areas with a subjectively similar severity of erosion risk, irrespective of the conditions that would produce this erosion.
20. The Hot Spots Map, commissioned by the EEA, is a third example of the expert-approach. The spatial representation of areas at risk from erosion is too general to be of use to policy makers, but the study that produced it did extract data from the literature on actual sediment losses for a number of locations in Europe.
21. The availability of digital data sets in recent years has facilitated application of the model-based approach.
22. The USLE is a simple empirical model, based on regression analyses of rates of soil loss from erosion plots in the USA. It is designed to estimate long-term annual erosion rates on agricultural fields.

23. The map of erosion risk in Europe produced using the USLE model was a first attempt, using a standardised approach, to quantify soil erosion by rill and interrill erosion for the whole continent.
24. The Pan-European Soil Erosion Risk Assessment - PESERA - project has developed and is currently calibrating a process-based, spatially distributed model to quantify soil erosion by water and assess its risk across Europe.
25. However, other modelling approaches are needed in areas where other forms of erosion are dominant, e.g. by wind, snowmelt, etc.
26. The most extensive and most severe wind erosion is mapped in southeastern Europe with moderate wind erosion observed in the Czech Republic and parts of France, the UK and Hungary.
27. The EU-projects WEELS and WELSONS suggest that the area affected by wind erosion is probably much larger than previously thought. The estimated losses by wind of 21 t ha^{-1} yr^{-1}, over a 30-year period in southeast England, compare closely with estimated rates of water erosion in other parts of northwest Europe.
28. It is clear that erosion by water and wind is irreversibly degrading the soils in many parts of Europe, sometimes in a dramatic way in southern Europe and also in a less obvious but still damaging way in northern areas. In both cases off-site impacts are damaging as on-site effects.
29. The existing European Soil Database provides a harmonised basis for broadly identifying the areas most at risk and for examining the processes responsible. This coupled with CORINE land cover, a suitable DEM and climate data, provides a good basis for modelling erosion.
30. However, at present, reliable point data on actual soil loss and its trend in future are very scarce, particularly in southern Europe.
31. Process-based models, such as PESERA, offer some hope for obtaining better predictions of soil erosion by water than estimates made in the past.
32. Of the models reviewed here PESERA is the most conceptually appropriate because it takes into account: (i) runoff and eroded sediments separately; (ii) daily rainfall accumulated by month; (iii) dynamic crusting and vegetation cover by month; (iv) other climatic information such as freezing days.
33. The results of national studies from Austria, Belgium, Bulgaria, Czech Republic, France, Germany, Hungary, Italy, Spain, Slovakia, Switzerland and UK are briefly reported here. Though these provide valuable data for checking model estimates, such as those from PESERA, they cannot be a substitute for a standard European approach.
34. For precise environmental auditing, model estimates must be validated at sites where actual sediment losses are measured and, to quantify trends, erosion measurements should be added to the list of those that are needed for the whole of Europe.
35. Nothing less than a continent-wide soil monitoring network will be needed to provide such data. Refining erosion models and improving the resolution and accuracy of spatial data should go ‘hand in hand’ with real measurements, albeit at selected benchmark sites.
36. However in the immediate future, the area identified as being at high risk from erosion should be used as an overall ‘indicator of state’, and thereafter monitoring land cover can provide a valuable insight into whether or not the amount of erosion is likely to be increasing.
37. The status and distribution of the secondary threats of compaction and salinisation are also described in this report.
38. The overall deterioration in soil structure caused by compaction can (i) increase the risk of soil erosion on sloping land, through the concentration of excess water above compacted layers; and (ii) accelerate effective runoff from and within catchments.
39. Soil salinisation affects an estimated 1 to 3 million hectares in the enlarged EU, mainly in the Mediterranean countries. It is regarded as a major cause of desertification and therefore is a serious form of soil degradation. With recent increases in temperature and decreases in precipitation, characteristic of climate in recent years, the problem of salinisation in Europe is getting worse.

2.1 Soil erosion processes or mechanisms causing soil loss

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

Resulting changes to the soil cover allow natural forces of erosion to remove the soil much more rapidly than soil-forming processes can replace it. Any soil loss > 1 t $ha^{-1}yr^{-1}$ can be considered irreversible within a span of 50-100 years

Erosion literature commonly identifies 'tolerable' rates of soil erosion, but these rates usually exceed the rates that can be balanced by weathering of parent materials to form new soil particles. Erosion is a normal process of soil formation and may be considered acceptable from an economic viewpoint. It is clear that on most productive land there is an overall loss of soil material that is becoming increasingly unacceptable.

Soil erosion is regarded as the major and most widespread form of soil degradation, and as such, poses severe limitations to sustainable agricultural land use. Soil can be eroded away by wind and water. Strong winds can blow away loose soils from flat or hilly terrain. Erosion by water occurs due to the energy of water when it falls to the earth and flows over its surface.

2.1.1 Background

Agriculture, forestry and urbanisation strongly affects the rate and types of hillslope processes, and the way in which land is managed can dramatically influence whether soil erosion remains at an acceptable level, or is increased to a rate leading to long-term and perhaps irreversible degradation of the soil.

Slope sediment transport processes are of two very broad types, first the weathering and second the transport of the regolith, with a number of separate processes within each type (Table 2.1); many of these processes occur in combination. Most slope processes are greatly assisted by the presence of water, which helps chemical reactions, makes masses slide more easily and carries debris as it flows. For both weathering and transport, the processes can conveniently be categorised as chemical, physical and biological (Gobin *et al.*, 2002).

2.1.2 Soil erosion by water

Although a small amount of material is washed through the soil, the most important erosion processes take place at the surface. Material may be detached by two processes, 'raindrop impact' and 'flow traction', and transported either by saltation through the air or by overland water flow (surface runoff). Combinations of these detachment and transport processes give rise to the main processes, 'Rainsplash', 'Rainwash', 'Rillwash', and 'Sheet wash' as indicated in Table 2.2 (Gobin *et al*., 2002).

Raindrops detach material through the impact of drops on the surface. For the largest drops, the terminal velocity is 10 m s^{-1}, but they only attain this after falling through the air for about 10 metres. If rainfall is intercepted by vegetation (throughfall), the raindrops hit the ground at a much lower speed, and have much less effect on impact. As raindrops hit the surface, their impact creates a shock wave, which dislodges grains of soil, or small aggregates and ejects them into the air in all directions.

The total rate of detachment increases rapidly with rainfall intensity. Where the raindrops fall into a layer of surface water that is more than about 5 mm thick, the impact of the drop on the soil surface is largely lost. Raindrop impact is also effective in breaking down soil aggregates into constituent soil particles. These particles are re-deposited between aggregates on and close to the surface, forming 'soil crusts', which seal the surface, and limit infiltration by filling the macropores between the aggregates.

These crusts may make the surface more resistant to erosion, but their greatest importance is in increasing runoff from storm rainfall. Susceptibility to water erosion is closely associated with the formation of soil crusts by rain falling on unprotected surfaces. In the immediate vicinity of crusted surfaces, erosion is less than on soil with no crust, but nearby downslope the increased volume of water flowing over the surface results in more erosion. Thus the destruction of crusts by tillage, freeze-thaw and drying can increase erosion risk locally.

If water is flowing with sufficient velocity, it exerts a force on the soil that is sufficient to overcome the resistance of soil particles. Resistance is due to friction, which increases with particle size, and cohesion between grains, which increases with the specific surface area of contact, and hence decreases with increasing particle size. There is virtually no cohesion between grains larger than 2mm (Birot, 1968). Resistance is lowest for small non-cohesive grains, particularly silt and fine sand sized particles with low clay content.

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

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

2.1.2.1 Rills and runoff

Runoff is the total amount of water reaching a point in the landscape, which may be a stream or river, and it is the most important direct driver of severe soil erosion. Processes, which influence runoff, must therefore play an important role in any analysis of soil erosion intensity, and measures, which reduce runoff, are critical to effective soil conservation.

Perhaps the most important control on runoff is the degree of crusting of the soil surface. This has a very strong influence on infiltration and therefore affects runoff rates. Of secondary, but still major importance, is the micro-topography of the soil surface and the sub-surface soil structure, particularly the presence or absence of macro-pores in the form of cracks and/or voids between soil aggregates. Micro-topography consists of random roughness on the surface, together with cultivation features such as plough ridges and terracing.

Figure 2.1 Rill erosion in Hungary (Photograph by Erika Micheli)

Where flow is sufficiently intense to entrain soil particles directly, small channels or rills (Figure 2.1) are formed on the surface, and material is eroded by ‘rillflow’, which is concentrated along these drainage lines (Figure 2.2a & b)
In cultivated land, resistance to erosion is commonly low within the cultivated layer, but increases considerably at the plough pan, which may be a layer of increased resistance, forming a transition to the undisturbed and more

consolidated un-ploughed soil beneath. Rills therefore rarely penetrate beneath the plough layer, and are generally obliterated by later cultivation, as farmers seek to prevent further erosion.

Figure 2.2 Rill erosion in Severn Valley, UK (Photographs by P.N. Owens)

2.1.2.2 Gully erosion

During storms with very heavy rainfall, and where gradients are at least locally steep, erosion may lead to greater incision, forming gullies, which are too large to be obliterated by normal tillage. The development of gullies can fragment farmland, and by steep gradients to adjacent fields, lead to rapid extension of a gully network, which then makes cultivation impracticable (Figure 2.3).

In steep mountainous terrain, soil masses from landslides can accumulate in existing gullies on slopes. During intensive rainfall, these gullies are often transformed to rapidly flowing streams. When the water flow becomes strong enough, the accumulated soil masses begin to flow. Together the water charged soil material (mud) forms a debris flow that builds up a high kinetic energy capable of causing severe erosion and damage along the gully. Where such gullies continue into urban areas, debris flows can cause severe damage to property and loss of human life.

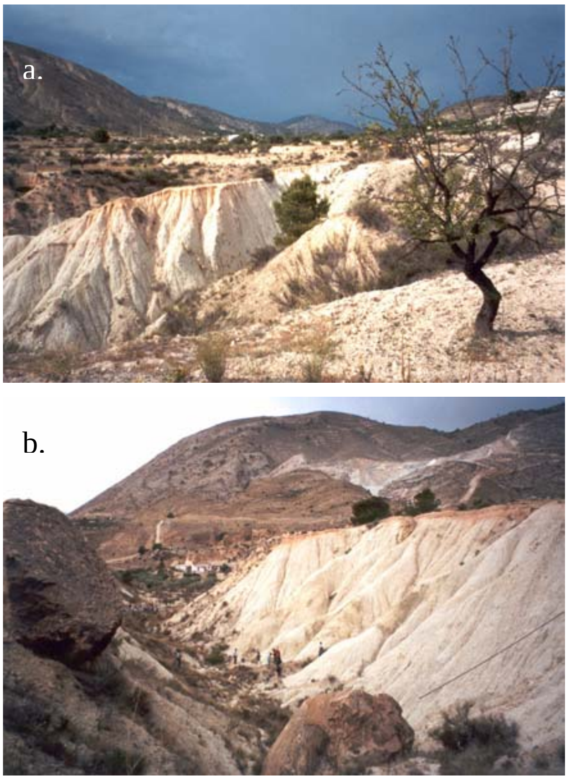


Figure 2.3 Gully erosion of former olive groves in Pedrera, Alicante Spain (Photographs by R J A Jones)

Remediation of gully systems requires radical measures, including the possible re-grading of entire landscapes (land-levelling).

2.1.2.3 Snowmelt erosion

In northern parts of Europe, e.g. Norway, Sweden and Finland, erosion is often caused by snowmelt during winter and early spring – see Figure 2.4a. – (Lundekvam 1998, 2002). In these areas soils may be frozen during winter, restricting infiltration resulting in high surface runoff and subsequent erosion.

Topsoil conditions can vary from an ice- and snow-covered surface to a thawed surface with frozen subsoil. Saturated soil has low shear strength and high erodibility such that high losses may occur when snowmelt moves over or rain falls on partly frozen ground with an unfrozen topsoil overlying frozen subsoil (Figure 2.4b).

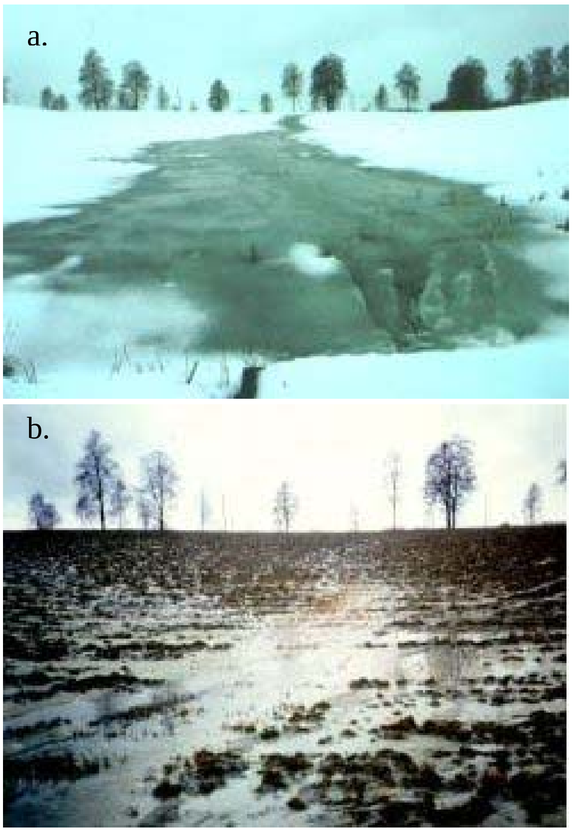


Figure 2.4 Snowmelt erosion Norway (Photographs by L. Øygarden.)

In Norway, the risk of erosion is high in areas under cereal production because autumn ploughing leaves the soil unprotected when rainfall can be heaviest, and in winter when snow melts on frozen ground (Lundekvam *et al.*, 2003). In some years, winter is the most important period for erosion. The combination of intense rainfall, frozen subsoil and saturated surface soil with low bearing strength during snowmelt, leads to both rill and gully development (Øygarden, 2003).

Annual soil losses during snowmelt are regularly measured to be in the range of 1-9 t ha^{-1}, but rates of >100 t ha^{-1} have been measured in gullies that have developed down to the depth of land drain pipes. If climate change leads to mild and unstable winter conditions, with several freezing and thawing cycles, more extreme erosion events might be expected.

In northern Sweden also combinations of intense snowmelt and heavy rainfall are reported. Heavy thunderstorms, which occur after warm spring days in May and June causing intensive snowmelt, triggering landslides in glacial till slopes that are often followed by debris flows.

Snowmelt erosion has also been reported in Germany, Poland, Slovakia, Austria, Italy and Switzerland (Kværnø and Øygarden 2002).

Most erosion models in use in Europe are designed to estimate erosion caused by rainfall-induced runoff. Such models cannot predict erosion from snowmelt and, consequently Lundekvam (2002) has developed an erosion model – ERONOR – for Norwegian conditions, and for Finland the ICECREAMS- model is being used. The development of these models illustrates the need for process-based models appropriate for the dominant erosion process.

2.1.2.4 Bank erosion in rivers and lakes

This is another kind of extreme form of erosion by water occurring only in specific locations in river valleys and along lake shores. Bank erosion can be exacerbated by rapid runoff after heavy rainfall. The increased volume of water in the drainage channel raises the water level and increases the speed of flow. This can quickly under cut banks and cause the river or stream to change its course.

Many processes of soil loss and sources of sediment are responsible for the sediment load in rivers and streams but Owens *et al.* (2000) found that bank erosion contributed 40% of the sediment load in the River Tweed in Scotland. In addition to soil loss caused by surface runoff on tilled fields, particles might be lost through preferential flow to a drainage system. If tillage has been performed on the bank side without leaving a buffer zone, erosion occurs as 'slides' along the stream banks (Figure 2.5).

Figure 2.5 Bank erosion in close proximity to cultivation (Photograph by L. Øygarden.)

In periods with high runoff there can also be erosion and scouring along the bank sides of the streams (Figure 2.6a). There is a link between bank erosion and landslides, as both are examples of mass movement of soil material, and can be associated with grassland (Figure 2.6b). Freeze-thaw is another cause of bank erosion.

Measures to control excess runoff should result in less water reaching the streams and rivers and hence reducing their ability to erode the banks. Such measures could also reduce the risk of flooding.

2.1.3 Disturbance or translocation erosion

Soil erosion can be initiated and/or excerbated by disturbance through tillage, excavation and animal activity. The following sections describe these processes.

2.1.3.1 Tillage Erosion

An important anthropogenic process is 'Tillage Erosion', which is the result of ploughing, either up and down slope or along the contour. Each time the soil is turned over, there is a substantial movement of soil. Up- and downhill ploughing produces a direct downhill component of movement as the turned soil settles back. Increasing use of mechanised cultivation has also led to a substantial increase in rates of tillage erosion.

Figure 2.6 Bank erosion (a, b) R Swale, northern England UK (Photographs by P N Owens)

Contour ploughing can move material either up or down, according to the direction in which the plough turns the soil. Contour ploughing, in which the soil is turned downhill, moves approximately 1000 times as much material as soil creep. Contour ploughing in both directions (soil turned uphill and then downhill or vice-versa), or ploughing up- or down-hill produces a smaller net movement, but the overall rate is still about 100 times greater than natural soil creep.

The spatial distribution of tillage erosion in Europe has not been systematically mapped, but research has shown that the intensity of tillage erosion depends on:

1. Slope variation or curvature: tillage erosion is most severe in areas of 'rolling topography', *i.e.* with a lot of convexities

(where erosion occurs) and concavities (where deposition occurs);
2. Management parameters: tillage depth, tillage speed, plough direction; and
3. Type of tillage implement.

Although the effect of soil type has not been investigated in depth, this parameter seems to be less important compared to the former ones (Van Muysen, pers. comm.). In Belgium, tillage erosion intensity has been mapped for Flanders (see section 2.2.2.2).

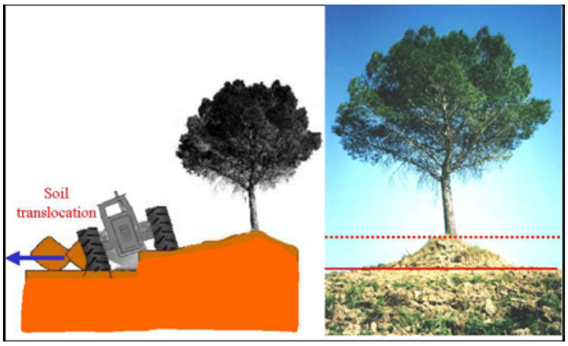


Figure 2.7 Tillage erosion caused by ploughing (P. Bazzoffi, pers. comm.)

Table 2.1. Classification of the most important Hillslope Processes.

	WEATHERING PROCESSES	*TRANSPORT PROCESSES*	*Type(S/T)*
CHEMICAL	Mineral Weathering/decomposition	Leaching	S
	(oxidation solution carbonation chelation,	Diffusion (ionic, molecular)	T
	hydrolysis, hydration, base-exchange,)		
PHYSICAL/	Freeze-Thaw	Mass Movements	
MECHANICAL	Salt Weathering (growth of salt crystals)	Landslides	S
	Thermal Shattering (through expansion &	Debris Avalanches	S
	contraction	Debris Flows & Slides	S
		Soil Creep	T
		Gelifluction & solifluction	T
		Tillage Erosion	T
		Rockfall	S
		Particle Movements	T
		Through-fall	T
		Rainsplash	T
		Rainflow	T
		Rillwash	
BIOLOGICAL/	Faunal Digestion (earthworms)	Biological Mixing (often	T
ORGANIC	Removal by mammals (rabbits, moles,	included within Soil Creep)	
	ground squirrels etc.);		
	Root Growth		

Types: T = Transport Limited: **S** = Supply Limited removal (Gobin *et al.*, 2002)

Table 2.2. Types of soil erosion by water.

Detachment by:	*Transportation*	*Mode*
Rainsplash (through the air)		N/A
Overland Flow Traction	Rainflow	Rillwash
	Snowmelt	Gully Erosion
		Sheet wash/slope wash
		Mud flows/earth flows
		Bank erosion

Soil translocation due to tillage is particularly intense in Mediterranean countries, e.g. Italy, Greece and Spain, because of the dominant morphology (Figure 2.7), and since mouldboard ploughing is often performed at a depth of 40 cm or more (Bazzoffi, 2003). Whilst the long-term effect of tillage is that of smoothing and sculpting the landscape, at field borders, steps and discontinuities are produced that often resemble grassed terraces. This soil removal on hillslope convexities leads to significant and possibly adverse changes in soil properties.

Such changes will affect soil quality and productivity and may also influence water and wind erosion rates by exposing more erodible subsoil (as it often the case in Italy and Greece). Values from extensive surveys in Tuscany (Borselli *et al*., 2002) indicate that tillage erosion is often close to 2 cm yr^{-1} with peaks in convex spots up to 4 cm yr^{-1}.

Sediment transport is more rapid using modern heavy machinery than with primitive ploughs, and it is clear that tillage erosion may have been responsible for more soil movement in the last few centuries than natural soil creep during the whole of the Holocene. The accumulated effect is often seen in the build-up of soil behind old-field boundaries.

2.1.3.2 Land levelling

Land-levelling, the mechanical translocation of soil by bulldozers to adapt the slope surfaces to mechanised agriculture, is common in many parts of Europe, especially in Italy, where it is extremely widespread in the Apennines and hilly pre-alpine regions. This operation is performed to clear shrubs in view of the cultivation of marginal lands and before the plantation of modern specialized orchards, vineyards and olive groves. Land levelling is generally followed by deep ploughing to about 1m depth to ensure a sufficient depth of rootable soil. Recently P. Bazzoffi (pers.com.) estimated that in Italy the area highly prone to risk of land levelling is about 10% of the area under permanent crops. After levelling, land is in a vulnerable condition and a few storms can easily cause severe soil losses. Bazzoffi *et al*. (1989) measured 454 t $ha^{-1}yr^{-1}$ of water erosion with the formation of a gully after six rainfall events of medium intensity.

During the late 1970s in Norway, extensive land levelling was stimulated by subsidies. This led to a two- to three-fold increase in soil erosion. The increase was especially high when former ravine landscapes used for pasture were levelled and turned into arable land that was ploughed in autumn. The clearly visible erosion and increasing negative offsite effects on water quality, together with overproduction, put an end to the subsidies for land levelling, but not before 13% of the agricultural area had been levelled with the support of these subsidies. The most visible effect was erosion caused by concentrated flow, including severe 'gullying' resulting from reduced infiltration, longer slopes and inadequate measures to handle concentrated flow. Now, land levelling is not allowed without special permission.

2.1.3.3 Soil loss by harvesting root crops

It is well known that soil particles attached to the surface of root crops, for example potatoes, carrots, beet root etc., can result in significant removal of soil from cultivated fields. In particular this is a problem in areas growing early potatoes because harvesting normally takes place when the topsoil is moist or very moist and soil readily adheres to the surface of the potatoes. However, preparation of the crop for marketing usually involves cleaning (washing) and removing the soil but returning it to the fields from where it came is not always advised, because of the possibility of spreading disease.

2.1.3.4 Erosion by trampling and burrowing animals

The surface pressure exerted by the hooves of grazing animals can destroy vegetation leaving a bare soil surface vulnerable to erosion by water. High stocking densities cause destruction of vegetation cover and cause erosion of the type reported by Evans (1977, 1997) in England and Wales and E. Bruneau (pers comm.) in Scotland. It is also a problem elsewhere in Europe where livestock dominate the agricultural sector.

Burrowing animals, such as rabbits, moles and ground squirrels, can also initiate or exacerbate soil erosion. Surface water entering burrows then erodes the unprotected sidewalls and floor of the tunnel, in extreme cases causing collapse. The resulting indentations on the surface then act as drainage channels for the removal of surface runoff and normal fluvial processes continue further erosion of the land.

2.1.4 Soil erosion by wind

Wind erosion tends to be less well researched in Europe, probably because it is less extensive than soil erosion by water. In northern Europe, the problem is only severe on light sandy soils when they are in a dry condition (Figure 2.8). Wind erosion also occurs on silty and clayey soils in the drier parts of southern Europe (Figure 2.9).

Figure 2.8 Wind-blown soil in N Germany (Schäfer et al., 2003)

Erosion of soils by wind has been recognised for millennia. Archaeological evidence reveals that wind erosion, exacerbated by cultivation and over-grazing, has occurred since Neolithic times. Serious wind erosion was experienced in the Veluwe in the Netherlands in the 17^{th} century and the middle of the 18^{th} century. Von Linnaeus described wind erosion in Scania at a time when deforestation and cultivation of new land by an expanding population had put the agricultural system in crisis (Warren, 2002).

Gross (2002) summarises the occurrence of wind erosion in Europe and cites Oldeman *et al* (1991) as the main source of reference. The most extensive and most severe wind erosion is mapped in southeastern Europe - in Romania, the Ukraine and Russia. Moderate wind erosion has also been reported from the Czech Republic and parts of France, the UK and Hungary. Wind erosion is also an important problem in Iceland and the Quaternary deposits of the north European plain, which extends from Belgium to beyond Poland (see Figure 2.22).

Figure 2.9 Dust rising during tillage in Aragon NE Spain (Riksen et al., 2002)

Recent investigations by the EU-projects WEELS and WELSONS suggest that the area affected is probably much larger than previously thought (Gross, 2002). The WEELS project has estimated rates of 21 t ha^{-1} yr^{-1} over a 30-year period in part of East Anglia, a rate that compares closely with estimated rates of water erosion in other parts of England.

Gross (2002) describes methods for estimating the distribution and severity of wind erosion but there are major difficulties in applying current models at European level.

2.1.5 Coastal erosion

In many areas, coastal erosion causes severe damage and high costs for society and individuals. Commonly, there is no problem until structures are built within the impact zone of storm surges or close to soft rock cliffs. The combined effect of infrastructure development and the erection of defences to protect them have created, in many areas, a narrow coastal zone. This is especially true in low-lying areas where a wide intertidal area, which adjusts to the

changes in sea level, storms and tides, is replaced by an inflexible barrier that does not.
As sea levels rise and storms increase in response to climate change, problems of coastal erosion and the risk of flooding increase. This may be critical in areas where seafront development, enclosure by dykes, embankment of tidal areas and seaward coastal defences has taken place. The difficulties of protecting this narrow inflexible barrier are increased where the natural resilience of the coast is lost as sedimentary systems and eroding cliffs are destroyed or stabilised.

Another important factor affecting natural coasts is the capacity of rivers to supply new sediments to the shoreline. In the past an important source of material for habitat creation in estuaries and deltas was provided by erosion in the catchments and the transport of sediment to the coast along rivers. Today river canalisation, dams, irrigation works and activities in the river catchments themselves have resulted in a dramatic reduction in sediment availability on the coast. In extreme cases, this can result in micro-tidal river deltas and macro/meso-tidal estuaries moving from accreting systems into eroding ones.

Relative sea level change is another key issue. Nordic countries benefit from post-glacial isostatic uplift, which helps to counteract the general trend of rising global sea level, and in many areas the land is actually rising faster than sea levels. In other parts of Europe, where the land is sinking, relative sea level rise is made worse.

Scientific studies – including those of the UN Intergovernmental Panel on Climate Change (IPCC) – indicate that the current rise of sea level will accelerate over the next decades, leading to considerably higher sea levels overall. In combination with an increasing frequency of exceptional storms and storm surges, the risks and the impacts of erosion and flooding are expected to increase considerably during the 21st century.

The combined impact of all these factors has been described as effecting a ‘coastal squeeze’. This is the process whereby intertidal land is continually removed from the influence of the sea through enclosure, which causes the direct loss of habitat. In areas where relative sea level is rising or where sediment availability is reduced, there is a further squeeze resulting from a steepening beach profile and foreshortening of the seaward zones.

Coastal erosion is well documented by civil authorities in the Member States and is not generally affected by land use or management. Furthermore, coastal erosion is normally taking place on such a large scale that it is hard to formulate any component of a Directive on Soil Protection that would alleviate or change it.

However, a programme EUROSION (www.eurosion.org) is compiling a database on erosion phenomena at local level, on the nature of coasts – sandy, rocky, with or without cliffs, etc. There are also other European projects such as ROCC (Risk of cliff collapse) 1998-2001, INTERREG II, and PROTECT (Prediction of the erosion of cliffs) 2001-2004 - 5 PCRD.

2.1.5.1 National coastal erosion

In Sweden, coastal erosion occurs mostly in the S and SW of the country in areas where sand, silt and till form the coast. In some places 300m of land has been lost in the past 150 years. However, the length of coastline subject to erosion is very small in comparison with the coastline of Sweden that totals 7000 km. Much of the coastline in Poland is considered eroded, with losses of up to 1m per year. Records, started in Roman times, reveal that the North Sea coast of Holderness in Eastern England has been severely eroded, with losses of land several km wide in places.

However, even accelerated erosion of coastlines results in deposition of the eroded material elsewhere. In the case of Eastern England, a large spit has formed across the Humber estuary comprising material from the eroded coast further north. Thus the erosive process does not always result in a negative effect.

2.1.6 Floods and Landslides

Floods and landslides are mainly natural hazards intimately related to soil and land management. In Europe, landslides form an increasing threat due to population growth, increasing summer and winter tourism, and to intensive land use and climatic change.

Floods and landslides are not a threat to soils in the same manner as soil erosion, but they can result in part from soil not performing its role of controlling the water cycle due to compaction or sealing. The result of development increases the incidence of floods and landslides by changing their topographic, soil, and vegetation controls.

Consequently, there is an increasing concern because the spread of roads, development of leisure and recreational areas, changes in agricultural practices and forest management, are having an adverse effect. Additionally, climate change can similarly increase the incidence of floods and landslides. Landslide hazard has clearly a European dimension, and concerns mountain as well as coastal environments (Maquaire and Malet, pers. comm.).

2.1.6.1 Floods and mudflows

Local flash flooding caused by intensive short duration rainfall (Figure 2.10), is often exacerbated by changing soil characteristics. Land management practices can lead to soil surface sealing and compaction, which are reducing infiltration capacity and hydraulic conductivity, leading to increased surface runoff. Furthermore, soil erosion itself leads to a thinner soil layer, which in the long term reduces the soil water storage capacity and thus causes increased surface and subsurface runoff.

However, many of the floods occurring cannot be reduced by changing land management practices. Long duration rainfalls or short periods of heavy rainfall will most likely always produce extreme discharges. Adaptation strategies should be further developed to improve forecasting and warning techniques, as well as spatial planning to move vulnerable land use types out of flood prone areas. Also, increased retention capacity could be created by enlargement of floodplains, building retention polders or water reservoirs.

These adaptation strategies should be evaluated at the scale of an entire river basin, as is done with the LISFLOOD model developed by the Joint Research Centre, Ispra (http://natural-hazards.jrc.it/floods/Prevention/). During the development of these adaptation strategies, it should be taken into account that extreme flood magnitudes and frequencies are likely to increase as a consequence of climate change.

Figure 2.10 Flooding in the Po, October 2000 (Photograph by Ad de Roo)

Several initiatives exist on floods in Europe. The Dartmouth Flood Observatory (http://www.dartmouth.edu/~floods/) has created overview maps of floods mapped using satellite data, including European floods. The European Commission's Concerted Actions RIBAMOD (River Basin Modelling), MITCH (MITigation of Climate induced natural Hazards) and ACTIF (Achieving Technological Innovation in Flood Forecasting) are trying to translate advances in knowledge into practical benefits across Europe. A DG RTD funded research project such as EFFS (European Flood Forecasting System) have paved the way for the development of a European Flood Alert System at the Joint Research Centre (http://natural-hazards.jrc.it/floods/Preparedness/), which aims at providing medium-range flood alerts 3-10 days in advance. The FLOODGEN project (King, 2001) was another research project that studied flooding at European level.

In France, a national mapping programme has resulted in an inventory of mudflows based on insurance claims filed for natural catastrophes between 1985 and 1995 (Figure 2.11).

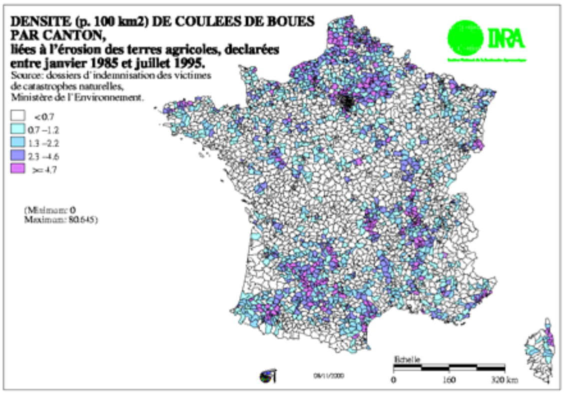


Figure 2.11 Map of mudflows in France (1985-1995)

2.1.6.2 Landslides

Landslide is a generic term for all forms of slope movement. The form and scope of slides, falls and debris flows are very diverse because of the multiplicity of initiating mechanisms. These mechanisms include erosion, deformation, dissolution and rupture under static or dynamic load, combined with topography (height and gradient of the slope etc.); lithology (characteristic and susceptibility of material – solid, plastic, viscous, liquid); structure (overhang, fracturing, superimposed layers); characteristics of the water table; and relative proportion of water to solid material (Maquaire and Ph Malet, 2003).

On the basis of the velocity of movement, which indirectly expresses risk level because it determines the possibility of avoidance at the onset of the event, two types of landslides can be distinguished:

- slow-moving landslides *(rotational, translational*) corresponding to mass displacements of more or less coherent soil, with limited internal deformation.;
- fast-moving landslides that may accelerate suddenly. They can be subdivided into two groups, depending on whether the material is propagated as more or less individual particles (*rockfall, rock avalanche*) or as reworked mass (*mudslides, earthflows, debris flows)* – see Figure 2.12.

Landslides are associated with a gravitational displacement of mass of destabilized earth and/or rock under the effect of natural processes (snowmelt, heavy rainfall, earthquake, action of the sea, etc.) or to human activity (terracing, mining, deforestation, exploitation of materials or water tables). Causes are generally multiple, a combination or superimposition of several factors, including predisposition and triggering factors such as rainfall or earthquake.

It is now increasingly clear that landslide hazard assessment forms an important part of land use planning in mountain and coastal environments. Authorities with the responsibility for protecting livelihood and infrastructure from the threat of landslides are particularly concerned with four critical aspects: (1) spatial distribution of landslides, (2) understanding of their mechanisms, (3) predicting (short- and long-term) occurrence and impact, and (4) mitigating impacts.

There is not much accurate data on landslides in Europe at a sufficient spatial and temporal scale, mainly because of the variety of landslides types with drastically different behaviour. Landslide management relies heavily on using the information available and on previous experience. Current knowledge must be extended by analysis and interpretation of well-documented case histories, preferably those from instrumented sites and catchments.

In areas with highly erodible soils, steep slopes and intense precipitation, such as the Alpine, Scandinavian and the Mediterranean regions, landslides are an increasing problem. They pose an increasing threat caused by population growth, increasing tourism, intensive land utilisation and climatic change (Maquaire and Ph Malet, 2003, Unpub.).

Figure 2.12 Debris flow, Cairngorms, Scotland UK following intense rain, 30 July 2002 (Lilley et al.) (Photograph by P. Moore)

Recent events have shown that landslides can be very destructive, e.g. Sarno, Italy, May 1998, 160 people killed; Gondo, Switzerland, October 2000, 13 died. In several European countries, this problem is being increasingly recognised and landslides are one of the primary hazards being mapped by the different civil authorities.

In Italy for example, more than 50% of the territory has been classified as having a high or very high hydro-geological risk, affecting 60% of the population or 34 million inhabitants. It has been estimated that more than 15% of the territory and 26% of the population are subjected to a high risk.

In Scandinavia, the post-glacial isostatic readjustment of the land during the past 10,000 years has raised some areas of the sea floor above the current sea level. The result is that today areas covered by marine clays suffer from landslides because of these clays are often unstable and easily eroded by rivers and streams.

Landslides associated with levelling of land for mechanised agriculture are quite common due to a general destabilisation of the levelled areas with contiguous surfaces upslope. Losses >500 t $ha^{-1}yr^{-1}$ due to all the known forms of soil erosion acting simultaneously, e.g. rills, gullies, piping and landslides have been estimated (Bazzoffi *et al.*, 1989; Chisci, 1986).

2.1.7 Subsurface erosion by groundwater

Subsurface runoff is generally slower than its erosive counterpart over the land surface, and can lead to water saturation of the upper part of the soil profile. It can cause gravity-induced mass movement on hill slopes (e.g. landslides) and is also responsible for the translocation (migration) of dissolved products of chemical weathering down a hill slope.

Calcareous rocks, such as chalk and limestone are subject to a distinct type of chemical weathering (Holmes, 1965; Monkhouse, 1968). Rainwater containing carbon dioxide slowly dissolves calcium carbonate, the principle mineral of chalk and limestone, which is removed as calcium bicarbonate. In addition, water passing through soil may also pick up additional carbon dioxide, generated by plant roots, bacteria, and other soil-dwelling organisms.

Because of the great permeability of these calcareous rocks, due to their jointing, underground water has played a major part in subsurface chemical weathering and erosion, producing intricate cave systems, distinct surface features, such as ‘swallow holes’ or ‘sinkholes’, depressions caused by the coalescence of several of these holes, dry valleys and gorges. The extent of porous calcareous rocks, e.g. limestone and chalk, can be identified from the European Soil Map highlighting areas where problems at the surface could occur.

Table 2.3. Types of erosion: occurrence at national level.

Country	Rill & Interrill	Gully	Snow melt	Bank	Tillage	Animals	Wind	Land-slides	Ground water	Coastal
Albania	XX	XX	X	XX	X	XX	?	XX	X	X
Austria	XX	X	XX	XX	X	N	?	XX	N	N
Belgium	XX	X	N	X	X	N	X	X	N	X
Bosnia Herzegovina	XX	XX	X	XX	X	X	X	X	X	N
Bulgaria	XX	XX	XX	X	X	X	X	X	?	N
Croatia	XX	XX	X	XX	XX	X	X	XX	X	X
Cyprus	XX	XX	X	X	XX	?	?	X	X	X
Czech Rep.	XXX	X	X	X	X	?	?	X	?	N
Denmark	XXX	X	N	X	X	N	XX	?	N	X
Estonia	XX	N	N	?	?	X	X	N	N	?
Finland	X	N	XX	X	?	X	N	N	N	N
France	XXX	XX	XX	XX		X	X	XX	X	X
Germany	XX	X	X	X	X	?	XX	XX	X	N
Greece	X	XXX	X	XX	X	XX	X	X	X	X
Hungary	XX	XX	X	X	XX	X	X	X	N	N
Iceland	X	XX	XXX	XX	N	N	X	XX	N	X
Ireland	X	N	N	XX	X	XX	N	N	N	X
Italy	XXX	XX	X	X	XX	?	X	XX	X	X
Latvia	XX	N	N	?	?	X	?	N	N	X
Lithuania	XX	N	N	?	?	X	?	N	N	?
Luxembourg	X	N	N	X	N	N	N	?	?	N
Macedonia FYROM	XX	XX	X	XX	X	X	?	X	X	N
Malta	X	XX	N	N	N	X	N	X	X	X
Montenegro	XX	XX	X	XX	X	XX	?	X	X	X
Norway	X	X	XXX	X	N	X	X	XX	N	X
Poland	XX	X	X	X	?	?	XX	XX	N	N
Portugal	XX	XXX	N	X	X	?	?	X	?	?
Romania	XX	XX	X	XX	X	X	?	X	?	N
Serbia	XX	XX	X	XX	X	X	X	X	X	N
Slovakia	XX	X	?	X	?	?	?	X	?	N
Slovenia	XX	XX	X	X	XX	?	?	XX	X	N
Spain	XX	XXX	X	X	X	X	X	XX	X	X
Sweden	X	XX	X	XX	N	X	X	XXX	X	XX
Switzerland	X	X	XXX	XX	?	X	?	XX	N	N
The Netherlands	X	N	N	?	N	?	X	N	N	?
United Kingdom	XX	X	X	XX	X	XX	X	X	X	X

Legend	XXX	Predominant
	XX	Important
	X	Minor
	?	Not know
	N	Not found

2.2 Soil erosion assessment methodologies

For assessing soil erosion risk, various approaches can be adopted. A distinction can be made between *expert*-based and *model*-based methods. Van der Knijff *et al.* (1999, 2002) describe in detail the main aspects of these two approaches. In addition, there have been many recently implemented erosion risk assessment programmes/projects to assess erosion at European and national scales. The following sections briefly review the most relevant examples.

2.2.1 European Scale

Gobin *et al.* (2002) have described in detail recent attempts to assess soil erosion at European level in a spatial context. Drawing on Gobin *et al.*'s work, the following sections briefly review these assessments highlighting their strengths and weaknesses.

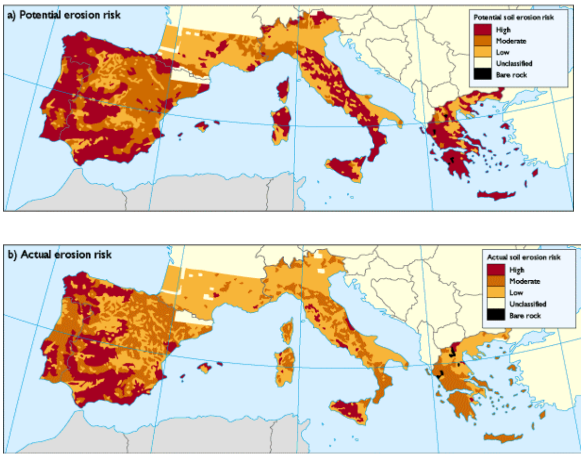


Figure 2.13 Potential versus actual erosion risk as estimated by the CORINE methodology (CORINE, 1992).

2.2.1.1 CORINE Approach

The CORINE methodology is based on the Universal Soil Loss Equation (USLE), a well-established technology (Wischmeier and Smith, 1978) that has been very widely used, both in North America and elsewhere in the world. It is an expert-based approach using a factorial method applied on a 1km x 1km grid. Conventional wisdom suggests that the method correctly identifies areas of the Mediterranean that have the highest risk of erosion (Figure 2.13).

As a product of its time, it has considerable merit, and could be improved with the more detailed land cover classification now available. The CORINE report (CORINE, 1992) concedes that 'future development of this work would allow more sophisticated models of soil erosion to be used and improving the factors used in the procedure, notably in the calculation of erosivity and soil erodibility, and in the classification of land cover.'

However, the CORINE approach has the limitation that it is restricted to southern Europe, whereas present needs for erosion data apply to the whole of the European area. Furthermore, CORINE assessments are not validated and show significant differences from risks assessed by other methods.

2.2.1.2 RIVM Approach

As part of a major report on strategies for the European Environment (RIVM, 1992), a baseline assessment of water erosion was prepared in 1990. This assessment of current risk (Figure 2.14) was combined with climate and economic projections within the framework of the IMAGE 2 model to generate scenario projections for 2010 and 2050. This approach, also expert-based, has the advantage of making explicit scenario projections, a feature lacking in other approaches. However, it is currently only available at 50km resolution, so that it cannot readily be interpreted at sub-national scales.

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

The RIVM soil erosion model is a factor model, like CORINE, but in many ways has similarities to the Universal Soil Loss Equation (USLE) model. The RIVM method exploits the potential, inherent in any physically based or factor based assessment, of providing scenario analysis, through the inclusion of two dynamic components, the monthly rainfall totals (affecting erosivity) and land cover (affecting the assessed actual erosion) for Europe.

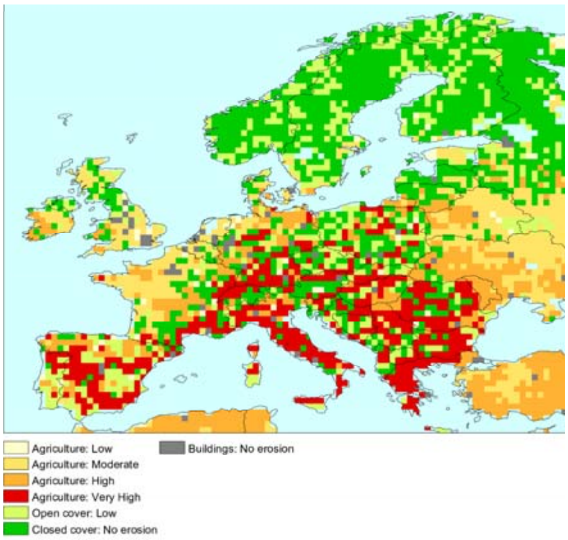


Figure 2.14 Water erosion vulnerability for 2050, according to the baseline scenario by RIVM (RIVM, 1992).

However, neither the 50km resolution nor the implementation of the factors contributing to erosion is now seen as providing a 'state-of-the-art' assessment. In simple terms, it is too crude for supporting the current policy making process.

2.2.1.3 GLASOD approach

The main objective of the GLASOD project – Global Assessment of Soil Degradation - was to bring to the attention of decision makers the risks resulting from inappropriate land and soil management to the global well being. Although its aims were limited, GLASOD is the only approach that to date has been applied world–wide.

It is based on responses to a questionnaire sent to recognised experts in all countries (Oldeman *et al.*, 1991) and thus depends on a set of expert judgements. Its weakness is that there was very little control or objectivity in comparing the standards applied by the different experts in the different areas. The information and data on soil erosion and physical degradation in the Dobris assessment (EEA, 1995) are based on an updated version of the European part of the GLASOD map.

For this update, questionnaires (van Lynden, 1994) were sent to scientific teams in each European country for comments and additions to the original GLASOD assessment. Not all countries completed and returned the questionnaires and the degree of detail of the information received varies greatly. It must also be noted that the scale of the maps (1:10,000,000) limits the detail that can be shown, providing a minimum resolution of approximately 10 km.

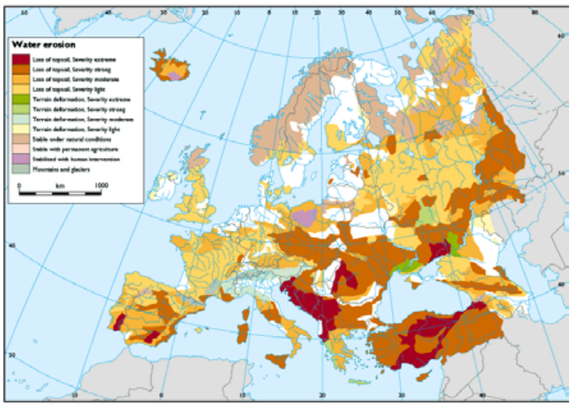


Figure 2.15 Water erosion of soils in Europe according to the GLASOD approach (Van Lynden, 1994).

The GLASOD map (Figure 2.15) identifies areas with a subjectively similar severity of erosion risk, irrespective of the conditions that would produce this erosion. Thus it too is an example of the expert-based approach. For water erosion, areas are grouped together primarily on the basis of the severity of topsoil loss. It is clear from comparison with other maps that there are substantial differences between the objective standards applied in different regions, although parts of southern Spain, Sicily and Sardinia are described as areas of high erosion risk in all assessments.

The results indicate that water erosion is the dominant degradation process in Europe, and that overall less than 10% is considered to be strongly or severely degraded. However, in specific regions the proportion of degraded land is much larger.

The GLASOD map is still widely used and quoted, although its authors and critics alike recognise the need for a more detailed and more quantitative assessment. A major drawback is that it is not possible to make truly objective comparisons between and within areas.

Regarding other assessment programmes at European scale, a study was carried out in order to assess the reliability of the GLASOD map to characterise the soil erosion process in Spain (Sánchez *et al*., 2001). Two maps were used to perform the comparative analysis. On the one hand, the 1:5,000,000 scale erosion map from the CORINE project (CORINE, 1992). On the other hand, the erosion map at the scale of 1:2,000,000 compiled by ICONA (MOPT, 1991). The latter synthesises information from studies dealing with soil erosion of watersheds at the scale of 1:400,000.

The comparison between the GLASOD map and the erosion risk map of the CORINE project revealed differences in spatially assessing water erosion in Spain. Such differences were accentuated when comparing the GLASOD map with information synthesised from maps prepared at a more detailed scale (ICONA map). It was concluded that for most of Spain the GLASOD map did not correctly assess water erosion.

Given that there are now improved methodologies, based on more quantitative analysis of particular problems, such as soil erosion, it is unquestionably timely to abandon the GLASOD approach, whilst not rejecting the data from local erosion sites to calibrate more quantitative models.

2.2.1.4 ‘Hot-Spot approach of EEA

An analysis and mapping of soil problem areas (Hot Spots) in Europe was published in the EEA-UNEP joint message on soil (EEA, 2000). The map (Figure 2.16) produced has been developed from earlier maps (Favis-Mortlock and Boardman, 1999; de Ploey, 1989), based on local empirical data, using expert knowledge to identify broad zones for which the erosion processes are broadly similar. Hot Spots are then highlighted within each zone, and associated with the best estimates, from the literature, of rates of erosion.

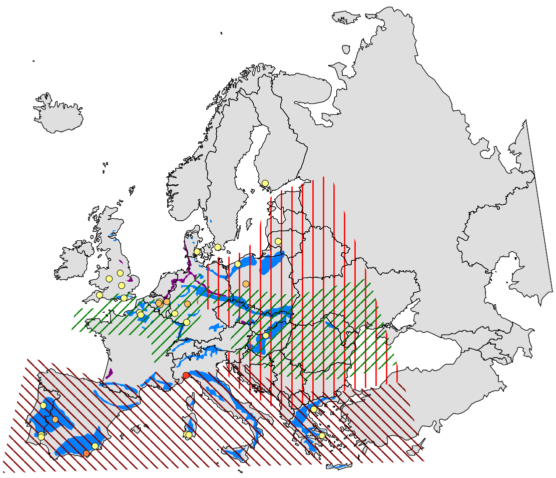


Figure 2.16 Hot Spots Map for water and wind erosion (EEA, 2000).

The intention is to identify areas of current erosion risk, under present land use and climate, as opposed to either evidence of past erosion, or of the potential for erosion under some hypothetical conditions. The data provide general or particular information about water erosion for approximately 60 sites or small regions across Europe, with measured erosion rates, which could be placed on the map at 35 sites. Measurements are taken from erosion plots, fields and small catchments.

Three groups are identified: Eastern Europe, the loess belt and southern Europe. This primarily represents different land use history, parent materials and climate respectively (Figure 2.16). Although there are advantages in concentrating on measured empirical data where this is abundant, and interpolation can be meaningful, the sporadic distribution and episodic occurrence of soil erosion makes this approach ill-suited. The most important information contained in the Hot Spots map probably lies in the considerable experience of its compilers, which it is hard to document or to quantify.

Within the area of overlap with the CORINE map in southern Europe, the Hot Spots map inherits from the De Ploey map a greater concentration on parent material as a key factor in localising significant erosion. It is also clear that sites of high erosion risk identified on this map are definitely areas of high impact, but that there is no reliable way to extrapolate these local results, even to surrounding areas. The main limitation here is that the spatial representation is much too coarse to be of practical use to policy makers.

2.2.1.5 USLE approach

The well-known Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) has been used for many research studies on soil erosion. The USLE is a simple empirical model, based on regression analyses of rates of soil loss from erosion plots in the USA. The model is designed to estimate long-term annual erosion rates on agricultural fields.

Although the equation has many shortcomings and limitations, it is widely used because of its relative simplicity and robustness (Desmet and Govers, 1996). It also represents a standardised approach and a revised version is now available (Renard *et al.*, 1997).

The application of the USLE in Europe by Van der Knijff *et al.* (2000) is a first attempt to quantify soil erosion by rill and inter-rill erosion, based on a 1km x 1km data set for all-Europe (Figure 2.17). The estimates of sediment loss, based on the European Soil Map (CEC, 1985), are not validated in most cases but relative differences are thought to be real in broad terms, e.g. between northern and southern Europe. It is a classic example of the model-based approach.

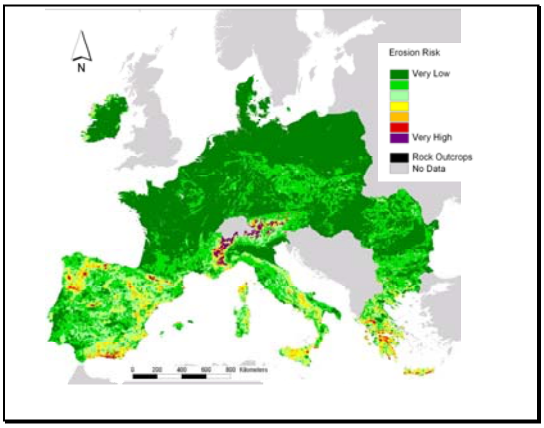


Figure 2.17 Actual soil erosion risk in Europe.

Potential erosion risk was also estimated by re-running the USLE assuming a total absence of vegetative cover. The resulting potential erosion risk map is shown in Figure 2.18 and represents the most extreme case for any area. One of the main advantages of the USLE model is that it is well-known and has been applied widely at different scales.

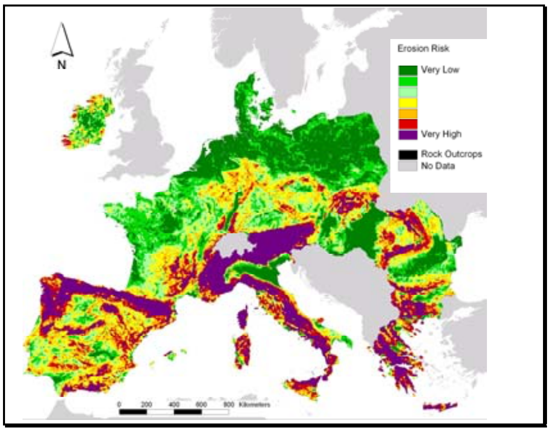


Figure 2.18 Potential soil erosion risk in Europe.

Compared with the expert-based methods described above, it probably gives the most objective information about the European-wide distribution of soil erosion risk. Its value lies in the fact that the estimates of erosion risk are based on standardised, harmonised data sets for the whole of Europe and the model produces quantitative output as actual sediment loss, for example t $ha^{-1}yr^{-1}$, which is important for policy-making.

However, in this study for Europe, a quantitative assessment may not be considered appropriate in view of the quality and resolution of the available data. Furthermore, it is not appropriate to use the maps to predict soil losses on any individual agricultural parcel, nor to predict soil loss for any individual year. Only rill- and inter-rill soil erosion by water flow is taken into account and deposition is not included. Thus, the maps should not be used to predict the occurrence of mass movements like landslides.

The effect of management practice is nearly impossible to assess at the small scale used here. Compared with other models, the USLE is one of the least data demanding erosion models that has been developed. However, there are still some uncertainties associated with the various data and it should be appreciated that, in many cases, management practice may be one of the most important factors affecting erosion. In conclusion, the results of this study may be considered as a further step towards a harmonised soil erosion risk map of Europe, though some major improvements could be achieved by using a more precise elevation, rainfall, soil and vegetation cover data sets.

2.2.1.6 INRA approach

This approach, elaborated by INRA (Institut National de la Recherche Agronomique, France), is an intermediate step towards ‘state-of-the-art’ erosion modelling at the European scale, subsequent to the USLE approach (Van der Knijff *et al.*, 2000) and prior to the initiation of the PESERA project.

Figure 2.19 shows the annual soil erosion risk for Europe, based on empirical rules that combine data on land use from the CORINE Land Cover database, soil crusting susceptibility, soil erodibility (determined by pedotransfer rules from the European Soil Database at scale 1:1,000,000), relief (1km x 1km resolution) and meteorological data (Le Bissonnais and Daroussin, 2001).

The INRA approach is based on modelling using an hierarchical multi–factorial classification designed to assess average seasonal erosion risk at regional scale.

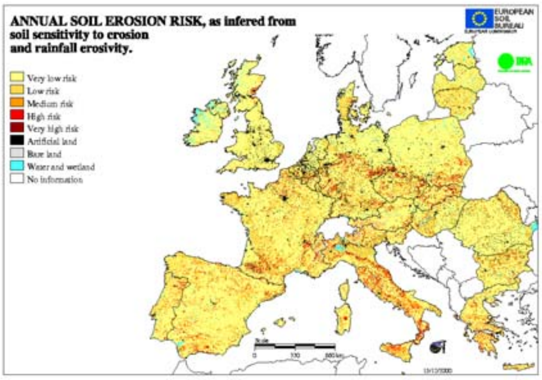


Figure 2.19 Annual Soil Erosion risk in Europe

The model is based on the premise that soil erosion occurs when water, that cannot infiltrate the soil, becomes surface runoff and moves soil downslope. A soil becomes unable to absorb more water either when the rainfall intensity exceeds surface infiltration capacity (Hortonian runoff), or when the rain falls onto a saturated surface because of antecedent wet conditions or an underlying water table (saturation runoff).

The INRA approach is simple and versatile and, as with the USLE, it does not require parameters that are not available at national scale. It probably gives more precise and accurate results than the CORINE erosion model but the disadvantage in the INRA model is that it is essentially qualitative and the final information is provided on a 5-class scale of risk, not linked to quantitative values of erosion, nor is it possible to assess the errors associated with the results.

2.2.1.7 PESERA approach

The Pan-European Soil Erosion Risk Assessment - PESERA - approach (Gobin *et al.*, 1999) uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe. The conceptual basis of the PESERA model can also be extended to include estimates of tillage and wind erosion. Preliminary results for PESERA (Figure 2.20) are currently being validated using erosion measurements from several European countries (Van Rompaey *et al.*, 2003).

Thus PESERA, being a quantitative model, has the potential for dealing with Pan-European applications, more easily than an expert-based approach, and forms a basis for replacing estimates from CORINE, without making excessive data demands. However, further development of the model and a substantial amount of calibration and validation work are essential if PESERA is to become operational. Preliminary results suggest that, although the model can be applied at regional, national and European levels, low resolution and poor quality input data cause errors and uncertainties (Kirkby *et al.*, 2004).

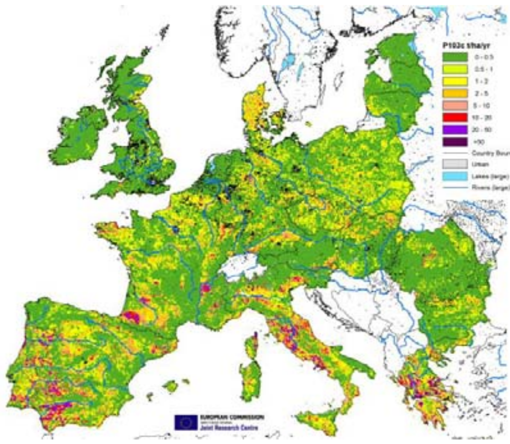


Figure 2.20 PESERA: Estimated annual soil loss by water erosion in Europe.(S.P.I.04.73).

Soil erosion indicators developed from a physically based model will not only provide information on the state of soil erosion at any given time, but also assist in understanding the links between different factors causing erosion. Another advantage for policy-making is that scenario analysis for different land use and climate changes is possible using PESERA. This will enable the impacts of agricultural policy, and land use and climate changes to be assessed and monitored across Europe.

At the European scale, the initial need is seen to be the development of an effective tool for erosion risk assessment, and to offer it as a component of decision support systems that can explore the implications of policy options. The PESERA model itself incorporates as many of the physical parameters as can be quantified, but it is important for policy making to assess the impact of the physical soil loss.

2.2.2 National Scale

Soil erosion estimates have been made in several EU and Candidate Countries, but these are based mostly on national systems and the results are not yet harmonised. Therefore, combining them at a European level will not provide a basis for policy making. However, the results of national erosion studies can be invaluable for assessing the performance of a model such as PESERA designed for application at European level.

Thus, some examples from Austria, Belgium, Bulgaria, France, Germany, Hungary, Italy, Spain and Switzerland are briefly described in the following sections.

2.2.2.1 Austria

Figure 2.21 shows an evaluation of soil erosion risk for Austrian communities, based on a classification using the USLE approach. Slope information was collected from a DEM with a grid resolution of 250 m. Information on land use was obtained by merging the CORINE data set with exact land use data on a community level.

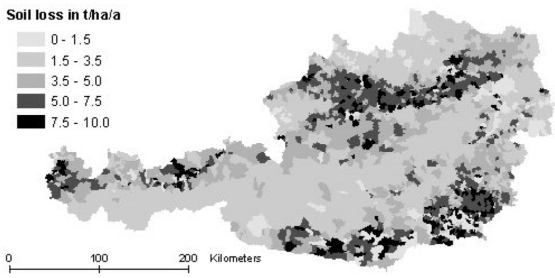


Figure 2.21 Soil erosion by water from arable and pasture land in Austria, based on USLE approach.

Soil information was obtained from the Austrian mapping system at the scale of 1:50,000. Rainfall was obtained from mean annual rainfall data on community level using a transfer function to erosivity (Strauss *et al.*, 1994).

As a result, Figure 2.21 does not quantify total soil losses within a community as these depend not only on the extent of agricultural land but also on the proportion of forests and paved areas. Protected areas, such as the terraced landscape of the Wachau region in the Danube valley are not included in the analysis and problems with data quality in Alpine regions are even more important.

2.2.2.2 Belgium

Soil erosion in Belgium mainly occurs in the loess belt, which stretches from east to west across the central part of the country, i.e. in the south of Flanders, and in the north of Wallonia. Verstraeten and Poesen (1999) questioned 123 municipalities in southern Flanders about the occurrence of muddy floods and 53 indicated there are serious soil erosion problems on the agricultural fields in these municipalities.

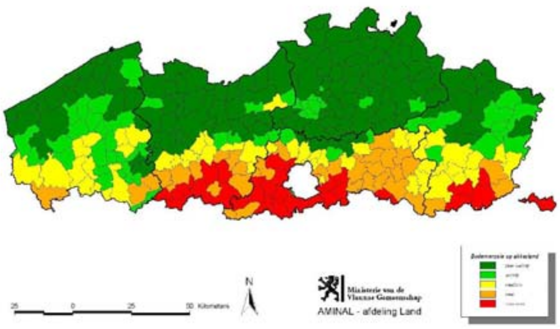


Figure 2.22 Actual Soil erosion risk (from water and tillage erosion) on arable land at municipality level in Belgium (Vandekerckhove et al., 2003)

The Flemish administration based its erosion policy on a map with mean annual soil erosion values (t ha^{-1} yr^{-1}) for pixels of 20m x 20m, which can be aggregated at the field parcel level or at the municipality level (Van Rompaey *et al.*, 2000). Both soil erosion by water and by tillage are considered. For each pixel, the net soil loss rate by water erosion, and the net soil loss or deposition rate by tillage translocation are calculated. Soil loss by water erosion is predicted using the RUSLE, adapted to a two-dimensional landscape by the procedure proposed by Desmet and Govers (1996). The calculation of tillage erosion was based on the work of Govers *et al.* (1994) and Van Muysen *et al.* (2000).

Vanderkerckhove *et al.*, (2003) show soil erosion risk on the basis of municipality (see Figure 2.22).

2.2.2.3 Bulgaria

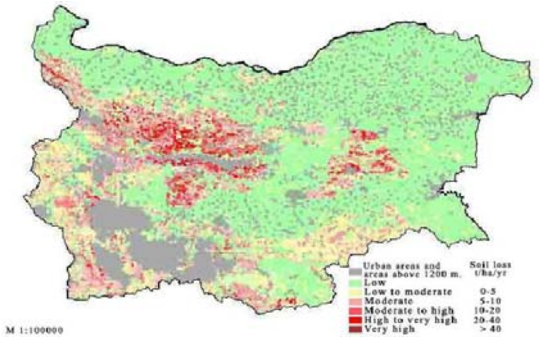


Figure 2.23. Soil erosion risk in Bulgaria, based on the USLE approach (Yordanov, pers. comm.)

The Executive Environment Agency in Bulgaria has produced potential and actual soil erosion risk maps on the basis of the USLE equation, which was adapted for Bulgarian conditions. An example is shown in Figure 2.23.

2.2.2.4 Czech Republic

The map of soil erosion risks in the Czech Republic (Figure 2.24) was drawn using the Universal Soil Loss Equation method (Wischmeier & Smith, 1978) in combination with GIS tools (Dostal *et al.*, 2003).

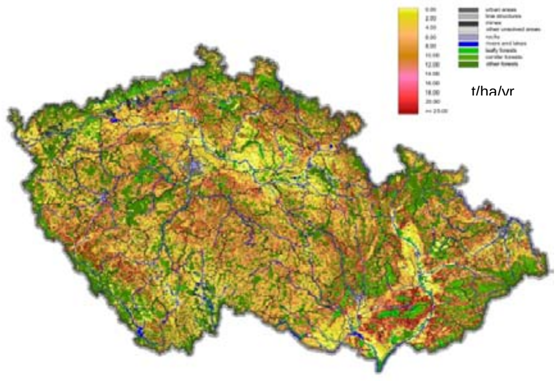


Figure 2.24. Soil loss by erosion in Czech Republic estimated using USLE (Dostal et al., 2003, unpubl.)

The soil categories examined comprise agricultural soils and so-called mixed areas, including mostly agriculturally cultivated soil. The resulting map at 1:200,000 gives numerical estimates of soil loss and sediment transport. The input data are listed in Table 2.4.

2.2.2.5 France

An early version of the PESERA model was applied to appropriate data for France, and a map showing erosion risk (Kirkby and King, 1998) demonstrated the feasibility of this new approach (Figure 2.25a).

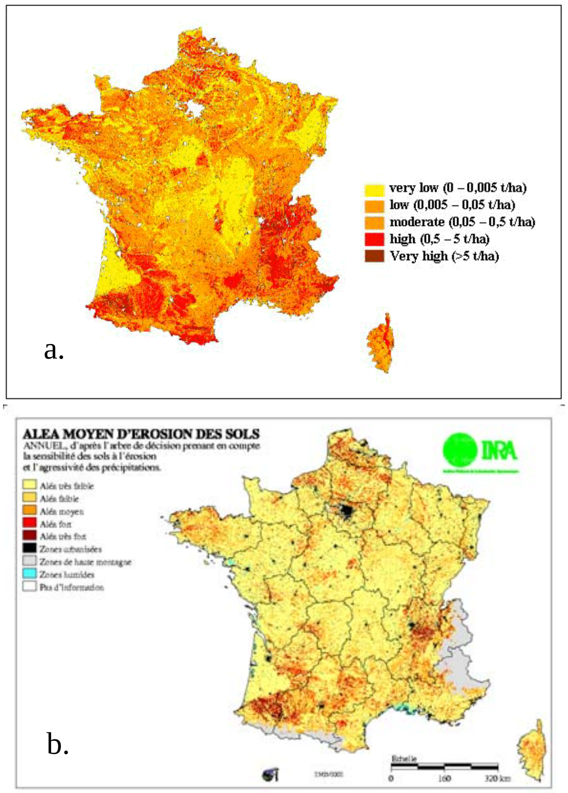


Figure 2.25 Soil erosion risk in France (a) using PESERA and (b) using the INRA approach

INRA Orleans have also produced a map of erosion risk in France (Figure 2.25b) using the methodology described by Le Bissonnais and Daroussin (2001).

2.2.2.6 Germany

Under a programme for soil conservation conducted by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, Hennings (2003) has produced the first draft of a nationwide erosion risk map (Figure 2.26) showing the vulnerability to soil erosion by water as a function of topsoil texture class, rainfall erosivity and slope class. The map is based on the 1:1,000,000 scale soil map of Germany (BÜK 1000) and high-resolution digital elevation data.

Assessments are restricted to arable land and semi–quantitative vulnerability classes range from 'negligible' to 'very high'. The long-term objective is to produce a map showing classes of mean annual soil loss.

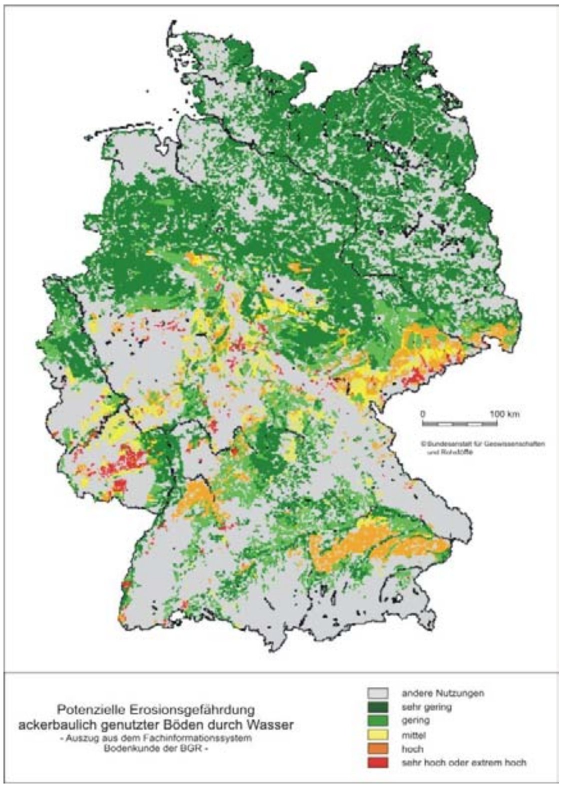


Figure 2.26 Vulnerability to soil erosion by water in Germany (Hennings, 2003)

With respect to soil erosion by wind the German Institute for Standardisation (DIN) is currently preparing a standard in order to determine the soil exposure risk from wind erosion (DIN 1976, Draft standard). Based on this standard, the Geological Survey of Lower Saxony (NLfB) has produced a map of potential wind erosion risk (Figure 2.27).

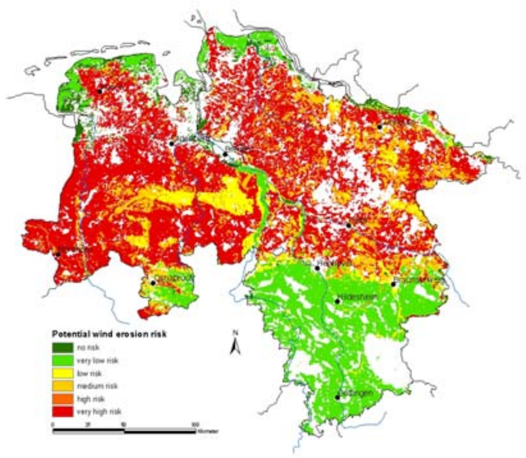


Figure 2.27 Potential soil erosion risk by wind in Lower Saxony, N Germany

2.2.2.7 Hungary

Figure 2.28 shows predicted soil erosion in Hungary, which has been produced using the USLE approach. The data used for this map include erosivity at 1:100,000 scale prepared by Szilárd Thyll (1992); erodibility estimated from an Agrotopography map of Hungary at 1:100,000 scale (1985); a DEM at 1:100,000 (1981); and CORINE Land Cover 100 (1997).

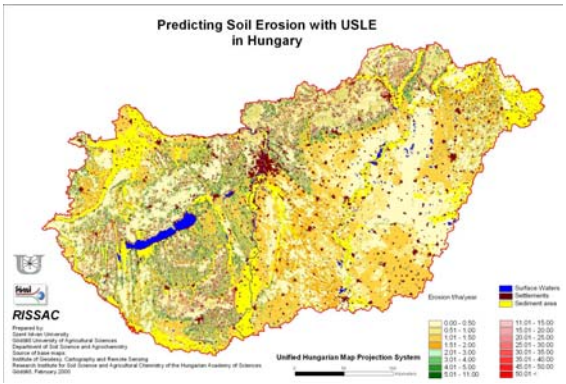


Figure 2.28 Actual Soil erosion risk in Hungary, based on the USLE approach.

The map shows arable lands with a crop cover factor of 0.5, equivalent to continuous cultivation of corn. About 14% of the land belongs to the 2-11 t $ha^{-1}yr^{-1}$ class and 6% suffers severe erosion (>11 t $ha^{-1}yr^{-1}$).

Changing corn to winter wheat, changes the C factor from 0.5 to 0.25 and this increases the areas estimated to suffer <2 t $ha^{-1}yr^{-1}$ by 6 %. It is thought that, in general, this study underestimates erosion in Hungary (Berenyi Uveges, pers. comm.).

2.2.2.8 Italy

Running the USLE model for Italy (Van der Knijff *et al.*, 1999, 2002; Grimm *et al.*, 2003), on the basis of 250-m resolution elevation data instead of the 1km data used for the European scale, gives the distribution of estimated annual erosion risk in Italy shown in Figure 2.29.

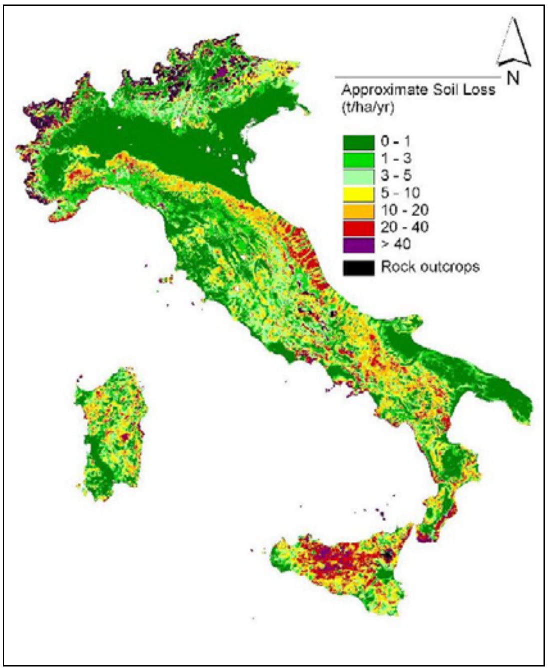


Figure 2.29 Actual Soil erosion risk in Italy, based on the USLE approach.

2.2.2.9 Netherlands

Approximately 4% of the surface of the Netherlands is affected by wind and/or water erosion. Wind erosion involves some 97,000 ha (2.6%) in the Netherlands. The areas mainly occur in:

1. the coastal dunes;
2. sandy arable soils in South-Brabant and the North of Limburg;
3. central sections of the Netherlands (Veluwe)

4. the arable raised peat bog soils in the North (Groningen and Drenthe).

Quantitative data on rates of soil loss are lacking, mainly due to the nature of wind erosion. Economic costs are therefore difficult to estimate. There are no policy instruments to combat wind erosion.

About 61,000 ha. (1.6%) of the country is affected by water erosion, which occurs mainly in the southern part of the province of Limburg.

2.2.2.10 Norway

The Norwegian Institute of Land Inventory (NIJOS) has used its soil information system to produce a potential soil erosion risk map (Nyborg and Klakegg, 1998), assuming conventional autumn ploughing. This map is based on an adjusted version of the USLE approach.

2.2.2.11 Slovakia

Potential soil erosion maps at 1:1,000,000 scale and actual soil erosion at 1:500,000 scale for Slovakia have been produced by Suri *et al.*, and published in the Landscape Atlas of the Slovak Republic (2002, p.286-8). Potential erosion has been estimated using the USLE and actual erosion by a national methodology. The estimated actual soil erosion by water is shown in Figure 2.30.

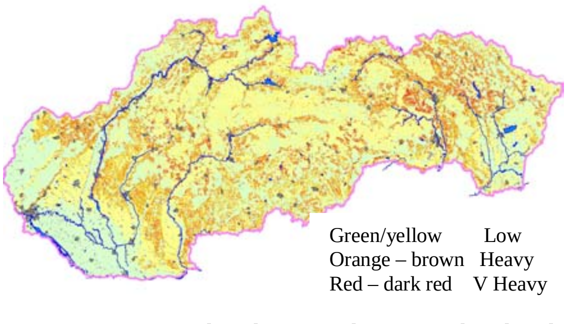


Figure 2.30 Actual Soil erosion losses in the Slovak Republic (M. Suri,T. Cebecauer, E. Fulajtar jun, J. Hofierka, Landscape Atlas Slovak Republic (2002.).

2.2.2.12 Spain

The Spanish National Action Programme on Desertification – PAND (MMA, 2001) has generated a Map of Erosive States at scale 1:1,000,000 for the whole country (Figure 2.31). This map is based on previous work done by the National Institute for the Conservation of Nature-ICONA (1987-1994), which applied a methodology based on the Universal Soil Loss Equation (USLE) to generate maps of the erosive state in each of the main catchments in the country (Ibanez *et al.*, 1999).

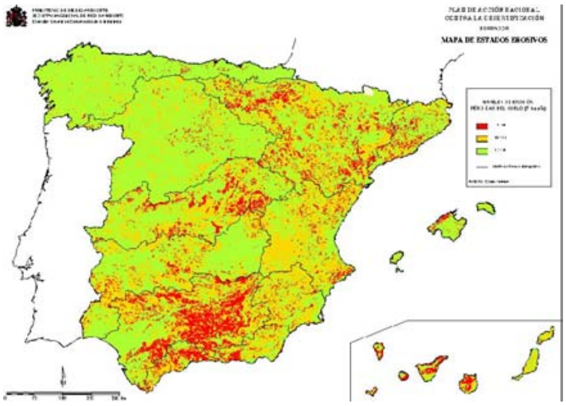


Figure 2.31 Actual Soil erosion risk in Spain based on the USLE approach.

The methodology applied by ICONA consisted of defining homogeneous land units, based on existing information (land use, topographic and geology maps, and aerial photographs), and designing a sampling scheme for gathering information about the USLE factors in each unit. Soil loss estimates for each unit were classified into 7 classes reflecting different erosive states.

A map at scale 1:400,000 was generated by the PAND for each of the main catchments within the Spanish territory. The maps were digitised, joined and adjusted, and the erosive states were aggregated at national level and assigned to one of the following 3 classes: 1 (green) 0–12(t ha^{-1} yr^{-1}), 2 (yellow) 12–50 (t ha^{-1} yr^{-1}), 3 (red) >50 (t ha^{-1} yr^{-1}), as shown in Figure 2.31.

2.2.2.13 Sweden

Field measurements of soil erosion by water are very few and for wind erosion measurements are even fewer. Locally the problem is considerable for arable land but there is no general quantification. No simple or direct relationship between average slope angle and transport of suspended concentrations has been found from fields observed. However, in most fields with soils >35% clay concentrations of suspended solids can be quite high.

An inventory of 29 selected fields with erosion problems in the county of Scania revealed large and varied amounts of eroded material between 0.5-300 t $ha^{-1}yr^{-1}$. Problems of erosion also occur around Lake Mälaren on agricultural land with heavy clay soils. In addition, erosion of silty soils occurs along the coast in the north and west of Sweden.

A national survey of landslide stability conditions is carried out regularly in the different provinces of Sweden. A similar survey of the debris flow risks is planned.

2.2.2.14 Switzerland

A map showing erosion risk on arable land, based on a simplified USLE-model, has been produced in Switzerland, with a spatial resolution of about 6 km^2. More recently, erosion risk maps, based on different models or mapping methodologies, have been prepared at regional or local level.

During the period between winter 1997/98 and summer 2001 a total of 770 erosion damages was assessed and analysed. The results show that every year about 20% of the arable land was affected by soil erosion. Mean soil loss from all fields during this period was 0.67 t ha^{-1}, but losses amounted to 20 t $ha^{-1}yr^{-1}$ from single fields in some places. With mean soil losses of less than 1 t $ha^{-1}yr^{-1}$ overall, soil erosion on arable land in Switzerland is generally a less serious problem than in other countries.

2.2.2.15 United Kingdom

Soil erosion has been observed intensively in England and Wales for the past 4-5 decades (Evans, 1996, 2002). Previous reviews of erosion in Britain include those by Morgan (1980) and Boardman & Evans (1994). The erosion risk for associations of soils delineated on the National Soil Map of England and Wales has been described in detail by Evans (1990).

In addition, a map at a scale of 1:250,000 has been prepared by the National Soil Resources Institute showing erosion risk for land under winter cereals (R. Palmer, pers. comm.). Both classifications are based on observation and expert judgement.

More recently, Boardman and Evans (In press) have produced a map showing the distribution of water, wind and upland erosion in Great Britain as a whole (Figure 2.32).

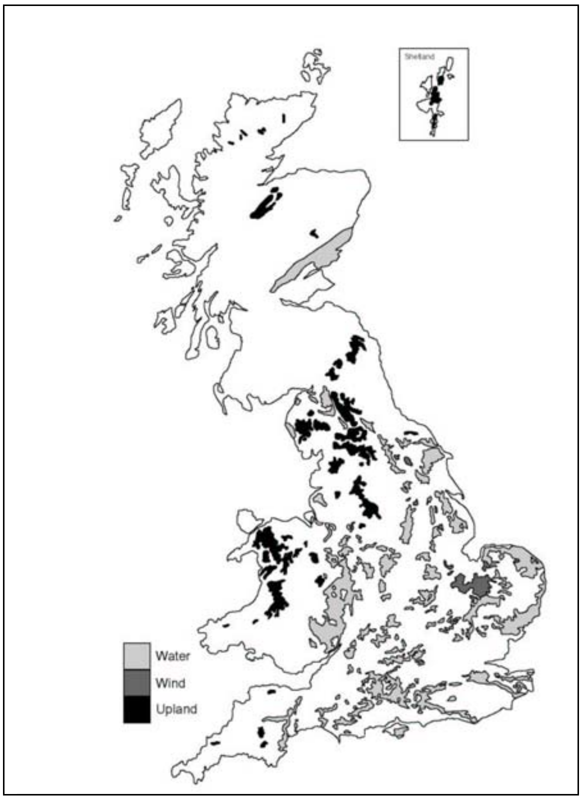
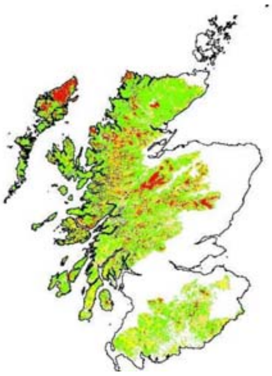


Figure 2.32 Actual soil erosion in Great Britain.

Birnie (1993) has described peat erosion due to overgrazing in the uplands (Figure 2.33) and Lilly et al. (2002) have defined the inherent geomorphological risk of soil erosion by overland flow in Scotland (Figure 2.34).

Thus, although no erosion model has been applied nationally in the UK, there is a very large number of records of observed erosion events from all over the country.

Figure 2.33 Peat erosion, south of Glenartney, Perthshire. Scotland UK. (Photograph MLURI)



	Low	Moderate	High
Minimal	low risk of erosion occuring		
Medium term	low vulnerability with moderate exposure	moderate vulnerability with moderate exposure	high vulnerability but moderate exposure
Short term	low vulnerability but high exposure	moderate vulnerability but high exposure	high vulnerability but high exposure

Figure 2.34 Inherent geomorphological risk of soil erosion by overland flow in Scotland, UK (Lilly et al., 2002)

2.3 Current extent of soil erosion in Europe

Soil erosion by water is a widespread problem throughout Europe. A report for the Council of Europe, using revised GLASOD data (Oldeman *et al.*, 1991; Van Lynden, 1995), estimates that 12 million ha of land, in Europe (including part of the former Soviet Union), or approximately 10% of the area considered, is strongly or extremely degraded by water erosion.

The most dominant effect is the loss of topsoil, which is often not conspicuous, but nevertheless potentially very damaging. Physical factors like climate, topography and soil characteristics are important in the process of soil erosion. In part, this explains the difference between the severe water erosion problem in Iceland, and the much less severe erosion in Scandinavia, where the climate is less harsh and the soils are less erodible.

The Mediterranean region is particularly prone to erosion. This is because it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils, resulting in considerable amounts of erosion.

This contrasts with NW Europe where soil erosion is slight, because rain falling on mainly gentle slopes is evenly distributed throughout the year. Consequently, the area affected by erosion in northern Europe is much more restricted in its extent than in southern Europe.

In parts of the Mediterranean region, erosion has reached a stage of irreversibility and has practically ceased in some places, because there is no more soil left! With a very slow rate of soil formation, any soil loss of more than 1 t $ha^{-1}yr^{-1}$ can be considered as irreversible within a time span of 50-100 years. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe, with losses of more than 100 t ha^{-1} in extreme events (Morgan, 1995).

Figure 2.35 Intensive Olive (5–80 years old) cultivation near Sevilla, Spain

It may take some time before the effects of such erosion become noticeable, especially in areas with the deepest and most fertile soils or on heavily fertilised land.

Table 2.4. Assessment of erosion: use of models and observation at national level.

Country	Model	Observat.	Other	Soil	Land use	Topography	Climate
Albania	?						
Austria	USLE			1:50,000	250m	250m	commune
Belgium	RUSLE	Regional		1:25,000	250m	20m	
Bosnia Herz.	?						
Bulgaria	USLE			?	?	?	?
Croatia	?						
Cyprus	?						
Czech Rep.	USLE	Regional		1:200,000	100m	1:25,000	1:50,000
Denmark	?						
Estonia	?						
Finland	USLE	Regional					
France	National	Regional		1:1,000,000			
Germany	National	Regional	wind	1:1,000,000		High resol.	?
Greece	?						
Hungary	USLE			1:100,000	100m	1:100,000	?
Iceland	?						
Ireland	N						
Italy	USLE			1:250,000	100m	250m	366 stns
Latvia	?						
Lithuania	?						
Luxembourg	?						
Mace-FYROM	?						
Malta	?						
Montenegro	?						
Norway	USLE	National		?	?	?	?
Poland	?						
Portugal	?						
Romania	USLE						
Serbia	?						
Slovakia	USLE	National		1:500,000	250m	High resol.	1:5,000
Slovenia	?						
Spain	USLE	National		1:1,000,000	?	?	?
Sweden	?						
Switzerland	USLE			?	?	?	?
The Netherlands	?						
United Kingdom	N	National		1:250,000	1:250,000	?	5km

Legend		
	USLE	Universal Soil Loss Equation
	National	National models
	Observation	Survey by experts, regional and national
	?	Not Known
	N	Not used

However, this is all the more dangerous because, once the effects have become obvious, it is usually too late to do anything about it. The main causes of soil erosion are still inappropriate agricultural practices (e.g. Figure 2.35 shows the effect of intensive olive cultivation in Andalucia), deforestation (including forest fires), overgrazing and construction activities (Yassoglou *et al.*, 1998).

Of the models reviewed in Section 2.2, PESERA is the most conceptually appropriate because it takes into account:

1. Runoff and erosion sediments separately, which are the 2 components of the global erosion process;
2. Daily frequency distribution of rainfall month by month, which includes both regular and exceptional events;
3. Dynamic crusting and vegetation cover, month by month (Le Bissonnais *et al.* 2003);
4. Other climatic information such as freezing days that in part cater for the effect of snow.

The other models – USLE, INRA etc. – do not take these aspects into account. However, a comparison of the results obtained from the three models PESERA, USLE and INRA identifies with more confidence areas that are eroding from those that are not. Figure 2.36 presents such a comparison on the data currently available at European level.

In conclusion, no model can give good estimates of erosion if the input data are poor. At European level, the aim should only be to provide a tool for decision making at European level. No modelling approach at this level can produce results relevant at local level (Y. Le Bissonnais, pers comm.).

The following data, at European level, are needed if models such as PESERA are to give satisfactory results:

1. Soil parameter data derived from 1:250,000 scale surveys;
2. Digital elevation model (DEM) at 250m minimum resolution;
3. Climatic data (e.g. precipitation) at 10km x 10km resolution;
4. Land/crop cover data at 250m resolution that are up to date;

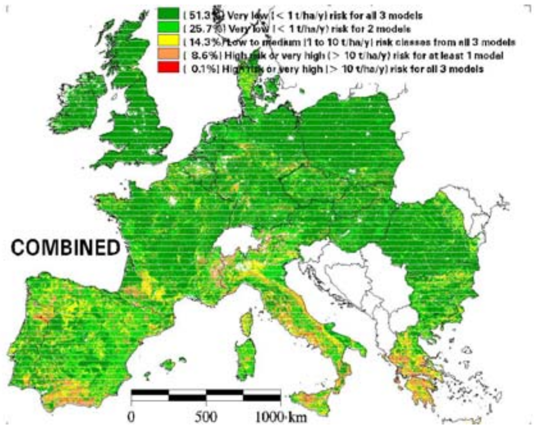


Figure 2.36 Soil erosion (by rill and inter-rill) estimates for Europe by combination of 3 models (Le Bissonnais and Daroussin, pers. comm.)

Finally, it must be accepted that any model selected for application throughout Europe will not give satisfactory results in areas where the main process taking place is not included in the model. In the case of PESERA, the results will not be appropriate for areas where snowmelt erosion or erosion from land-levelling is the dominant process. This limitation is not so important, since such processes are dominant only locally.

2.4 Indicators of state

The OECD has defined a core set of indicators for environmental performance reviews (OECD, 1993). These indicators were translated by Gentile (1999) to relate to soil erosion. A number of them have been critically reviewed by Gobin *et al.* (2004) who conclude that the area actually affected by erosion is the best indicator of state and this area should be directly related to the area at risk from erosion. The area at risk can be estimated using an appropriate model of soil erosion, together with the necessary spatial data sets to define the boundaries of these areas.

Soil erosion takes place at the field scale, and the main problem is that the digital data sets used to quantify the factors causing erosion are usually too coarse (in terms of spatial resolution) to provide accurate estimation of soil losses at this scale. These conclusions are in accordance with the earlier findings of Düwel and Utermann (1999), who proposed the approach outlined in Figure 2.37.

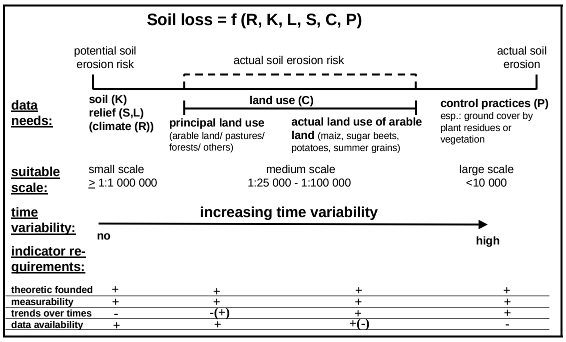


Figure 2.37 An approach to assessing soil erosion

Especially with regard to agricultural land this approach means: the higher the proportion of crops which increase the risk of soil erosion (‘row crops’, e.g. corn, sugar beet, potatoes) of total arable land in areas with a high potential soil erosion risk, the higher the actual soil losses due to soil erosion, unless accompanying protection measures are applied. Soil, climatic and relief conditions cannot be changed by human activities, at least not in the short-term. Consequently ground cover measures should be used to combat soil erosion in other forms of land use as well.

An important surrogate indicator of actual erosion is its risk. A *risk* is the chance that some undesirable event may occur. *Risk assessment* involves the identification of the *risk*, and the measurement of the exposure to that risk. The response to risk assessment may be to initiate categorisation of the risk and/or to introduce measures to manage the risk. In some cases, the risk may simply be accepted. In other cases, the priority will be to adopt a mitigation strategy. Various approaches that can be adopted to assess soil erosion risk are presented in section 2.2.

The area affected by erosion is the key indicator for soil erosion. Trends in soil erosion could be established from periodic estimates. A number of national databases are available for making estimates at national level.

One of the major negative aspects is that national databases are not available for all EU countries. Estimates of the area actually affected by soil erosion at regional and national levels are not readily available. This is because measurements of actual erosion are difficult and usually expensive to make. Soil erosion often takes place surreptitiously and over long periods before the true extent is observed and appreciated. Accurate data are, therefore, scarce. Estimates from European countries, based on national data sets, could be compared with estimates derived from European data sets (e.g. the European Soil Database, CORINE land use and climate data).

Although, there are difficulties in making measurements, existing data should be compiled and stored centrally for comparison with model estimates. Erosion models offer the main mechanism whereby the area affected by erosion can be estimated. An appropriate model should be identified and used in conjunction with standard data sets to provide standardised estimates of the areas at risk from soil. The result would be to provide an appropriate state indicator including time series for use by policy-makers. The currently implemented PESERA project should provide such a model within the next two years (Gobin *et al.* 2004).

2.5 Secondary threats

The Soil Communication (CEC, 2002) identifies compaction and salinisation as threats to soil. The current policy initiative places a higher priority on erosion, loss of organic matter and contamination. Nevertheless, all threats to soil are important and thus the Technical Working Group on Erosion was given the remit to report on the extent of compaction and salinisation in Europe.

2.5.1 Compaction

Soil compaction occurs when soil is subject to mechanical pressure through the use of heavy machinery or dense stocking with grazing animals, especially in wet soil conditions (Figure 2.38). Compaction reduces the pore space between soil particles and the soil partially or fully loses its absorptive capacity.

Figure 2.38 Compacted soil. (Photograph by Erika. Micheli)

Consequently, intensification of agriculture is now recognised as often having a detrimental effect on soils, not least the widespread development of compaction. Compaction can occur at the surface or below in subsurface soil horizons. Compaction of deeper soil layers is very difficult to reverse.

2.5.2 Effects of compaction

The worst effects of surface compaction can be rectified relatively easily by cultivation and, hence, it is perceived to be a less serious problem in the medium to long-term. On the contrary, once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate. Furthermore, remedial treatments usually need to be repeated. The risk of subsoil compaction increases with the growth in farm size, increased mechanisation and equipment size, and the drive for greater productivity.

The response of the engineering industry to the demands of agriculture has been impressive over the past 30 years. Larger and larger machines have been developed but, from the soil standpoint, the result has been a significant increase in axle loads not always matched by reductions in ground contact pressures to prevent or minimise compaction. (Renius, 1994; Tijink *et al.*, 1995; Chamen *et al.*, 2001).

Research into the causes and effects of compaction in topsoils and subsoils in Europe has demonstrated the detrimental effects on the farming system (Hakansson, 1994). It is now clear, however, that the detrimental effects go far beyond agricultural concerns of a decrease in yield and increase in management costs. The overall deterioration in soil structure that may result from compaction can: (i) increase the risk of soil erosion on sloping land, through the concentration of excess water above compacted layers; and (ii) accelerate effective runoff from and within catchments. Other effects impact mainly on contamination trough transfer of pollutants. These effects are illustrated in Figure 2.39.

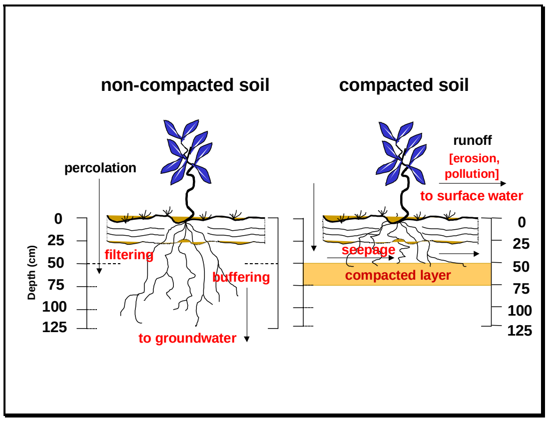


Figure 2.39 The Impacts of subsoil compaction

Subsoil compaction is the manifestation of increased bulk density, and therefore, can be related directly to soil properties. External aspects, such as land use and the use of machinery, also play an important part in the occurrence and distribution of compacted subsoils.

2.5.3 Extent of compaction in Europe

Knowledge concerning the vulnerability of subsoils to compaction in Europe is now an increasingly important requirement within agriculture and for planning environmental protection measures. Fortunately, subsoil compaction has been the subject of two recent Concerted Actions (Van den Akker, 1999; Van den Akker and Canarache, 2001) funded by the EU.

Under these projects, a database of experimental results on subsoil compaction has been compiled, and Jones *et al.* (2003) have produced a preliminary map (Figure 2.40) showing the susceptibility of subsoils to compaction by applying a structured model to the European Soil Database (Heineke *et al.*, 1998).

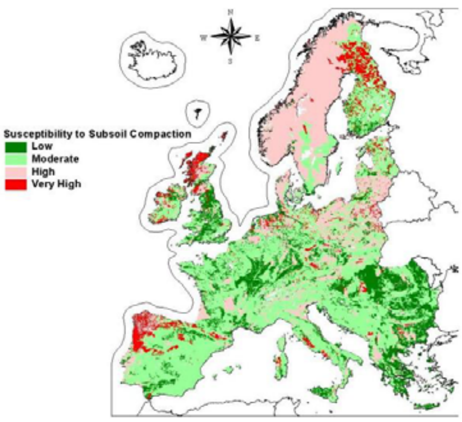


Figure 2.40 Extent of susceptibility to subsoil compaction in Europe.

The following proportions of land in the four susceptibility classes are as follows: low 20%; moderate 44%; high 28%; very high 9%. Thus more than a third of European subsoils are classified as having high or very high susceptibility to subsoil compaction.

A study of compaction in Italy by R. Barberis (pers comm.) provides information for comparison with the susceptibility map for Europe (Figure 2.40). Ilavaska, Houskova and Granec have published a map of the susceptibility of agricultural soils to compaction in the Landscape Atlas of the Slovak Republic (2002, p.281).

2.6 Salinisation

Salinisation is the accumulation in soils of soluble salts of sodium, magnesium, and calcium to the extent that soil fertility is severely reduced. This process is often associated with irrigation as irrigation water always contains variable amounts of salts, especially in regions where rainfall is low, evapotranspiration is high, or soil textural characteristics impede the washing out of the salts, which subsequently build-up in the surface soil layers.

Irrigation with water of high salt content dramatically worsens the problem. In coastal areas, salinisation can also be associated with over-exploitation of groundwater (caused by the demands of growing urbanisation, industry and agriculture) leading to a lowering of the groundwater table, and triggering the intrusion of salt water from the sea. In Nordic countries, the winter maintenance of roads with salts can lead to local salinisation.

2.6.1 Extent of salinisation in Europe

The precise evaluation of salt-affected soils is difficult (ISRIC-UNEP 1990), because the problem of salinisation develops progressively and it is difficult to detect the problem in its early stages. There have been several attempts to assess the extent of salt-affected soils in Europe. In the world as a whole, this area exceeds 10% of the total land surface (Szabolcs 1996).

In Europe, the problem of salinisation is restricted to Austria, Bulgaria, Slovakia, France, Greece, Hungary, Italy, Portugal, Rumania, Spain, Russia, Bosnia, Ukraine, Serbia and Croatia. The largest area of salt affected soils in Europe can be found in the semi-arid steppe and forest steppe regions of Russia, Ukraine, on the lowlands of the Danube in Slovakia, Romania, Hungary, Croatia and Serbia, and in Spain. The main climatic conditions favouring salinisation are arid, semi-arid and semi-humid.

Figure 2.41 shows the distribution map of salt affected soils in Europe (Szabolics, 1974, 1996). It is possible to distinguish three scenarios depending on the type of salinisation processes taking place.

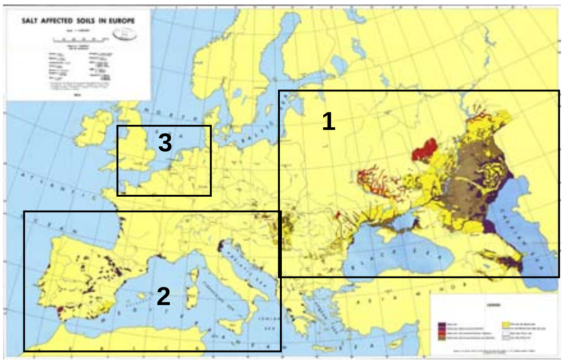


Figure 2.41 Salt affected soils in Europe (Szabolcs, 1974)

Scenario 1: Soil salinity caused by the extension of irrigated agriculture. More than half of European irrigated areas can be found in this category. The climate of these areas is continental to semi-arid. They are located mainly in Russia and Ukraine, and occupy 22 million ha, but considering the potential risk they can be extended to 41 million ha.

Scenario 2: Soil salinity caused by climatic changes. The Mediterranean is the region most likely to be affected by increased salinisation if temperature increases and precipitation decreases. These salt affected soils occupy approximately 2.8 million ha, mainly in the dry areas of the Iberian peninsula (Ebro Valley, Castilla, Mediterranean coast see Figure 2.42), with small areas in south-western France, Italy, Sicily (Dazzi & Fierotti, 1996) Sardinia, Corsica, and the Dalmatian coast of the Balkans.

Scenario 3: Soil salinity caused by sea-level rise. This territory occupies about 1 million ha, mainly in coastal areas of north-western Europe (western Netherlands, Belgium, north-eastern France, and south-eastern England).

Estimates of the area of EU and Candidate Countries affected by salinisation vary from 1 to 3 million ha. In Spain about 3% of the 3.5 million hectares irrigated land is severely affected, significantly reducing its agricultural potential, and another 15 % is at serious risk. In Greece about 30% of the approximately 0.5 million hectares of irrigated land is affected by soil salinisation (Katakouzinos, 1968).

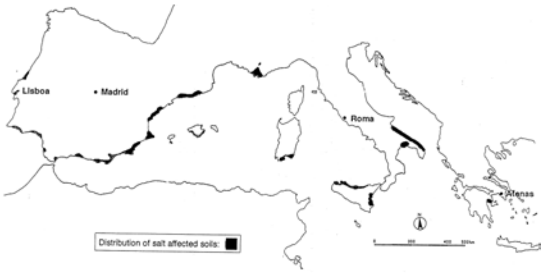


Figure 2.42 Map of Salt affected soil in Europe elaborated by Gisbert (1991).

In the GLASOD study about soil degradation at global scale, Bridges and Oldeman (1999) assessed that 4 million ha of soils of Europe have a moderate to high level of degradation by salinisation. The GLASOD methodology was based on expert judgement (type, extent, degree, rate and cause) on a national/sub-national level and the resulting map at 1:10,000,000 scale is, therefore, only approximate and not appropriate for supporting soil protection and conservation policies at European level.

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SOIL EROSION

Task Group 3 on
IMPACTS OF SOIL EROSION

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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.

Excecutive 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 CO2, 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.

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SOIL EROSION

Task Group 4.1 on MEASURES TO COMBAT SOIL EROSION

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Executive Summary and recommendations

Measures to combat soil erosion cover a wide range of actions to be applied in a wide range of scenarios, according to the diverse driving forces, threats, and target areas. Specific measures vary according to a number of related and non-excluding approaches:

- Source oriented measures and (off-site) impact oriented measures.
- Prevention, mitigation, and restoration measures
- Activity-specific measures: agriculture, livestock management, forestry, transport and construction infrastructures, etc.
- Specific measures depending on local and regional environmental and socio-economic conditions

General principles underlying the proposed measures to combat soil erosion are:

- Production systems should be adapted to land capability and soil suitability.
- Prevention measures should rely on sustainable land use and management; sustainability of land use systems needs to meet both environmental, social and economic conditions.
- Soil protection measures need to be designed in accordance to water management programmes.
- Promotion of protective vegetation cover and/or organic debris (residues, litter) cover.
- Optimisation of soil organic matter levels.
- Promotion of water infiltration.
- The principles of ecological restoration should feed restoration programmes to combat soil erosion.
- An integrated management approach should feed land use planning to prevent coastal erosion, bank erosion, landslides, gullies and debris flows.
- Education and training of land users; increasing awareness of short- and long-term environmental and economical benefits of controlling erosion.

Recommendations

The following table summarises recommendations on measures to combat erosion, according to the activity involved and the stage of degradation driving-forces: active (prevention and mitigation measures) or ceased after degradation (rehabilitation and restoration measures). In addition to these general recommendations, regional- local- and site-specific measures may be applied to deal with specific environmental and/or socio-economic conditions (see report for details).

Synthesis of key measures to combat soil erosion

Land use	**Prevention and mitigation measures**		
Agriculture	Agricultural practices	Land use planning	Identification of best and marginal agricultural lands; relating major land use to land capability.
			Crop selection and diversification according to soil suitability and soil erosion risk.
			Management of abandoned agricultural lands, particularly in arid and semiarid lands, to avoid further degradation.
		Soil management practices	Improvement of soil properties that positively contribute to reduce erosion, maintaining proper soil organic matter levels.
			Minimising soil tillage, the level depending on soil situation and climate
			Proper timing of tillage practices, avoiding tillage when the soil is too wet or too dry.
			Crop rotations.
			Soil cultivation following contour lines (on the basis of slope and soil type, certain lands may be excluded of this recommendation; e.g. steep slopes)
			Reduction of soil compaction by machines; avoidance of wheel tracks and furrows running up and down the slope.
		Landscape elements	Preservation and maintenance of plant-covered field edges, especially of those which run along the contour. Preservation and maintenance of hedge rows and groves.
			Preservation and maintenance of terraces.
	Rural-landscape engineering to support agricultural practices		Proper size, shape and direction of agricultural fields and farm tracks.
			Rural engineering measures to control runoff (secondary measures to control symptoms): drainage of fields, derivation of inflow from neighbouring areas, derivation of sub-surface water outlets, installation of infiltration areas, obstructing linear depression.
			New constructions of landscape elements: wooded strips, permanent grass strips as buffer areas within fields, contour strips, strips along riverbanks, terraces, etc.
Livestock and grazing management			Establishment of the proper stocking rate, kind of grazing animal, season and duration of grazing for each site. Some useful rules can be established defining limits for the utilisation percentage, the stubble height by the end of the grazing season, and for degradation trend indicators.
			Overgrazed areas should be left aside for some time to recover.
			Integrated management systems involving forestlands, rangelands, agro-pastures, and cultivated lands.
			Grazing and fire can be combined in rangelands and silvopastoral systems provided that a management plan is drawn which specifies when prescribed fire should be used and how the burned areas should be grazed
			Avoidance of practices that cause poaching and high-stocking rates in wet climates/weather
			Access to communal use of public natural pastures in accordance to the application of best management practices

Synthesis of key measures to combat soil erosion (cont.)

Land use	Prevention and mitigation measures	
Forestry	Criteria for afforestation. Forest management	To minimise impacts on soils of site preparation techniques for afforestation: planting holes and contour subsoiling are suitable site preparation techniques; bench terracing and subsoiling along the slope should be avoided.
		Reducing impact on soils of thinning and clearance actions.
		Application of best practices in forest exploitation: planned reduced-impact logging; reduced clear-cutting areas.
		Minimising impact on forest floor materials and soil conservation measures, such as spreading woody debris over skid trials.
		Silvicultural actions aimed at improving stand structure and functioning.
	Fire prevention and post-fire management	Specific programmes for preventing uncontrolled burnings, because it is deeply rooted in the rural population. Co-ordinated actions of persuasion, conciliation and prosecution to modify the human behaviour of the rural population in the use of fire.
		Promote fire prevention through silviculture.
		Controlled burning to reduce fuel load in combination to grazing management.
		Avoidance of savage logging in erosion-prone sites, unless strong soil conservation measures are provided.
Transportation, construction and other sectors	Land use planning	To identify risk areas: areas prone to floods, landslides, and debris flows. Introduction and practise of the Integrated Coastal Zone Management approach.
	Prevention / mitigation	Specific technical approaches and measures available for prevention and mitigation of erosion in transport and construction structures (see report).
		Constructions/solid structures to fix the position of the coastline (revetments, breakwaters, groins etc.).
		Working with natural processes (sand nourishment, stimulate natural protection processes etc.).

Rehabilitation and restoration measures	
Restoration to combat soil erosion	Restoration/reforestation programmes aimed at preserving soil and water and controlling erosion and floods should be designed as ecologically sound, multi-purpose measures, adapted to the new social demands.
	New ecological approach based on (i) restoring ecosystem functioning; (ii) site-specific restoration strategies; (iii) a wide set of species choices; (iii) the introduction of vegetation according to environmental heterogeneity and natural vegetation spatial patterns, with the aim of recover previous landscape processes;
Post-fire soil conservation and restoration	Application of emergency soil-conservation treatments in erosion-prone areas, using on-site slash as mulching materials.
	Promotion of fire resilient plant communities and forest cover restoration.
Rehabilitation of degraded soils	Application of exogenous organic matter (EOM) in accordance with the precautionary principle to maintain soil functions on a sustainable basis. To avoid harmful changes to the soil, exogenous organic matter shall only be applied when there will be no accumulation of contaminants in the soil. Attention must be drawn not only to heavy metal loads, but also to organic pollutants and other environmentally harmful substances.

1. Introduction

The framework for combating soil erosion is land use planning, according to the principles of land capability and soil suitability, and sustainable land use and management. Hence, there is also a need to determine land vulnerability. Within this framework, actions aimed at enhancing or maintaining soil organic matter levels, water infiltration, and vegetation or plant residue cover specifically address soil erosion.

Most key is educating users to look after the soil. Education and dissemination actions aimed at increasing awareness on the environmental and economic benefits of controlling erosion should be a major part of any programme for implementing control measures. Training and support for changing traditional management is needed.

All actions need to be targeted on particular areas that are vulnerable to erosion. This will be more effective in protecting these areas than a broad brush approach. There are only **limited financial and human capacities**. Therefore it is necessary to use these limited capacities in an efficient way. Activities or measures have to focus on those aspects where problems concerning the health of soils are evident.

The following approaches of combating soil erosion can be distinguished, although a strict subdivision of measures into these classes is not always possible as some measures fit to more than one approach:

Prevention, mitigation and restoration measures

- Prevention and provision are oriented to the potential risk of the site, even though damages did not yet occur. These measures mainly focuses on proper land and soil management
- Mitigation and defence actions, which are applied when relevant erosion is currently occurring. In case of severely degraded and eroded soils, mitigation measures may include the abandonment of the exploitation system.
- Once the land is degraded and the spontaneous reversion of degradation processes can not be expected at management time scale, even if most of the erosion driving forces have ceased, ecosystem need to be repaired by rehabilitation and restoration actions.

Source oriented measures and impact oriented measures[1]

- Source oriented measures control the soil erosion process directly at the place where it starts, they aim at reducing kinetic energy of falling drops with a protective vegetation cover, maintaining infiltration capacity and reducing flow velocity of surface runoff. In agricultural lands, these measures include soil management practices leaving great amounts of plant residue at the soil surface or maintaining a permanent or semi-permanent plant cover in perennial crops (conservation agriculture techniques). Other measures controlling the amount of runoff generated within a field can also be considered as source-oriented, such as contour ploughing (increasing soil surface roughness), and the maintenance of linear landscape elements (decreasing slope length). A correct choice of land use respecting the principles of land capability and soil suitability also belongs to the source-oriented measures, implying the provision of soil erosion damage that did not yet occur, oriented to the potential risks of the site. Sustainable grazing management, sustainable forestry, fire-prevention actions and most restoration actions to combat soil erosion are also source-oriented measures.
- Impact oriented measures control the effects of soil erosion as close as possible to its source. Most of these measures aim at reducing the amount of sediment (detached soil material) being transported into surface water bodies (streams and lakes…) and any other area or infrastructure to be protected (housing, roads, nature reserve…). Such measures include grass buffer strips, grassed waterways, earth dams, retention ponds, etc. in agricultural lands; check dams, soil-retaining vegetation barriers, etc. in forest lands and drainage systems in transport infrastructures, among others. However, they also contribute to the prevention of soil erosion downstream, by controlling both velocity and amount of runoff. The more upstream in the catchment such measures are located, the more source-oriented they are, whilst the more downstream, the more impact-oriented.

The above-mentioned approaches are very closely related. Thus, most source-oriented measures are preventive actions and most impact-oriented measures are mitigation or defence actions. In the long-term, prevention and source-oriented actions are the most effective measures in reducing both the risks of on-site-damages as well as risks of off-site-damages.

Specific approaches also depend on land use. The present report analyses erosion control measures according to target activities: agriculture and livestock, forestry, transport and construction infrastructures and others. The context of desertification deserves special mention. Training, monitoring and research actions are also considered.

2. Concrete measures in agriculture (including pasture lands)

2.1. Agricultural Practices to combat soil erosion

This report analyses agricultural practices within the following major topics:

- Land use planning: Location of agricultural land and crop diversification.
- Soil management practices; improvement of erosion reducing soil properties.
- Preservation of the natural landscape elements that contribute to control overland flow and soil erosion.

2.1.1. Land use planning: Location of agricultural land and crop diversification

Land use planning policy should relate major land use to *general land capability* and *relative soil suitability*, for each particular site and socio-economic context, which can be really based on knowledge and information following the traditional land evaluation analysis. Rural planning tools (directives; regional, national and local regulations; etc.) can be used at the various scales concerned.

[1] Kainz, 1991. Schutzmaßnahmen gegen Bodenerosion. Berichte über Landwirtschaft, Bodennutzung und Bodenfruchtbarkeit, Band 3, 83-98, Parey

Agricultural marginal lands used to be a suitable scenario for soil erosion. The relationship between current land use and agricultural capability (potential use) is clearly unbalanced in many European regions. As an example, about 1 million of hectares of rain fed agricultural lands in Andalusia, Spain, should be changed to forestry, grazing or natural lands in order to get a balance between land capability and land use[2]. On the other hand, soil exploitation of best agricultural lands for building purposes should be minimised. Therefore, the first land use decision is the identification of the best and the marginal agricultural lands, and the identification of high-risk soils.

In Northern countries, good land use planning would for instance imply that arable farming of marginal land for cereal production is avoided. These lands can be transformed into grazing land, hay fields, forest lands or can be used for the production of bio-energy, or for Christmas tree plantations.

Within the framework of land consolidation, the different land uses can be redistributed in critical areas in order to reduce potential damages related to soil erosion. For example, this can lead to a corresponding interchange between pasture and arable lands within an area. A critical area is a site with remarkable soil loss and/or overland flow risks that is located nearby a protected area; "nearby" means areas from which overland flow and erosion material can easily reach a protected subject (or a subject needing protection).

Within the agricultural lands, all soils can be used for almost all crops if sufficient inputs are supplied. However, each soil unit has its own potentialities and limitations (soil suitability), and each crop its biophysical requirements. In order to minimise the socio-economic and environmental costs of such inputs, the second major objective of land use planning is to predict the inherent suitability of a soil unit to support a specific crop or crop rotation for a long period of time[3].

The development and essay of methods and techniques to assess the soil suitability and vulnerability related to land uses are necessary in order to exploit in an environmental friendly way the multifunctionality of soil. The soil key attributes used in land use planning for soil erosion, through the land evaluation analysis, are mainly soil physical/chemical indicators. At present, the soil biological indicators are not used in land evaluation. Site quality indicators of particular relevance to soil erosion mainly relate to soil erodibility, infiltration capacity, and slope conditions (steepness, length, and shape). The distance to an off-site area that is to be protected (e.g. surface water) is also relevant.

2.1.2. Soil management practices

√ ***Improvement of soil properties***

Improvement of soil properties that positively contribute to reduce erosion risk and develop stable top soils. These measures include: enrichment of organic matter in order to reach the site-typical humus level by adding animal manure or other materials; promotion of an equalised humus balance; support of stable soil aggregates and soil structure by stimulating the biological activity, by liming, by promoting stable humus forms.

Long-term benefits associated with ***organic farming*** include increased soil organic matter content, greater topsoil depth and moisture retention, which in turns contribute to reduce soil erosion[4]

√ Formulation of a ***conservation tillage system according to site conditions.***

Soil tillage is carried out to prepare the seedbed to grow crops, to control weeds, and to incorporate manure, fertilisers, pesticides and other amendments. Inappropriate tillage practices accelerate the soil degradation processes, especially soil erosion and compaction. To formulate the tillage type and intensity for each particular soil is a critical point to combat the soil erosion problem in the agricultural lands.

In general terms, tillage systems can range from full width intensive tillage to zero tillage (i.e. conventional tillage, reduced tillage, ploughless tillage, minimum tillage and no-tillage). ***Conservation agriculture*** (CA) includes practices that reduce, change or eliminate tillage and avoid residue burning to maintain enough surface residues through the year, so that the soil is protected from rainfall erosion. Specifically CA includes: direct sowing/ direct drilling/ no-tillage; ridge-till; mulch till/ reduced tillage/ minimum tillage; and cover crops.

A common technique is ***mulching***, e.g. after freezing in winter, catch crops or small-grain cereal form a layer of mulch on the soil surface. In spring the crop can be drilled directly into the mulch and the soil is completely protected till the new crop forms a consistent canopy. In general, leaving stubble uncultivated is preferable to leaving the soil bare.

The conventional repeated tillage system accelerates decomposition of organic matter thus affecting soil physical, chemical and biological attributes of soil quality. On the contrary, with the no-tillage system (direct sowing), several studies[5] show that continuously organic matter increases and soil structure improves, restoring and improving soil quality, crop yields increase, and soil erosion is controlled. However, other studies[6] point out how the level of success in no-tillage system varies with i) crop species, ii) soil type, iii) climatic conditions, and iv) growing season length.

A major concern with CA is the application of herbicides and pesticides. The need of such herbicides is generally assumed to be higher, especially for the most drastic forms of CA, i.e. no till/direct drilling. However, this may be site-specific (e.g. humid environments may suffer more from fungi or slugs than dry areas) and information is scattered and incomplete. In fact, the environmental consequences of CA have not systematically been investigated, and this needs to be done for different forms of CA in different agro-ecological zones. A critical and objective literature review is required, and probably, further research is needed to investigate which forms of

[2] AMA, 1987. Evaluacion ecologica de recursos naturales de Andalucia. Scale 1:400,000. Coordinators: D. de la Rosa and J.M. Moreira. Agencia de Medio Ambiente Pub. Sevilla

[3] De la Rosa D. and Van Diepen C. 2002. Qualitative and quantitative land evaluation. In W. Verheye (ed.) Land use and land cover, Encyclopedia of Life Support System (EOLSS-UNESCO), Eolss Publisher, Oxford. Http://www.eolss.net.

[4] Reganold J P, Elliott L.F., Young L.U. (1987) Long-term effects of organic and conventional farming on soil erosion. Nature 330, 370-372.

[5] e.g. Tebrugge F. and During R.A. 1999. Reducing tillage intensity - a review of results from a long-term study in Germany. Soil & Tillage Research 53: 15-28.

[6] e.g. Arshad M.A. 1999. Tillage and soil quality: Tillage practices for sustainable agriculture and environmental quality in different agroecosystems. Soil & Tillage Research 53: 1-2.

CA can be applied in which ago-ecological zones with acceptable environmental impacts.

In order to rationalise the soil tillage practices, a conservation tillage system should be formulated for each specific site, giving details on the operation sequence, implement type and intensity.

Timing of tillage practice is as important as tillage intensity. Tillage operations should be avoided when the soil is too wet or too dry. The limits in soil water content can be predicted in terms of soil composition through the use of pedotransfer functions.

For Mediterranean climatic conditions, repeated tillage under dry soil conditions appears to promote topsoil pulverisation and enhance soil erosion. Finely pulverised soils are usually smooth, seal rapidly and have low infiltration rates.

In Western Europe, a lot of the erosion problems are caused by a wet climate particularly in late summer and autumn when most cultivation takes place. Tilling at the wrong time i.e. when the soil is too wet, leads to compaction or soil sealing which prevents water infiltration and increases run-off, which can result in extensive sheet erosion and gullying on all soil types. Any type of cultivation, conventional or otherwise, will result in a degree of compaction if carried out when the conditions are too wet.

Soil cultivation following contour lines. On the basis of slope and soil type, certain lands may be excluded of this recommendation, e.g. steep slopes and in case water is concentrated in natural drainage lines (hollows).

Ploughing along contours should be practised with turning earth in direction against the slope (partial erosion compensation). It is useful when all the other agro-technical measures (drilling, agro-chemistry measures, etc.) are also made following the contours.

√ ***Crop rotations***.

The use of crop rotations leads to soil protection by ensuring plant cover as much as possible, which supports the enrichment of humus in the soil through the incorporation of their organic remains. On erodible land, crops that can be considered as low-protection crops should be avoided in a rotation, and should be forbidden in monoculture in case no sufficient erosion control measures have been set. Examples of such crops are maize, other row crops (sunflowers) and root crops (potatoes, sugar beet, endive roots, etc.). On the contrary, a crop rotation on erodible land should include cover crops or catch crops for reducing the loss of soil and nitrogen during winter time; e.g. use cover crops such as rye or mustard in late summer or early autumn. Cover crops should also be grown in perennial crops on steep slopes, particularly in no-tillage systems on soils with low infiltration rates and prone to surface sealing.

√ ***Reduction of soil compaction*** by machines and avoidance of wheel tracks and furrows running up and down the slope.

The increased density of the soil just beneath the depth of tillage (subsoil compaction) is one of the most striking effects of management systems. Tillage and traffic with increasing weight of agricultural machinery cause the subsoil compaction. This problem is especially severe in heavy-textured and poorly drained soils. Sub-soiling, deep ploughing, para-ploughing and numerous other devices have been developed to alleviate the problems created by compaction. The compaction risk or vulnerability of agricultural soils, measured by the pre-compression stress, can be used to give recommendations for site specific farming systems (e.g. implement type, wheel load, and tire inflation pressure). Also, it can allow the agricultural machine industry to develop site-adjusted machines to support the ideas of good farming practices. For more details on measures to prevent soil compaction, we refer to the report on work package 5.

√ Other site- and use-specific measures such as:

- To ***keep waterways on the fields covered*** with stubble and grass or catch crops, at least during most risky periods.
- In Northern Europe countries: to ***avoid autumn ploughing*** of arable land with high and very high erosion risk.
- To drill winter cereals early, without gaps in tramlines.
- To ***avoid fine seedbeds*** that will run together and seal soil surface. Rough seedbeds are more stable.
- Proper ***orientation of crops*** in vineyards and orchards.
- Careful ***irrigation management*** to avoid runoff and erosion. Assessment of crop water needs and control of water droplet size.

2.1.3. Preservation of the (semi-) natural landscape elements

√ Preservation and maintenance of ***plant-covered field edges***, especially of those that run along the contour.

√ Preservation and maintenance of ***hedge rows and groves*** which are able to absorb and infiltrate overland flow respectively to hold up erosion material.

√ Preservation and maintenance of ***terraces*** (in cases, in which they are not more suitable for special land use management or special crops, management or crops should be changed, but terraces should be preserved if possible).

Terraces in the Mediterranean region.

At present, Southern Europe faces crucial problems regarding terraced landscapes due to (i) the extensive abandonment of mountain rural areas and therefore of their soil and water conservation structures and (ii) intensification in modern agriculture that leads to land levelling operations destroying the structure of the terraces.

Four main issues need to be addressed:

1. Conservation of terraces.
2. Restoration of degraded terraced landscapes.
3. Identification of hot spots in Europe where terraces have a special risk for abandonment and related land degradation and erosion problems.
4. Preservation of knowledge about the traditional way of making, repairing and maintenance of terraces. How to stimulate and spread this knowledge? The relation with cultural landscape and national heritage should be highlighted.

The main challenge in the Mediterranean Basin through the history has been, and should be at present, to sustain the fragile and scarce natural resources of water and soil. Since the Roman period, natural and/or man-made terraces throughout the basin have been utilised for water harvesting and soil conservation. These structures were/are part of the indigenous agricultural domains i.e. the agroscapes allocated for particular traditional crops of the Mediterranean such as the olives, vineyards, pistachio, almonds, figs, etc., and grazing for small ruminant such as the goat. Natural Pleistocene terraces were also used as agro-ecosystems. Conservation of these natural and man-made surfaces seeks to secure and/or increase the suitability of the soils overlying calcretes (caliches) and karst limestone for rainfed crops.

The indigenous technical knowledge on how to manage terraces and their crops, which secured the sustainable management of the land in the past, should be taken into account when designing current measures to control soil erosion. This technology comprises a minimal initial tillage and irrigation, so degradation of soil structure as well as leaching of nutrients and loss of limited water resources were prevented.

Measures for terrace conservation may not to be able to cope with the extensive abandonment of mountain rural areas that has experienced the Mediterranean region in the last decades. Therefore, at present and in the next future, a widespread collapse of terraces can be expected. To set priorities for actions, identification of degradation hot spots and sites of particular interest is needed. Specific restoration measures to prevent soil erosion in degraded terraced landscapes should be developed and tested.

2.2. Measures of rural and landscape engineering to support agricultural practices.

2.2.1. Size, shape and direction of agricultural fields, construction of farm tracks

Land use management (tillage, direction of crop rows etc.) along the contour lines can be promoted by a suitable shape of the field and by a respective course of the farm tracks; this should be considered and used in lands at high erosion risk.

In case that land ***levelling*** is needed an ***impact assessment*** should be necessary to look at the impact on erosion, and adequate measures against erosion should be taken

2.2.2. Rural engineering measures to regulate the runoff conditions

These measures are mainly designed to combat the symptoms rather than the causes of soil erosion; accordingly they are secondary measures.

- √ ***Drainage of fields****:* Additionally to the measures by which the farmer can improve the infiltration and avoid the formation of overland flow on arable field or grassland, drainage (pipe, mole or slit drainage) can reduce overland flow on the field itself and onto farm roads, tracks, concrete areas and other off-site objects. Control drainage water from fields by maintaining land drains, pipe outlets and ditches; remove sediment deposited in ditches and drains. Avoid unstable system of ditches in erodible terrain.
- √ ***Contour ditches on more gentle slopes***, with distance spanning 60 to 100 metres, represent a new system for defining sufficiently large surfaces for machinery. The ditch's depth is set up below the plough sole so that a sub-surface draining action is guaranteed.
- √ ***Derivation of subsurface water outlets*** on slopes, which can cause linear erosion forms or mass movements; the derivation of these outflows normally can be made by single incepting drains;
- √ ***Derivation of inflow from neighbouring areas***, e. g. from a farm track running above the effected field or from a neighbouring field together with more or less erosion material; if the real cause cannot be eliminated, the derivation normally can be made by a suitable ditch track or by discharging the inflow water in an intake area;
- √ ***Installation of intake areas*** (infiltration areas), e. g. above boundary strips. Infiltration areas can be located on flattened areas at the lower edge of fields (at the end of linear erosion forms, but also at locations where sheet erosion and overland flow are crossing over a wide line), provided that soil and subsoil are sufficiently capable of absorbing at these locations; intake areas may also be installed for runoff derived from subsurface water outlets (see above);
- √ ***Sedimentation ponds*** would positively contribute to the quality of water resources.
  Adding Al or Fe compounds to water flowing into the sedimentation ponds helps to bind P. This measure is cheap (Euro 3,5/ha) and has been applied in some Northern countries. However, there is a risk that Al will appear in free form in lakes with a low pH, which is toxic for the fauna. Therefore, this method should be only applied under strictly controlled situations (e. g. in a water purification plant).
- √ ***Obstructing linear depressions***: in addition to control off-site damages, this measure contributes to the conditioning of critical local relief properties and of prominent ways for overland flow; these linear depressions are exposed to rill and gully erosion and along them runoff and erosion material can be transported for long distances.

2.2.3. New constructions of landscape elements (buffer strips, terraces etc.) and repair or extension of existing ones

Different landscape elements help to reduce the erosion-effective slope length, they support a harmless discharge of runoff and protect surface waters and other parts of the landscape.

- √ ***Wooded strips, hedgerows and groves*** with intensive undergrowth (low-growing vegetation) running along the contour lines. These strips subdivide long slopes, absorb sediments and overland flow. However, it must be prevented that linear erosion and runoff forms (rills and gullies) break through these strips.
- √ ***Permanent grass strips*** as buffer areas within fields; ***contour strips*** (alternating crops, e.g. strips of grains or grass within root crop and maize fields).
- √ ***Strips along river banks***: broad vegetation strips with well developed undergrowth; their role of protection is comparable with that of the aforesaid landscape elements; they shall reduce the input of erosion material and of loaded overland flow into surface waters; but it must be paid attention again that linear forms (rills, gullies) do not break through.
- √ ***Terraces, plant-covered boundary strips***; they subdivide the slope and diminishes the slope length and steepness; new constructions of terraces are however very expensive; Linked bench terracing has been proposed for valuables vineyards on sloping surfaces in the sandy soils of the Asti province (Piedmont, Italy). These terraces follow a zigzag path up and down the slope, allowing continuity between subsequent planes.
- √ ***Integrated biological systems***: by ecological means, the landscape elements mentioned above should be connected with each other in an integrated system.

2.3. Specific measures to combat wind erosion

Most of the above measures have been designed for preventing soil erosion by water. Lowlands and plains are target areas for measures to combat wind erosion. Most vulnerable to wind erosion are texturally light soils (sandy, loamy).

Specific protection measures against wind erosion are:

- Wind breaks, typically consisting of three or five rows of plants along affected fields, planted for example in the order:
  - o *low hedge – high hedge – low hedge*,
    or
  - o hedge *– low tree – high tree – low tree – hedge*.
- Diminishment of field length in main wind direction (by wind breaks or by strip farming),
- Suitable crop rotation,
- Conservation agriculture,
- Improvement of humus level,
- Maintenance of soil surface roughness,
- Change of land use, if possible, on exceedingly endangered sites (grassland instead of arable land).

2.4. Concrete measures for pastures lands and grazing management

The European Common Agricultural Policy (CAP) determined, by means of premiums, regulatory measures and quotas, some trends in farming systems that increased the risk of soil degradation. Temporary grassland, that exerts beneficial effects on soil, declined, while fodder maize for ensilage increased also under rather unfavourable conditions (e.g. in areas liable to flood, or on slopes). The number of sheep and goats in EU has remarkably increased after a quota system was introduced.

Grazing by domestic or wild herbivores is an ecological factor contributing to ecosystem function, diversity and stability. In central European alpine regions, the recession of the use of high mountains pasture often is a reason for beginning erosion and landslides. Accordingly, maintaining and promotion of high mountains pasture is an important measure against erosion, as long as the management intensity of the pasture is adapted to this sensitive alpine vegetation cover. Grazing however must be rational and adapted to specific conditions of each ecosystem and landscape. This means that the stocking rate should be equivalent to the grazing capacity of a particular site, and the type of grazing animals and the grazing system, namely the season and duration of grazing, should be appropriate for the type of vegetation/rangeland to be grazed; e.g. in the Mediterranean rangelands, it is always recommended to combine grazers and browsers.[7]

The stocking rates may be defined depending on climate conditions; e.g. livestock densities in forage production lands in Spain must comply with the following thresholds:

Annual rainfall < 400 mm: 0.5 Livestock Unit/ha
Annual rainfall 400 – 600 mm: 1 LU/ha
Annual rainfall 600 – 800 mm: 1.5 LU/ha
Annual rainfall > 800 mm: 2 LU/ha

Grazing and fire can be combined in rangelands and silvo-pastoral systems, provided there is a management plan that specifies when prescribed fire should be used and how the burned areas should be grazed. Overgrazed areas should be left aside for some time to recover before animals are again introduced so that overgrazing effects are mitigated.

Additional measures to control erosion in pasture lands include:

√ Avoid practices which cause poaching (problems can occur from gateways, high stocking rates in wet weather, etc.).

√ Avoid overgrazing near or with access to riverbanks. Fencing may be required.

√ For outdoor pigs: careful site location to minimise erosion risks; take account of location, slope, soil type and rainfall. Site management to maintain grass cover or rotate sites.

√ To locate supplementary feeding areas away from water courses; regularly move feeding areas.

2.5. Preventive measures in abandoned agricultural lands.

After the abandonment of agricultural land, especially in dry lands, a management programme has to be established in order to prevent further degradation. Since degradation processes depend on the state of the land at the time of abandonment, prevention measures should include land-abandonment accompanying actions aimed at ***maintaining the soil covered*** (e.g. by leaving plant residues on site).

In case of abandoned land in humid and sub-humid regions, the self-regulating development of natural vegetation (grass, weed, bushes, later wood) normally doesn't need support – except for the first years of abandonment and except for keeping the landscape free of unwanted vegetation developments. However, in central European alpine regions, where the recession of the use of high mountains pasture often is a reason for erosion and landslides, maintaining and promotion of high mountains pasture is an important measure against erosion, as long as the management intensity of the pasture is adapted to this sensitive alpine vegetation cover.

In the case of semi-arid lands, abandonment is usually followed by further degradation, and this is enhanced by the destruction of soil conservation structures (like terraces). Terraced old fields usually concentrate the deeper soils on the hill slopes, therefore they constitute preferential spots for land restoration.

Nowadays, ***maintenance of soil conservation structures*** (dams, terraces) is not a cost-effective measure, unless the socio-economic conditions at the site (e.g. areas of high unemployment) allows the maintenance works, and/or the site is of particular interest for keeping them up, and/or off-site damage risk is very high. In most cases, collapse of these structures will occur. Measures to prevent soil degradation and erosion should be focused on creating ***soil-retaining vegetation barriers*** of deep-rooting and high cover shrubs and trees.

Often, fire-prone ecosystems develop after land abandonment in southern Europe due to fuel accumulation and landscape homogenisation, and this mostly occurs in the vicinity of settlements. These areas should be priorised target areas for fire prevention

[7] Papanastasis, V.P. (2003). Grazing management in the framewok of sustainable management. MEDRAP workshop on Prevention and Mitigation Actions to Combat Desertification. Alicante, June 2003.

actions.

There is an urgent need to devise recommendations for the Mediterranean region taking into account its particular environmental conditions. Particular emphasis should be placed on finding feasible land use alternatives to agricultural marginal areas. The CAP measures for ***afforestation of marginal fields*** are promoting the use of a wide range native species. However, careful selection of the suitable species for each site is needed. Studies on the possibilities of utilising native vegetation for conservation and economic return should have high priority in such areas. Control of subsidies through the assessment of the quality of the restoration programme, species selection, and techniques, is recommended.

3. Concrete measures in forestry

Concrete measures in forestry to prevent soil erosion deal with a wide range of conditions, from highly productive systems, where afforestation and reforestation are managed towards wood production, to non exploited systems that mainly contribute to soil and water conservation. Between these two cases, a large variety of intermediate levels of exploitation of forest lands can be found. Whereas productivity is still important in the best lands, the shift in the weight of direct productivity objectives to other objectives providing goods and services with no market value so far introduce a new socio-economic framework of reference.

3.1. Criteria for afforestation and reforestation

The criteria for afforestation and reforestation should be based on the knowledge on the state of the soils and climatic constrains. Afforestation and reforestation projects must be preceded by a soil evaluation process from which potential plant dynamics can be estimated and the needs and type of soil preparation and cultural treatments can be established.

In the context of prevention and reduction of soil erosion, general criteria for afforestation and reforestation include:

√ ***To minimise impacts on soils of site preparation techniques***. In erosion-prone lands, extensive afforestation with heavy machinery often generates greater erosion problems than those initially existing in the area.

- Planting holes and contour subsoiling are suitable site preparation techniques; bench terracing and subsoiling along the slope should be avoided.

- Clearance of existing vegetation before or during reforestation actions should be minimised and it should be avoided in drylands

√ ***To improve plantation success*** and foster plant cover for accelerating soil protection

- Selection of suitable species. Attention must be drawn not only to their growth rates and easy management, but also to their potential contribution to the ecosystem functioning; the use of exotics should be avoided.

- Proper cultural treatments, including inorganic fertilisation and organic amendments -to enhance plant growth and improve soil structure and infiltration.

- Field techniques to reduce transplant shock and improve resource availability, such as tree shelters, mulches, water-catchment basin around each plant, etc.

√ To establish an appropriate trade-off between enhancing growth of target species and maintaining a minimum protective soil cover, by reducing impact on soils of thinning and clearance actions.

3.2. Soil protection in forestry. Forest management

With increasing mechanisation of forest logging the impacts on soil have also increased. Fragile soils with poor soil cohesion are very sensitive to the impacts of heavy machinery and clearance of vegetative cover, particularly on steep slopes. Sources of impacts include bank erosion, skid trails, logging roads, and timber extraction. Skid trails and logging roads have been identified as the major sources of sediment. Mitigation measures include:

√ Application of ***reduced-impact logging*** to minimise soil compaction and rill erosion, e.g. to control the use of tractors and to design the skid trails to avoid runoff concentration lines.

√ To ***reduce clear-cutting area***, to replace clear-cutting systems by other low-impact cutting systems.

√ To ***vegetate barren roadsides*** as fast as possible using grasses and shrubs adapted to local climate and soil conditions and able to establish by themselves, especially in regions where the natural forest regeneration is slow.

√ To ***divert water flow*** from the road drainage system towards the nearby vegetation, ***bringing overland flow to infiltration*** on provided areas and thus preventing the fast release of this water to streams and rivers.

Organic forest floor materials, such as litter and woody debris, play a major role in preventing soil detachment and providing surface roughness. Practices extensively altering forest floor layer should be avoided. Prevention measures should include conservation measures, such as ***spreading woody debris*** over the skid trials

Northern boreal forests are often growing on organic soils. The removal of the forest cover over large areas causes a disturbance of the hydrological balance. Ground water level is rising and prevents natural regeneration of the forest. Improvement of drainage causes the disintegration of the peat and the release of nutrients polluting rivers and drinking-water sources. There is a need of reducing the size of cutting areas to keep the hydrological balance.

Silvicultural actions –aimed mainly at fire prevention (firebreaks, roads, removal of fire-prone shrublands; see below) but also at improving stand structure– may be self-defeating actions depending on the technique and intensity applied. Vegetation removal (thinning, clearing….) should be carried out without damaging the soil surface, working at some height above surface, and spreading slash on the soil.

3.3. Forest fire prevention and post-fire management

In forest lands, mainly in Mediterranean woodlands, a major and common threat for soil conservation is fire. The sequence 'summer fires - heavy autumn rains' is frequent in Mediterranean climates. In the more fragile soils where plant regeneration rates are slow, the risk of soil erosion is extreme on steep slopes.

The current number and extent of forest fires in many parts of the Mediterranean region are of the most serious environmental problems because it can lead to irreversible soil degradation and the loss of valued environmental qualities.

It is assumed that soil erosion is the most serious ecological impact of fire because of its low reversibility. Therefore, soil conservation is the main priority in reducing the ecological impact of fire. This can be addressed by fire prevention actions and, in case of fire, by post-fire soil conservation and restoration measures; the latter may also contribute to prevention of further disturbance impacts by increasing resistance and resilience of fire-prone ecosystems.

Fire-risk countries have strongly improved the suppression resources, limiting the damages at a high cost and following a policy of total exclusion of fire. Economical possibilities to increase those resources are nearly exhausted. So, forest fire management has to find more effective approaches by improving strategies and technologies for prevention[8].

Prevention on fire causes

Uncontrolled burnings must have a specific program of prevention, because it is deeply rooted in a well-identified segment of the population, the rural one. Prevention of fires caused by uncontrolled burnings needs co-ordinated actions of persuasion, conciliation and prosecution, to modify the human behaviour of the rural population in the use of fire. This program has to be permanent and continuous, with a comprehensive planification supported by a specific database.

Persuasion aims at teaching the rural people that they are directly damaged by the fires in their ownership and environment. This can be done through a variety of awareness raising campaigns or environmental education, and by co-ordinating concerted actions by forest managers, scientific groups and administrative departments. ***Conciliation*** of interests between farmers and Administration may be promoted through a program of controlled burnings in winter. ***Prosecution*** and punishment of people burning without a license and in a careless way is the object of the Penal Codes and the Regional Administrations rules. There are very few data on this preventive action needing analysis to evaluate its effect.

Structural measures to reduce fire hazard could include the diversification of forest land use, the management of recreation and illegal dumping, and the introduction and enforcement of appropriate legal instruments.

Prevention through silviculture

Creating both horizontal and vertical discontinuities requires a variety of techniques for the elimination of flammable matter. In choosing the most appropriate techniques for each case, social, ecological and economic conditions should be borne in mind. For example, in areas of high unemployment, manual clearance is to be preferred. If there is a demand for land on which to raise cattle, ***controlled pasturage*** is likely to be a good choice, since it makes for an economic return as well as clearing fuel-break areas.

Clearing techniques should be based in a deep knowledge of the biology of the target plant species in order to optimise the treatments.

Prescribed burning is a very economical technique that nevertheless requires specific training. When combined with controlled pasturage, it can be highly recommended. Prescribe burning must result in low severity fires, allowing fast plant recovery and organic horizons and burned debris remaining on the burned surface and, therefore, minimising erosion risk.

The use of ***phytocides should always be highly restricted***, in view of the cost and of the difficulty of controlling its effects outside the treatment zone.

Regarding prevention management focused on shaping woodland structure, the aim should be to ***create mosaics of species***, and to integrate other activities that ***give rise to discontinuity***, such as roads, electricity line fuel breaks, farm land, and recreational areas. Likewise, in exploiting the wood, an effort should be made to maintain its density, so as to limit undergrowth.

Wind is also a factor to be taken into account. Tall woodland is a more effective windbreak than scrubland, which is more effective than pasture. On ridges, where the wind changes, and along watercourses, which direct it, tree cover may be an important obstacle to fire, since it reduces wind speed. It is also worth keeping hillsides that face into the prevailing winds well covered with high vegetation that works as a windbreak, while opening fuel breaks on the leeward side, avoiding ridges.

Post-fire management.

It should be assumed that burned soils are highly unprotected and vulnerable to soil degradation, and therefore activities that may promote soil compaction and erosion should be avoided in the very short-term.

Burned lands should be ***protected from grazing*** until the vegetation recovers and protects the soil from erosion. In grasslands, one year is enough for such recovery but rangelands grazing must be deferred for about 2-3 years and shrublands for 4-6 years[9].

There is a moderate to high risk of rill erosion associated to ***post-fire savage logging*** that depends on the vulnerability of soils, with soils developed over marls, sandstone, and gypsum being the most sensitive. Severe logging, characterised by long log slides and high log density, very often results in severe rill erosion processes and therefore these practices should be limited in sensitive areas. However, any limitation to exploit charred wood should take into account the economic consequences for the owners that have to be compensated.

In all cases, post-fire logging should be delayed after the first post-fire rainy season to ensure some plant recovery that protects the soil surface. Vulnerable sites should be protected by conservation measures, such as ***spreading chopped wood debris*** over the log slides

4. Restoration and rehabilitation measures

4.1. Restoration measures to combat soil erosion. Watershed restoration

Restoration programmes aimed at preserving soil and water resources and controlling erosion and floods should be designed as ***ecologically sound, multi-purpose measures***, adapted to the new social demands. The traditional forest restoration approach has to fully evolve to a new ecological approach based on the development of ***site-specific restoration strategies***, on

[8] Vélez, R. (2003). Forest fire prevention in the framework of sustainable forestry. MEDRAP workshop on Prevention and Mitigation Actions to Combat Desertification. Alicante, June 2003.

[9] Papanastasis, V.P. (2003). Grazing management in the framewok of sustainable management. MEDRAP workshop on Prevention and Mitigation Actions to Combat Desertification. Alicante, June 2003.

a ***wide set of species*** choices, and on the introduction of vegetation according to environmental heterogeneity and natural vegetation spatial patterns, ***avoiding uniformly spacing plantings and creating landscape mosaics***, with the aim of recovering previous landscape processes.

The most suitable scale for the application of restoration programmes depends on specific objectives and threats. Degradation-risk hot spots require specific restoration actions to be applied in a very local basis. However, to obtain a significant effect on the threatened systems, the ***use of hydrological units*** is recommended. Watershed restoration typically includes the following actions: vegetation cover improvement, conservation and restoration; streambed of the secondary drainage network and plugging works; soil conservation practices; auxiliary actions (roads, fuel-break areas). This approach allows integrated management of erosion, transport and sedimentation processes

Native species offer a high potential for contributing to restore degraded ecosystems. Native herbaceous, shrubs and tree species might be used depending on the specific degradation stage of the ecosystem and the managerial objectives addressed. For seeder-dominated fire-prone ecosystems, ***reforestation with woody resprouters*** contributes to increase functional diversity and resilience.

The baseline for restoration activities should be a thorough analysis of past reforestation actions, both successful and unsuccessful experiences. In the same way, ***monitoring and data base elaboration*** should be intrinsic components of all restoration projects.

4.2. Post-fire soil conservation and restoration

The first question to address is in which conditions post-fire mitigation/restoration is needed. A second issue would be to set priorities for actions. A third question would be how to protect soils and to restore burned lands.

(A) ***Emergency treatments***. The following measures are proposed as emergency post-fire treatment[10]:

1) ***Previous assessment of site conditions*** and selection of areas with:

a) Poor regeneration potential (e.g. low resprouter cover)
b) High runoff and erosion risk (steep slope, compact soils)
c) High downstream risk of damage (infrastructures, homes)

2) ***Spreading mulch*** (preferably onsite slash) to ensure immediate soil protection

3) Application of ***seeding mixtures using native species***

a) Fast growing annuals
b) Perennials for the persistence of soil protection
c) Grasses and legumes
d) Shrubs and trees to enhance secondary succession

[10] Robichaud, P.R., Beyers, J.L. and Neary D.G. (2000). Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. USDA, Forest Service, Rocky Mountain Res. Station. Fort Collins, USA.

Other hill slope and channel treatments can be applied in certain conditions: contour-felled logs, silt fences, check dams, contour trenches, blankets, etc. Their cost is higher than for seeding/mulching practices, they are hardly applicable to wide areas and, in some cases, impact on soils is high. Therefore their application should be clearly justified.

(B) ***Post-fire restoration actions***

Post-fire restoration strategy faces two main environmental issues: ***promotion of fire resilient plant communities*** and ***forest cover restoration***.

The introduction of sprouting trees and shrubs will enhance the ecosystem resilience after wildfires, and improve diversity and structure of these formations. Controlling (e.g. clearing) fire-prone shrublands with very high fuel accumulation combined with woody resprouter introduction could be a measure to break fire cycles.

In general, all restoration projects for burned lands in fire-prone ecosystems should take into account the principles of fire prevention, e.g. to avoid mono-specific plantations, to reduce fuel accumulator species, to promote more resilient and late-successional vegetation, and to design all interventions in the landscape so to reduce the hazard of fire spread.

4.3. Rehabilitation techniques of degraded soils.

Many areas in Europe exhibit serious soil degradation, normally due to anthropogenic disturbances. Examples in agriculture are abandoned degraded agricultural soils and salinisation by irrigation with low quality water. A particularly low resilience to disturbances due to their low organic matter levels has exacerbated degradation.

Attempts to restore degraded soils need to consider physical, chemical and biological properties. Soil organic matter may play an important role in all of these soil parameters. The improvement of soil properties by the application of organic matter can be a promising strategy in restoring degraded soils, especially in more arid regions in Europe. Different organic materials, such as municipal solid wastes, sewage sludge or poultry manure, uncomposted or composted, have been tested for soil reclamation. Sewage sludge represents a pollution sink in the wastewater treatment process. The higher the purification efficiency is the higher the accumulation of contaminants in sewage sludge can be. To supply organic matter, more appropriate low-emission materials are available.

The ***application of exogenous organic matter*** (EOM) may improve the resilience of soils against degradation processes, long-term improvements can only be achieved if the soils are managed in accordance with the precautionary principle to maintain soil functions on a sustainable basis. To avoid harmful changes to the soil, exogenous organic matter which originates from biowastes or biodegradable wastes shall only be applied when there will be no accumulation of contaminants in the soil (especially by application of sewage sludge, compost, animal manure or mineral fertiliser). Attention must be drawn not only to heavy metal loads, but also to organic pollutants and other environmentally harmful substances (such as xenobiotics and antibiotics) and potential pathogen bacteria, which may have a severe impact on soil born organisms and neighbouring ecosystems. However the application of suitable EOM may help to reduce the vulnerability of degraded soils against erosion processes, it will not stop them. Its ability to reduce erosion is less important than soil cover and land management practices. Hence the dominating aspects in this matter are the concerns about pollutants and hazardous substances, which may be found in some EOM. (See also task 5 report on 'link between erosion and contamination).

Establishing a washing and drainage system may reclaim land affected by salinisation. However, this may be expensive and technically difficult. A net positive cost-benefit balance might be possible when a strong improvement of socio-economic conditions is expected in the reclaimed area: economic development, fixation of rural populations. ***Salt-capturing crops*** may be a suitable treatment.

5. Other sectors

5.1. Reduction of sediment transport in drainage networks. Protection of reservoir sedimentation

Erosion should be stopped at its sources. It is wrong and partly impossible to intercept erosion material and overland flow at the lower end of an erosion system. Nevertheless it is necessary to have measures at disposal, by which an existing or developing erosion system can be obstructed as near to its place of origin as possible.

Measures for that purpose have been described above (2.1. Agricultural Practices to combat soil erosion), particularly those mentioned as “rural engineering measures”, and also measures of installing wooded and vegetation strips. Runoff on farm tracks should be brought to infiltration beside the tracks.

Generally it should be tried to prevent or to reverse concentrated transport and runoff through the landscape and to bring existing overland flow to infiltration on provided areas. The exact identification of the transport pathway helps to find the area of origin and the reason of an erosion/sedimentation event.

5.2. Mitigation soil erosion measures in transport and construction infrastructures[11]

Principles and basis

In many areas, soil erosion causes severe damage and high costs for society and individuals. Different types of soil erosion are frequent such as coastal erosion, bank erosion, landslides, gullies and debris flows. In the following, a common description is given on these forms of erosion, followed by measures suitable for different situations of erosion.

Detailed studies of the problem of shoreline erosion and flooding in the USA point to the fact that there is no problem until structures are built within the impact zone of storm surges or close to soft rock cliffs. The conclusion is that once such structures are built, erosion problems usually follow. This is not only true for properties like houses and hotels protected by sea defences but also for the sea defence structures themselves. Although building a sea defence can provide protection (perhaps only temporary) for a property it may also enhance the risk of erosion or flooding elsewhere along the shore. This is especially true where eroding cliffs are artificially stabilised as this ‘locks up’ the sediments reducing the amount available to adjacent shores. As a result the balance between erosion and accretion will change, potentially increasing its susceptibility to erosion or flooding.

The combined effect of infrastructure development (which destroys habitat) and the erection of defences to protect them have created, in many areas, a narrow coastal zone. The difficulties of protecting this narrow inflexible barrier are increased where the natural resilience of the coast is lost as sedimentary systems. Today river canalisation, dams, irrigation works and activities in the river catchments themselves have resulted in a dramatic reduction in sediment availability on the coast. In areas where relative sea level is rising, there is a further coastal squeeze.

Measures

There is a wide range of techniques available to monitor and manage the many types of erosion and flooding that affect the coast and shores of lakes and rivers. Detection and monitoring techniques include visual observations, aerial surveys and remote sensing images, topographic and bathymetric surveys.

These coastal protection and flood defence techniques can be described in relation to the development of what are termed “hard and soft” engineering techniques. The hard engineering techniques involve the construction of solid structures designed to fix the position of the coastline, while soft techniques focus on the dynamic nature of the coastline and seek to work with the natural processes, accepting that its position will change over time.

Applying various techniques, which can be hard or soft, or a combination of both, provide the means of dealing with the problems. The solutions vary according to the local situation, but ultimately the aim is to identify the best option or options, which secure the coastline both in the interests of the environment and of people, in the most efficient and cost effective way.

An integrated Coastal Zone Management (ICZM) approach

Experience of several years of coastal protection has shown that hard engineering protection structures established by the national and local authorities along the coast, provide very local solutions which do not address the underlying cause of erosion (shortage of sediment) and generally accelerates the problem down-drift the coastal protection. To address this issue whose consequences may affect the whole lagoon ecosystem and related activities (fisheries, aquaculture, and tourism), the national and regional governments, municipalities, the harbour authority, and various universities have joined their efforts to find integrated solutions. As a result, the EU Commission has agreed on a Communication on an Integrated Coastal Zone Management approach. (COM (2000)547). ICZM is based on an integrated and broad “holistic” approach and could be an important instrument in the land use planning of coastal areas.

Coastal erosion – protection measures

As ***general principles for coastal erosion protection***, harbour authorities should apply a “sand by-passing” system through the harbour, thus reactivating the sediment transport processes. It is important to identify areas where natural coastal protection processes could be stimulated, such as dunes rehabilitated or beaches regularly supplied with non contaminated materials collected from dredging activities along navigation channels. It is also important to control illegal sand extraction activities and any other activity that may disturb natural beach and dunes restoration. Finally, the

[11] The text is to a large extent based on and extracted by the Eurosion project, Scooping Study. Final Draft Report of September 2002

urban seafront extension should be regulated; in order to maintain protection costs at a low level.

Coastal erosion occurs mostly in areas with sensitive substrata, such as sand, silt and till or, in minor extension, soft sedimentary bedrock, especially in densely populated areas and/or in areas where buildings and other artificial constructions are located. There are several ***specific measures available*** to mitigate or protect the coastline against erosion:

- √ The most environmentally appropriate method is sand nourishment. Sand is supplied to the coast and the purpose is to compensate for the loss of sand by natural erosion. A similar method is beach scraping where the sand is moved from the lower parts of the beach to the dune foot and works as a buffer in storm situations.
- √ Revetments are structures placed at the foot of a beach slope to protect against erosion in storm situations with high water levels and big waves.
- √ Breakwaters are shore parallel structures placed along the coast. The breakwaters reduce the wave energy passing the breakwater to the coast and reduce the longshore sediment transport capacity with sedimentation as result.
- √ Groins are structures placed perpendicular to the coastline from the beach to a certain distance outside the coastline. The groin is an obstacle to the longshore sediment transport, which means a reduced retreat of the coastal profile.
- √ Vegetation is another way to protect coastal areas against erosion and this can be achieved by establishing certain plants covering the soil.

Bank erosion – protection measures

In rivers and lakes rapid runoff of water with increased speed of flow will cause erosion of the slopes of the banks and sediment transport and deposit off-site. Measures for mitigation and protection against bank erosion are:

- √ Revetments by quarry stones, concrete blocks or gabions.
- √ Nailing vegetation.
- √ In rivers where dams are situated it is important to avoid large outflows from dams in order to avoid damages downstream.
- √ Diverting the watercourse may be applicable in some cases.

Landslides, gullies and debris flows

Forces of nature are working to adapt cliffs and slopes to equilibrium. The still ongoing land uplift and shore-level displacement results in unstable conditions especially for clay and silt deposits. Construction works and deposition of heavy masses on the ground as well as excavations are other factors that can alter the stability of the soils. The frequency of landslides has in fact increased during the last hundred years of industrialisation.

A proper land use planning is the best way to prevent these types of natural hazards.

Mitigation measures in landslide risk areas can be made by:

- √ Revetments (like bank erosion);
- √ Vegetation can be established on the slopes;
- √ Soil counter weight embankments could be applied in the lower parts of the slopes or unloading by excavation of the slope crest.

In many cases the measures are combined to achieve the most effective result.

To protect against debris flow it is important to maintain existing vegetation to prevent a fast run off of surface water. Also revetments by stones or concrete can be used. Dams and energy absorbers are common measures.

Transport infrastructures.

There is a wide range of techniques available to control talus erosion in transport infrastructures. It is important to apply the proper talus slope and sequence of actions:

- √ Removal and storing of the top soil prior to the works.
- √ Maximum talus slope: 2/3 (vertical/horizontal).
- √ Application of the stored top soil over the talus, with or without organic amendments.
- √ Hydroseeding of talus, particularly in wet climates.
- √ Alternative techniques such as blankets, organic nets, etc… .
- √ Planting shrubs and trees, before, after or instead of hydroseeding.

6. Development of programmes in education and training

6.1. Networks and platforms for the dissemination of information and transfer of technology

It is important to consider soil degradation as an issue involving and affecting the whole society. The scientific community should be encouraged to generate information on soil degradation. The dissemination of such information is essential to create awareness of the environmental problems associated with soil degradation. Information and environmental friendly methodologies should be provided to people affected by soil degradation but especially to those at the local level, who are the most directly affected. It is important to develop regulations at the owner level that lead to the re-structuration of inadequate agro-forestry, urban and recreation use of the land. Awareness raising actions need to be targeted in their approach, particularly within vulnerable areas.

In recent decades, Mediterranean countries have made a serious effort to combat soil degradation through a wide array of technical approaches. However, most of these experiences have been developed on a national, and even local basis, with poor communication and very limited co-ordination among the various countries. Detailed databases on prevention and mitigation measures are lacking, and co-ordination between actions has been very limited. A number of actions needed can be identified:

- √ Improvement and co-ordination of data on soil erosion by natural hazards.
- √ Databases for integrated risk management for public accessibility.
- √ Increase public awareness.
- √ Analysis of the policy for public-investment and of economical effects.
- √ Network for co-operation and information exchange.
- √ Network between researchers, practitioners and policy makers.
- √ Harmonisation of classification and

terminology.

Networks and platforms for the dissemination of information and transfer of technology on prevention and mitigation measures for combating erosion are needed for the diverse activities concerned (agriculture, grazing, restoration, forest management, etc). As an example, the EC-funded REACTION project aims at building up a database of relevant information and experiences on restoration projects, and therefore at facilitating access to high quality information for forest managers, scientists, policy makers and end users.

Regarding fire risk, in too many cases heavy investments are made in fire-fighting equipment
(Planes and fire engines) rather than in preventive silviculture. Measures co-ordinated among the Mediterranean countries concerned are therefore highly recommended.

Thematic permanent bodies could establish, centralise, harmonise and update databases on measures to control soil erosion, including a network of pilot projects, taking care of disseminating information for the appropriate stakeholders

6.2. Programmes in education, training and transfer of technology for farmers

Programmes in education, training and technology transfer should take into account the local situations and the socio-economic context in order to ensure that measures can be put into practice. The use of information technology, specially based on the Internet, need to be fostered in order to facilitate the dissemination of best practices. Measures/actions include:

√ **Advice/guidance booklets**. Example: Best farming practice; profiting from a good environment (Environment Agency for England and Wales).

√ **Demonstration Farms**. As an example, England has four demonstration farms across the country, which address soil management. Land managers can visit these farms and gain advice on good soil management.

√ **Voluntary Partnership**; examples: *Voluntary Initiative*, which is an industry alternative to the Government's proposed pesticide tax which aims to reduce the environmental impact of pesticides; Voluntary *Partnership - Diffuse Pollution Projects,* which are set up as partnership projects to tackle diffuse pollution on a local scale.

√ **Training from public institutions**. As examples in Northern Europe countries, both Municipalities and Extension Services in Norway support the farmers to write an Environmental Action Plan for his/her farm and take care to educate them. Extension Services make trials to show the effect of diverse measures on erosion. In Iceland the Soil Conservation Service tries to encourage responsibility of the individual land users

In practice most farmers are not aware that they have an own (financial) interest to reduce erosion and land degradation. By developing education material (national/regional) in which the on-farm consequences of erosion and the financial impact are shown, this awareness could be increased. This task may be carried out by a collaborative work of European and national Soil Conservation Services.

√ **Mapping examples**; e.g. the Norwegian Institute for Land Inventory is mapping agricultural soils in watersheds feeding into North Sea and Skagerrak, and producing erosion risk maps. The maps are free available for both municipalities and farmers.

√ **Agro-ecological decision support systems**: Soil quality evaluation and monitoring. Emerging technology in data and knowledge engineering provides excellent possibilities in the land use planning and soil management recommendations analysis. This analysis basically involves the development and linkage of integrated databases, biophysical models, computer programs, and optimisation and spatialisation tools, which constitute actually the decision support systems.

MicroLEIS (Http://www.microleis.com), analyses the influence of selected physical indicators on critical soil functions referred to land productivity: agricultural and forest soil suitability, crop growth and natural fertility; and referred to land degradation: runoff and leaching potential, erosion resistance, pollutants absorption and mobility, and subsoil compaction. Therefore, this system appears to be an appropriate approach to develop the soil physical quality evaluation.

The case of Conservation Agriculture: some lessons

Activities that can contribute to increase transfer of technology actions are:

1) Organisation of seminars and workshops for farmers to discuss technical and environmental aspects.
2) Organisation of field days and machinery demonstrations in farms. These field days are very important for the transfer of technology in the agrarian sector.
3) Provide Training Courses for farmers and advisers.
4) Provide Topic Sheets on practical implementation.
5) Recurring edition of bulletins with news, activities, technical advances, etc.
6) Promotion of no-till clubs at local level, where farmers can directly exchange experiences.
7) Organisation of seminars for technicians from administration and private companies. For the good implementation of agri-environmental measures, it is very important that the staff of the administrations concerned have a good knowledge of the techniques.
8) Participation in fairs, conferences and seminars of importance in the agrarian sector showing stands, etc.
9) Diffusion through mass media: articles in specialised mass media.
10) Dissemination of information through Internet (web sites).

6. Soil erosion monitoring

The following approaches are recommended:
- Monitoring systems focused on prevention, mitigation and restoration measures.
- Ground-based and remote sensing monitoring.
- Ground-based monitoring sites in erosion sensitive areas.
- Assessment of erosion risk based on land use.
- Develop monitoring system in relation to water quality monitoring.

- Action-driven and multi-purpose monitoring.
- Monitoring systems performing landslide warnings based on continuous measurements of pore water pressures or deformations in the soil layers.

For ground-based approach, evaluating and monitoring soil quality is a very complex undertaking. Knowledge-based decision support systems considering separately soil physical quality and soil biological quality appear to be an appropriate way to formulate, for each unique soil, the best agricultural practices to minimise land degradation processes such as soil erosion. On this important and timely topic much needs to be done. The development and use of these computer-based tools would be one of the major tasks of a possible EU Soil Conservation Service (e.g. USDA NRCS, Http://www.nrcs.usda.gov).

The Working Group on Soil Erosion developed a detailed proposal for soil erosion monitoring in Europe, as an input for the Working Group on Monitoring within the Soil Thematic Strategy.

7. Main areas where research is needed

Mechanisms

√ To define thresholds for land restoration.

√ Interactions on soil tillage-soil quality. Possibilities of no-tillage in different ecosystems.

√ Effects of different climate change scenarios on the erosion mitigation actions.

Monitoring and modelling

√ New tools to monitor, assess, and predict soil erosion under diverse management system.

√ Development of means to monitor and measure the extent of erosion in catchments that are robust and meaningful and relatively inexpensive.

√ Sensitive biological indicators of soil quality to evaluate extensive/intensive agricultural systems. For example, to explore the potentiality of biochemical properties (e.g. enzyme activities) in the assessment of soil quality.

√ Development of models (for practical use) for predicting linear soil erosion (rills, gullies), especially regarding their ability to break through till surface waters.

√ Development of models (for practical use) to assess the connection between soil erosion on agricultural land and sediment load of rivers.

Preventive measures

√ Develop new knowledge and implement existing knowledge in land-use planning.

√ Develop new preventive and mitigation measures against soil erosion for European conditions.

√ Development and implementation of land use DSS tools to formulate sustainable soil use and management systems.

Risk analysis

√ Improvement of hazard, consequence and risk mapping methods.

√ Identify areas and situations with high vulnerability.

√ Identify acceptable risk levels.

√ Cost-benefit analyses.

Others

Today, the use of new herbicides is drastically changing the methods of crop production, without knowing exactly their impacts on soil quality/degradation. Soil contamination risk by herbicides must be deeply analysed.

In Conservation Agriculture, there is a clear need of applied research for the practical implementation in different agro-ecosystems, providing farmers with recommendations on fertilisation, control of weeds, machinery. Effective weed management is needed for the correct adoption of zero tillage system. Emphasis is needed in research at farm level.

There is also a great need to investigate the 'side effects' of CA regarding the net greenhouse gas effect (carbon sequestration versus N_2O & CH_4 production).

SOIL EROSION

Task Group 4.2 on
POLICY OPTIONS FOR PREVENTION AND REMEDIATION

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Executive summary

1. The first point to make is that this paper has focussed on activities that cause soil erosion and the policies to address this. Much work has been done on identifying agricultural and forestry activities, however, more work is required to identify other sectors, such as the construction industry, and explore the possible policies to protect soil within them.

2. Soil erosion is a common problem in the European Union. However, distinguishing geological and climatic features of each Member State often lead to distinct policy priorities for tackling soil erosion. In general, northern European countries are more concerned with the off-site impacts of soil erosion, which can cause eutrophication in water courses, while Mediterranean countries are more concerned with desertification. Therefore, although the aim to reduce soil erosion is common, the answers lie in national solutions adapted to each country's needs.

3. As far as soil protection is concerned, a common issue amongst most European countries is the lack of specific legislation to combat soil erosion. Isolated and dispersed regulations on this matter may be found within the framework of other regulations focused on different subjects, such as protection of water quality and highways and roads. Only Germany, Austria, Switserland and Spain have a specific regulation for soil protection or conservation. Only in Switzerland, are there legal guide values for soil erosion (2 t/ha/yr and 4 ton/ha/yr for soil depths of < 70 cm and > 70 cm respectively). In Switzerland, the 'Law on Agriculture' provides a relatively high degree of soil protection, in particular (inter alia) against soil erosion. In Belgium, a Flemish Parliament Act on soil protection is under political discussion.

4. In most Member States, the principal instruments to tackle soil erosion are economic instruments in the form of cross-compliance (sanction) and agri-environment schemes (incentive). Member States are distinct in how they control soil erosion through these means. With regards to cross-compliance, some Member States have introduced specific environmental requirements targeted to soil protection. Most agri-environmental schemes have indirect measures - that is, their first purpose is targeted at conservation, landscape or biodiversity, not soil; a few schemes also have specifically targeted soil measures. Many Member States have voluntary Codes of Good Farming Practice (GFP) which give advice on soil conservation measures. GFP constitutes the baseline requirement for farmers wishing to join agri-environmental schemes. Only farming practices going beyond GFP may qualify for agri-environmental payments. These payments mainly cover the loss of farmers' income for adopting environmentally friendly practices. Measures related to less-favoured areas (LFAs) also require the respect of the codes of GFP. In general terms, good progress for soil conservation has been made in the agricultural sector through the agri-environment schemes and the introduction of codes of good farming practices. *We recommend that Member States should identify the soil resource more clearly as an objective of agri-environment schemes and increase the profile of soil within the codes of good farming practice. Agri-environment schemes need to be targeted on particular areas that are vulnerable to erosion and support in the form of advice and guidance to farmers is also important to ensure their effectiveness.*

5. A number of EU directives, regulations and agreements that have the provision to tackle soil erosion, have been identified in the text. The Water Framework Directive, the CAP and the Kyoto Protocol are among them. For example,

- Where "good status" in water bodies is not achieved by 2015, and the reason is identified as diffuse pollution, Member States will have to take action to control it. The links here between diffuse pollution, the WFD and soil erosion must be made.
- As a result of the latest CAP reform in 2003 and the growing importance of environmental principles introduced by the establishment of cross-compliance, soil protection has been specifically addressed by the agricultural sector i.e. good agricultural and environmental conditions to Regulation (EC) N° 1782/2003. Furthermore, rural development programmes foresee a large number of further specific measures to prevent soil erosion via agri-environment schemes, which should produce a higher level of soil protection over land in these schemes.
- Through the Kyoto Protocol, there may be a possibility to encourage soil carbon sequestration which, as well as combating climate change by reducing atmospheric carbon, would have a beneficial effect on reducing soil erosion.

6. *The WG identified different steps towards a European policy on soil protection: 1) Member States take a closer look at what is currently available to them in the form of existing European directives etc. to address erosion; 2) Member States identify the gaps in current directives in order to define the need for new legislation; 3) The Commission develops a soil framework directive.* Where it is envisaged that new measures are to be implemented in the framework of other policies, Member States must be aware of the importance of farmer support, in order to succeed in reaching the environmental requirements. Given the limited financial and human resources, and the fact that national initiatives already exist, member states should be encouraged to *rearrange and optimise budgets,* rather than incurring additional expenses. Furthermore, costs, effects and benefits of the measures have to be monitored.

7. *We recommend that the Commission should stimulate the process of the promotion and establishment of technology transfer programmes, structure modernisation plans, training programmes and research and development actions.*

8. It will be important for Member States to identify the gaps in national policies that control soil erosion and consider the following new recommendations:

- *Raise awareness of soil erosion, and suggest activities to reduce the risk*
- *Encourage measures to increase the soil water retaining capacity of the land in areas vulnerable to flooding*

- *Provide economic incentives (such as tax benefits, subsidies, etc.) to farmers who use sustainable production systems*
- *Set up a member state soil conservation service to ensure soil policies are implemented*
- *Explore the merits of Integrated Farm Management, Organic Farming and Conservation Agriculture as systems that contributes to soil protection through sustainable farm management.*
- *Introduce and practice the Integrated Coastal Zone Management approach.*

This section attempts to outline current policy measures to tackle the issue of soil erosion in a number of European countries. We cover countries in northern Europe, the Mediterranean and Eastern Europe – areas which all have different issues associated with protecting the soil. The measures are divided into regulations, economic instruments, such as incentives, and social measures, such as advice and information. We then highlight European directives where soil erosion could be addressed, but is not widely done so, as a signpost to member states. Finally we identify the policy gaps to tackling soil erosion successfully in Europe and suggest some recommendations in these areas.

4.2.1 – Identification of existing policy instruments in member states

Mandate*: consideration and better understanding of legislative, economic and social instruments currently applied in MS, taking into account regions and local situations. Attention should be paid to complexity and diversity of soil.*

Soil erosion is a very important issue in Europe which affects all European Union Member States. However, the range and concrete effects related to this subject depend on a large series of variables which refer to complexity and diversity of soil and climate all along our continent.

NORTHERN EUROPE

In **Norway**, there are no regulations that directly or indirectly cover soil erosion**.**

Land use changes have led to increased erosion, loss of the cultural landscape heritage and decreased biodiversity. As a result of this environmental crisis, the Norwegian government decided to prioritize the reduction of erosion and a soil mapping programme was established for the watersheds feeding into the North Sea and Skagerrak. Based on the soil maps, erosion risk maps were produced and an Agri-Environmental Scheme was established to support farmers in taking the right decisions to reduce erosion. The Environmental Scheme is voluntary.

As soil erosion in Norway mainly occurs in autumn and spring, the measures are targeted at reducing autumn ploughing in the areas with a high to very high erosion risk. Several environmentally friendly soil treatments are subsidized and the level of subsidizing is for some elements directly related to the erosion risk level. A specification of the support to a changed soil treatment and other measurements in 2002 is given given below.

NORWAY

Support to a changed soil treatment in Norway in 2002

Treatment	Support Euro/ha
Direct drilling autumn wheat	50
Superficial autumn harrowing	38
Autumn wheat after superficial autumn harrowing	38
Stubble during winter:	
Little erosion risk	50
Medium erosion risk	75
Large erosion risk	138
Very large erosion risk	175
Catch crops	138 / 88 [1]
Grass covered waterways	5 [2]
Spring ploughing in areas exposed for flooding	75
Spring ploughing in areas exposed for wind erosion	75

[1] depending on the region [2] support in Euro/metre.

The following technical measurements are part in the Environmental Scheme: construction of sedimentation ponds and riparian buffer zones and taking hydro-technical measurements on fields. The amount of support is related to the costs for the farmer. In the period 1994 – 2001 the cumulative subsidy for sedimentation ponds was 1.2 million Euro divided over 53 ponds; for riparian buffer zones the cumulative subsidy was in the same period 0.18 million Euro divided over 245 units.

In 2002, nearly 20 million Euros divided over 11806 farmers and covering ca. 205,600 ha, was given as support for changed soil treatment. In the last few years the interest for catch crops has increased considerably. The part of the scheme dealing with changed soil treatment has been highly successful and model calculations show that Norway has nearly reached the targets of the North Sea Declaration.

Another element in the scheme is the change from cereal production to permanent vegetation cover on fields marginal for cereal production and having a high to very high risk of erosion. Support is given to change arable farming land into grazing land, land for grass production and production for bio-energy, seeds and other crops giving a good protection against erosion. No support is given for afforestation and the production of Christmas trees and Christmas decoration. The support for altering covers 70 % of the costs for the farmer with a maximum of 625 Euro/ha. After altering, a yearly support of 125 Euro/ha is given.

Municipalities and extension services give farmers support and advice on how they can reduce erosion on their farm. Extension services provide demonstration farms to show how different measures can reduce soil erosion.

In **Finland** there is an Environmental Scheme based on the EG Directive 1257/1999. Its main objective is to reduce the consequences for the environment by improved agricultural methods to protect biodiversity in the agricultural environment, to protect flora and fauna and to protect the cultural landscape. An objective is to increase the organic content of the soil and to keep soil productivity stable or to increase it. The farmers get support to stop autumn ploughing and to keep the soil covered with vegetation during wintertime. The support is not dependent on the soil type, the erosion risk or terrain form and is 140 Finnish mark/ha.

We have no information of any regulation or social instruments to reduce soil erosion.

Policy instruments concerning soil erosion in **Sweden** may be found in legislation, codes, regulations and guidelines from governmental authorities and standards. Most of these documents are harmonised with other EU member states. Normally, soil erosion issues are not described in detail but will often be a consequence of or a part of a more general aspect. Some policy instruments, which influence soil erosion, are listed below.

The Planning and Building Act (PBA) **-** supplies a framework within which the municipality can act. Soil erosion issues should be considered mainly in land use planning. One characteristic feature of the PBA is that it sets out a series of general requirements to be observed in the planning and design of building development.

National Environmental Objectives - The Swedish Parliament has established 15 environmental quality objectives to guide Sweden towards a sustainable society. The environmental objectives will function as benchmarks for all environment-related development in Sweden, regardless of where it is implemented and by whom.

The Swedish Forestry Act - general legislation for forestry issues, several aspects which may cause soil erosion are described. The focus is to provide a valuable yield and at the same time preserve biodiversity.
The Environmental Code - The aim of this code is to promote sustainable development based on the understanding that nature is worthy of protection in its own right, and that man's right to exploit nature carries with it a responsibility. The Environmental Code is further elaborated and specified in the form of ordinances, regulations issued by public authorities and decisions taken in individual cases. We have no information on economic instruments.

In **Iceland** protection from grazing was an important part in early soil conservation measures and reclamation efforts. The Soil Conservation Service had an important role in that. Today emphasis is on the promotion of a sustainable land use and it has tried to involve individual land users. An important development is the recent agreement between sheep farmers and the government, where a part of the production subsidies are tied to "quality management" that includes sustainable land use.

In **Denmark**, policy is mainly based on protection of the environment, groundwater, surface water and types of nature.

There is no legislation for the regulation of agricultural practices in relation to soil erosion. However, subsidies can be obtained by farmers to prevent wind erosion, which is a major problem in Denmark. Farmers can participate on a voluntary basis, and receive a grant of 50 % for soil preparation, plants, planting and maintenance for 3 years if the hedges form part of a regional shelterbelt project. Despite the high investment costs, this policy resulted in the planting of 1000 km of shelterbelts per year (Veihe et al., 2003).

Furthermore, one piece of Danish legislation focuses on soil erosion, mainly protecting the coast and coastal zones. The general policy on coastal protection is based on natural development, and protection is only established if there is a risk of bigger loss of land or risk for human life. Both policies are summarized in Table 1.

Table 1: Legislation and arrangement to prevent soil erosion.

Legislation/arrangement	Type of arrangement	Effect	Administration by
Planting windbreaks	Subsidies	Slow down the wind.	National authorities
Dune preservation	Conservation		National authorities

Most legislation on the protection of land against soil erosion aims at preventing nutrient losses to the water environment, in order to protect surface water from pollution and conserve groundwater as drinking water. The legislation on environmental protection and planning regulates the use of land, for instance the discharge of wastewater, and might also have an effect on preventing soil erosion. Also the national river legislation has some rules about tillage free banks of the streams, which can prevent local erosion.

As far as farmland is concerned, there are several possibilities for the farmers to obtain subsidies for sowing persistent grass or planting new wood. The different arrangements are listed below.

DENMARK
Legislation and arrangement in the Farmland in Denmark to prevent loss of nutrient to the environment.

Legislation/arrangement	Type of arrangement	Effect	Administration by
Stream law	2 meter of tillage free riverbanks.	Less loss of soil to the stream.	The stream authority, mainly the municipalities and counties.
Water Environment Plan	65 % of the fields must be wintergreen. 6 % successive grow.	Reduces water erosion. Minor effect on wind erosion.	National authorities
Environmentally friendly land use	Subsidies of • Permanent grass • Set-aside • Catch crop • Buffer strips	Vegetation during the winter period reduces soil erosion. The roots stabilise the soil particles.	County authorities
CAP	Subsidies of set-aside	Permanent vegetation cover prevents soil erosion and improves soil structure by increasing C content. The roots stabilise the soil particles.	National authorities
Forestation	Subsidies to plant new forests		National authorities

Over the last few years, there has been a tendency to keep green cover for a longer time as a consequence of the water environmental plan. The main purpose is to prevent nutrients from being washed out of the soil, but the measures may have a minor impact on preventing soil erosion. Future actions to change agricultural practices towards higher protection against soil erosion will be more focused on advisory on best practices than on legislation.

In **England and Wales** soil erosion is not covered by any specific law. The only piece of legislation that could be used directly to prevent erosion from occurring is the Anti-Pollution Works Notices detailed in Section 161 of Water Resources Act 1990 (as amended). The legislation gives the Environment Agency for England and Wales the powers to require action to be taken to prevent potential pollution where activities are likely to result in polluting material entering controlled waters. In practice Anti-Pollution Works Notices are seldom used.

However, there are additional pieces of legislation that can be used to deal with the impacts of erosion once it has occurred. In practice these pieces of legislation provide erosion prevention controls by both the disincentive of prosecution and by requiring measures to be put in place to prevent the problem occurring again. In summary:

- The Highways authorities, responsible for the roads in England and Wales, have powers under Section 151 of the Highways Act 1980 to serve notices on the owner/occupier of adjoining land requiring them to take action to prevent soil from that land being washed onto the road.
- Local Authorities can also serve notice under Section 80, Environmental Protection Act 1990 requiring measures to be put in place to prevent erosion from occurring where the soil deposited causes a nuisance (as defined in Section 79). An individual may also act under Section 82 of the Act on a complaint made by any person on the ground that he is aggrieved by the existence of a statutory nuisance.
- The Environment Agency for England and Wales can take legal action where a person causes or knowingly permits any poisonous, noxious or polluting matter to enter controlled waters under Section 85, Water Resources Act (1991). The courts can impose up to a three month prison sentence, or up £20, 000 fine or both.
- Similarly, the Environment Agency can also take action under Section 4, Salmon and Freshwater Fisheries Act 1974 where a person has caused, or knowingly permits any liquid or solid matter to enter into any waters containing fish to the extent that it causes the waters to be poisonous or causes injury to fish, fish spawning grounds, spawn or the food of fish.
- In Scotland, the Scottish Environmental Protection Agency (SEPA) also has Anti Pollution Works Notices under section 46, Control of Pollution Act 1974 (as amended) that can potentially be used to prevent soil erosion. SEPA also has powers under Section 33, Environment Act 1995, to prevent, minimise, remedy or mitigate the effects of pollution on the environment, and under Section 35, Environment Act 1995, which places a duty on SEPA to consider adverse effects of activities on SSSIs when undertaking pollution control duties.

UK statutory designated conservation sites do not explicitly require the control of soil erosion, however, they indirectly reduce erosion risk by controlling stocking rates to avoid over-grazing. Operations such as ploughing, reseeding and drainage are also likely to be precluded if they are likely to result in degradation of, or changes to the characteristics of the site.

Within Less Favoured Areas (LFAs), farmers are obliged to abide by the Code of Good Farming Practice. The conditions do not explicitly refer to soil erosion but do refer to the Air (non-statutory), Soil (non-statutory), and Water (statutory) Codes that cover these issues

In **England** the agri-environment scheme is known as Countryside Stewardship (CSS). It is currently under review, and a new proposal is to add "protect the natural resources of water and soil" as an objective. Land managers that apply for the Scheme must follow "Good Farming Practice" conditions. Those which contribute towards reducing soil erosion include: avoiding overgrazing and supplementary feeding; not removing field boundaries; encouragement to follow soil and water codes of good agricultural practice; and protect hedgerows, rivers, streams and banks.

There are many measures in the Scheme that are aimed at improving habitats or enhancing the landscape but that also double to reduce soil erosion. These are laid out below along with payments that the schemes offers land managers, converted into euros (£1 = €1.4). A base-level agri-environment scheme is expected in England in 2005. It aims to encourage a large number of farmers across a wide area of farmland to deliver simple yet effective environmental management on their farm. One of the areas of focus is diffuse pollution and soil erosion and the application for the ELS contains an erosion risk assessment that farmers must complete to identify those fields at high risk. They are then directed to the relevant options to tackle erosion if they wish to use ELS to address them. The land manager will receive a flat rate of €42 / ha if they can ascribe 30 points/ha for undertaking management practices, each of which are valued by points. Those measures relevant to tackling soil erosion are set below, with the number of points attributable.

ENGLAND

England agri-environment scheme measures

Landscape Type and Feature	Payment €/ hectare (unless stated)
Arable	
Recreating grassland	394
Managing arable field margins (6m alongside fields and water courses)	45
2 m grass margins	11/100 m
2 m beetle banks	17/100 m
Overwinter stubbles: followed by a spring crop; low input spring crop; spring/summer fallow	56;176;731
Conservation headland (strip along edge cereal crop 6-24 m wide); unfertilised	127; 380
Recreating chalk and limestone grassland on cultivated land	394

Continued…

Landscape Type and Feature	Payment €/ hectare (unless stated)
Field boundaries	
Hedge laying/planting	4.2
Stonewall restoration	17
Bank restoration	14
Tree planting and management	1/tree
Buffer strips 4-12 m	8.4/100 m
Wildlife strips (e.g. along water courses suffering erosion)	22.5
Uplands - target restoration and management of heather moorland	
Upland hay meadows	210
Upland grazed pastures	84
Upland rough grazing	28-63
Regenerating heather on agricultural improved land	99
Waterside land	
Recreating waterside grassland on cultivated land	394
Capital items	
Fencing and gates	Average1.1/m
Wooden gate	150

Entry level Stewardship Scheme measures

Option	Points gained / ha
Soil management plan - only acceptable where at least 10% of fields are identified as being at risk from soil erosion	2
Buffer strip: 2 m, 4 m, 6 m	10, 20, 30/100 m
Uncropped cultivated margin: 2 m, 4 m, 6 m	10, 20, 30/100 m
Uncropped margin on intensive grassland: 2 m, 4 m, 6 m	10, 20 30/100 m
Overwinter stubble	70
Conservation headland in cereal fields; no fertiliser	80; 220
Management of maize crops to reduce soil erosion	15
Management of high erosion risk cultivated land	15

In **Wales** farmers in agri-environment schemes are expected to manage their land in accordance with the Air, Soil and Water Codes. Additional soil protection is provided by habitat protection measures within the Whole Farm and Voluntary Options sections of the scheme. Agri-environment schemes also protect traditional field boundaries, which are important in intercepting down slope run-off and so help reduce the extent of erosion. All agreement holders have to adhere to a set of general prescriptions applying to the entire holding. Those which contribute to reducing soil erosion are as below.

WALES

Agri-Environment Scheme measures in Wales

Prescriptions
Retain all existing traditional boundaries (eg stone walls, earth banks, hedges and slate fences) and maintain those that are stock proof.
Retain a buffer strip 1 metre wide from the base of the field boundary (on each side) without using any cultivations, fertilisers, lime, herbicides or other pesticides
All ponds, streams and rivers must be protected by a 1 metre wide buffer strip (extended to a width of 10 metres when using farmyard manure, slurry or other organic manures
Agree a whole farm stocking rates that avoids overgrazing or undergrazing. Overall stocking rates should not exceed 2.4 livestock units/ha
Agreement holders are expected to manage their land in accordance with the Codes of Good agricultural Practice for air, soil and water
The entire holding must be managed in accordance with the Good Farming Practice.

Payments are set out as below

Agri-environment payments in Wales

Measure	€ per ha
Winter stubbles (after a conventional crop; after an unsprayed crop)	112; 168
Rough grass margins	490
Uncropped fallow margins	630
Wildlife cover crop	490
Conversion of arable land to grassland	133-308
Streamside corridors	434
Hedging (planting, laying and coppicing)	2.8/m

In **Scotland** farmers in the agri-environment scheme must follow certain General Environmental Conditions and the Standard of Good Farming Practice, which apply over the whole of the land belonging to the farm. The conditions set out in the General Environmental Conditions that relate to erosion include: on some land you should avoid damaging the conservation interest by not undertaking new drainage works, ploughing, clearing, levelling, re-seeding or cultivating and ensure that livestock are managed to avoid poaching; you should follow the guidance approved by Scottish Ministers for the avoidance of pollution, i.e. The Code of Good Practice for the Prevention of Environmental Pollution from Agricultural Activity (PEPFAA Code).

The Good Farming Practice guidelines also require that the whole farm is managed to ensure that livestock is managed to avoid overgrazing and poaching (compaction).

The RSS contains a number of agri-environment options that though not designed specifically for erosion control can provide some protection, which include: management options for grassland, heath and moorland for birds and biodiversity; and prescriptions for field margins and boundaries.

Western and central Europe

In **Belgium**, existing instruments differ between regions (Flanders and Wallonia):

Flanders

A Flemish Parliament Act on soil protection has been prepared recently by the administration and is at present under political discussion. This act will provide the opportunity to lay down source and result oriented standards, to introduce protection measures and to demarcate soil protection zones. Hence, this act will be the first legal instrument for protecting the soil directly, for instance against soil erosion.

Until now, the protection of point and linear landscape elements such as hedgerows and sunken lanes through the Flemish Parliament Act on Nature Conservation, provides an indirect means of protecting the soil against excessive runoff. But there is no or hardly any legal way to impose erosion prevention measures to farmers, nor to punish them for damage or pollution by off-site sediments. Some municipalities set up police regulations, but these are restricted by the constitutional rights of land owners and land users, such as the right of ownership and the freedom to engage in professional activities.

In Flanders, both local authorities (municipalities) and farmers are being stimulated to take preventive and/or curative actions against soil erosion in high risk areas, for the sake of soil protection and protection of the environment in general (e.g. water quality). The most important trigger for the development of a real soil erosion policy, however, has been the numerous muddy floods causing a lot of damage to private properties and public infrastructure in Southern Flanders.

Subsidies for municipalities: Since December 2001 ([1] 'Besluit Vlaamse regering van 7 december 2001 houdende de subsidiëring van de kleinschalige erosiebestrijdingsmaatregelen die door de gemeenten uitgevoerd worden' or 'Erosion Decree'), subsidies can be attributed to municipalities to draw up a municipal soil erosion action plan, and/or to carry out small-scale soil erosion prevention or combating works. The respective subsidies amount to € 12.5 per ha planning area, and 75 % of the total costs of the works, including compensations for the landowners and for the farmers.

Subsidies for farmers: Today, individual farmers can be subsidized for taking environmental measures that have a wider scope than soil erosion prevention. These are adopted in the 'Flemish Plan for Rural Development' in the framework of the European regulations 1257/99 and 1750/1999, such as cover crops (€ 50 ha^{-1}/year), afforestation (between € 850 ha^{-1} for popular and € 3700 ha^{-1} for oak) and grass buffers strips along rivers and sunken lanes (€ 0.13 m^{-2} y^{-1}). Also set-aside can be beneficial for erosion prevention when it is applied to slopes prone to soil erosion. The set-aside subsidies vary between € 298 ha^{-1} and € 424 ha^{-1}, depending on crop type and the agricultural area (in 2002). However, grants for specific soil erosion prevention or combating measures at the field scale have only recently been proposed to and approved (26/6/03) by the European Commission for adoption in the 'Flemish Plan for Rural Development'. The new grant system is expected to be operational from 2004-2005. The measures are set out below.

Agri-environmental measures:
The new agri-environmental measures for the prevention and combating of soil erosion at the field scale in Flanders.

Measure	Financial support
Grass buffer strips at any field border or in the field	0.13 €/m²
Grassed waterways	0.16 €/m²
Small dams with retention pond:	depending on the height of the dam (between 0.3 and 1 m high):
- in arable land	- between 1 and 4.4 €/m
- in grassland	- between 0.7 and 3.4 €/m
Conservation tillage (non-inversion tillage)	80 €/ha
No till (direct drill)	200 €/ha
Preservation of grassland on strategic locations, i.e. on steep hillsides where it prevents erosion, or below arable hillsides where the grass functions as a sediment trap	200 €/ha

All values are on an annual basis. The farmer makes a contract with the Flemish authorities for five years. An additional compensation of maximum 30 % by the municipality or by the province can be granted.

Fields that are eligible for these grants will be indicated in a municipal soil erosion action plan. In the absence of such a plan, the Flemish administration will make the decision.

Apart from subsidies via the 'Erosion Decree', a municipality can get subsidies for organizing awareness raising actions with the farming community, such as showing erosion prevention techniques through demonstration fields (€ 125 per field), excursions with farmers to an erosion prevention project (€ 250) and advisory courses (€50 per session). Furthermore, once soil erosion problems have been inventoried in a municipal soil erosion action plan, a municipality is supported to approach individual farmers in order to put the proposed actions into practice (€ 50 per farmer).

Wallonia

The Walloon authorities are now paying more and more attention to soil erosion (origin, consequences, prevention and remediation). Before developing legislative tools or detailed action plans, the Walloon Region tried to inventory the areas where soil erosion could be considered as a real problem, not only from an environmental but also from a social and an economic point of view. Walloon Research Centres are now working on methodologies for mapping such areas, using data from meteorology, pedology, topography and land use. Existing measures and erosion action plans are largely integrated in more general (agri-) and forest environmental programmes (water quality,…) as well as in regional action plans aimed at preventing floods.

Efforts are mainly concentrated in the loamy region where the farmers are financially encouraged to adopt anti-erosive practices[1]. In forest zones, foresters are also encouraged to improve their practices (subsidies for replacing heavy machinery by horse-hauling for example[2]) and the management of the forest resources in order to reduce large-scale forest clear cuttings (< 3 ha), which are well known to favour soil erosion.

As in Flanders, Walloon farmers can be subsidised for taking agri-environmental measures.

Farmers undertake to apply these measures for five years. In some cases, these measures are able to combat soil erosion. They involve for example cover crops, afforestation or grass buffers strips along rivers. Although these measures are within the orientations of the common agricultural policy (CAP), they are also part of actions mentioned in the Environmental Plan for sustainable development in the Walloon Region[3] and the Contract for the Future of Wallonia[4] (CAW). In 2002, agri-environmental measures concerned nearly 10 % of the farmers population and were applied to about 110 000 equivalents-ha (14.5 % of the Walloon utilised agricultural area).

Wallonia:

Agri-environmental measures:

Overview of the subsidies allocated in 2002 for agri-environmental measures that can contribute to combat erosion in the Walloon Region.

Measures	Financial support	Approximate area (2002)	Subsidies allocated (2002)
a) Grass buffer strips at any field border or in the field.	900 €/ha/yr or 450 €/ha/yr if extensive	34,000 ha	2,700,000 €
b) Grassed waterways and banks protection	1,250 €/ha/yr	2500 ha (500 km along watercourses)	250,000 €
c) Planting and conservation of hedges and trees	50-1000 €/ha/yr according to the length of the hedge	36,000 ha	1,500,000 €
d) Ray-grass seeding between maize rows	150 €/ha.yr	180 ha	27,000 €
e) Soil coverage during winter period	100 €/ha/yr	20,000 ha	2,000,000 €
f) Reduction of seeding density for cereals and of tillage intensity	90 €/ha/yr if less than 200 grains/m^2		
g) Reduction of overgrazing	50 €/ha/yr if UGB/ha of permanent grassland is between 0.6 and 1.4		
h) Late or very late grasses mowing	125-250 €/ha/yr according to the time of mowing		

Continued…

A regional plan for preventing floods and erosion in Wallonia:

Soil erosion is also partly responsible of numerous floods recognised as public disasters in 207 of the 262 Walloon municipalities between 1992 and 2001. A "**PLUIES**" (Prévention et Lutte contre les Inondations et leurs Effets sur les Sinistrés. Notification du Gouvernement wallon du 9 janvier 2003 sur le plan de lutte contre les inondations et leurs effets sur les sinistrés.) plan aimed at preventing floods and minimising their effects was adopted in January 2003 by the Walloon Ministry. One of the objectives of this plan is to reduce and slow down at the watershed level water runoff to the stream. This plan proposes several actions to be taken for reducing soil erosion and amounts of sediments in watercourses (plantation and restoration of hedges, banks and groves, improvement of agricultural practices (reduction of autumn ploughing,…), coverage of agricultural soils during winter, construction of sedimentation ponds and riparian buffer zones…..

With the introduction of the Federal Soil Protection Act in 1998 in Germany (Anonymous 1998), soil functions became the standard for the assessment of the soil conditions and the required level of its protection. This includes the prevention of harmful changes to the soil, rehabilitation of the soil and precautions against negative soil impacts. Article 2 of the Soil Protection Act defines three main soil functions i) natural soil functions (e.g. as a basis for life and a habitat for people, animals, plants and soil organisms; and as a medium for decomposition, balance and restoration as a result of its filtering, buffering and substance-converting properties, and especially groundwater protection), ii) functions as an archive of natural and cultural history and iii) functions useful to man (e.g. land for agricultural and silvicultural use). The Federal Soil Protection Act is based on the German concept of the precautionary principle, which comprises the protection or restoration of soils and their functions on

[1] Arrêté du Gouvernement Wallon du 11/03/1999 (modifié le 15/12/2000) relatif à l'octroi des subventions agri-environnementales. Mesures agri-environnementales en vigueur en Région wallonne (AGRENWAL).

[2] Arrêté du Gouvernement Wallon du 14 novembre 2001 relatif à l'octroi d'une subvention aux propriétaires particuliers pour l'éclaircie et le débardage au cheval en peuplements feuillus et résineux.

[3] Plan d'Environnement pour le Développement durable en Région Wallonne (PEDD), 1995.

[4] Contrat d'Avenir pour la Wallonie

a permanent sustainable basis[5]. The precautionary principle requires the assessment of predicted incidents for the level of intervention, based on soil quality targets (e.g. permissible levels, trigger and action values).

Whenever the responsible party[6] carries out *actions on a site that can lead to changes in soil characteristics*, they are *obliged to take precautions against the occurrence of harmful soil changes that could be caused by their uses of the site or in its area of influence (*Article 7). *Soil impacts shall be avoided or reduced where this is a reasonable requirement also with respect to the purpose of the use of the site*. The obligations for precautionary measures in agricultural soil use are specified in Article 17 which refers to the code of Good Agricultural Practice to preserve the soil functions specified in Article 2, which also includes yield potential.

If a hazard to soil occurs or becomes likely to occur, preventive measures (Article 4), orders for risk assessment and investigations (Article 9) and obligations for the remediation (Article 10) of the soil are required by law. Within the scope of preventive measures an investigation is carried out to assess if appropriate precautionary measures were applied to avoid the hazards. In the case that the hazard occurs as a previous lack of precaution, in accordance with the obliged measures specified in Article 17 of the Act, this will give rise to liability issues (see also Bergschmidt 2003, pp. 2). Preventive measures against hazards or orders for the remediation of the soil need to be ordered in compliance with the local farm advisory service.

The Federal Ministry of Consumer Protection, Food and Agriculture has set-up the fundamentals of professional agricultural practice in "Principles for the Application of Good Professional Practice in Agricultural Soil Use" (BMVEL 1999) and concretised the principles for the agricultural advisory bodies to be applied in practice (published in: Federal Law Gazette #220a, 21. November 1998). These have been substantiated by a joint working group of representatives at the national and federal states level (BMVEL 2001). No quantitative criteria have been set up, no indicators for control have been defined nor have any penalties been established (Bergschmidt 2003).

To safeguard the protection of soils and their functions several federal states (Länder) have set-up regional support schemes for soil conservation practices in arable land-use.

In Saxony (Sachsen) for instance approximately 60 % of the arable farm land (~ 450 thousand ha) is vulnerable to soil erosion through water. Another 20 % of the arable farm land (~ 150 thousand ha) is vulnerable to wind erosion. The erosion risk occurs mostly in areas with silty soils where sugar beet, maize, oil seed rape and winter cereals are grown.

Supportive payments are granted for conservation soil management (no-till policy), mulching and intercrops or undersown crops. Farmers have to commit to the programme for 5 years, the degree of participation is over 25 % of the arable farm land.

North-Rhine-Westfalia (Nordrhein-Westfalen) has just introduced a programme for assigned areas of erosion risk. In such areas support for the following measures is granted:

- Mulch- or direct drilling after intercrops or into mulched straw (no-till policy)
- Converting arable land into perennial grass land (no fertilizer, no pesticides and no pasture after 15th June).

Amount of annual allowance:
- Mulch- or direct drilling: 102 € /ha.

- Conversion into perennial grass land: 306 €/ha up to 35 Points "Ertragsmesszahl" (Product of area and a classification according to the German land appraisal (Acker- or Grünlandzahl) divided by 100, higher numbers indicate higher yield potential), above this 7.5 €/ha per extra point (Etragsmesszahl), maximal 715 €/ha.

Other examples of anti-erosion measures taken by other regional authorities are given below.

GERMANY

Federal State	Measure	Support
Brandenburg	Promotion of conservation tillage and no-tillage for reduction of sediment and nutrients run-off.	25 € ha^{-1} y^{-1}
Nordrhein-Westfalen	Promotion of conservation tillage and no-tillage for reduction of soil erosion	102 € ha^{-1} y^{-1}
Rheinland-Pfalz	No inversion tillage / mulch tillage after cereals before seeding of maize and sugarbeets a) with cover crops b) without cover crops	115 € ha^{-1} y^{-1} 45 € ha^{-1} y^{-1}
Bayern	Mulch tillage including cover crops for row crops	100 € ha^{-1} y^{-1}

In **Austria,** the protection of agriculturally used soils is defined in the soil protection laws of the different Austrian provinces. In these laws, the aim of protection, the “maintenance of natural soil fertility and of an ecological functioning of soils” is defined. Additionally, the way to reach this aim is defined: a particular conservation measure may be set into practice. However, no explicit rule is included to which extent soil loss is tolerable. Because of this lack of a definition of tolerable soil loss, in general no intolerable soil losses – in terms of legislation – are observed (Klaghofer, 2002). With the participation of Austria to the European Community in 1995, the Austrian Agri-Environmental programme (ÖPUL) was started. The main aims of this programme in general is to stimulate the introduction or maintenance of agricultural production technologies, which are compatible with the protection and improvement of environment, landscapes and their characteristics, natural resources, soils and genetic diversity (BMLFUW, 2000). To reach this aim, a huge variety of different measures for all aspects of agriculture are offered to farmers on a voluntary contract basis. Compensations for the implementation of these measures are offered per measure.

[5] This concept goes beyond the COMMUNICATION FROM THE COMMISSION (Brussels 2.2.2000) on the precautionary principle: *"The precautionary principle should be considered within a structured approach to the analysis of risk which comprises three elements: risk assessment, risk management, risk communication. The precautionary principle is particularly relevant to the management of risk."*

[6] The property owner, the occupant over a site and the party who carries out, or has carried out by others, actions on a site [...].

Explicit erosion control measures
Three different forms of measures are offered under the heading erosion control:

- Soil erosion control in vineyards

This measure includes covered soil using either mulching, straw or cover crops within each row from 1st of November – April 30, or terracing.

- Soil erosion control in orchards

Covered soil using either mulching, straw or cover crops within each row for at least 10 months/year, or terracing.

- Soil erosion control in farmland

Conservation tillage (either direct drilling or mulching)

Implicit erosion control measures
Beside these contracts, erosion reduction effects may also be expected by the contracts of ÖPUL 2000, which are not explicitly dedicated to erosion control but to other or to more general environmental aspects. Some of these measures are offered on a regional basis, some of them are offered for the whole of Austria. These measures and possible positive effects are:

- Biological farming: shift from intensive crop rotations to less intensive crop rotations
- Cover crops during winter: reduction of winter erosion
- Maintenance of small agricultural structures, introduction of new landscape elements: reduction of the length of overland flow pathways
- Regional project of eco-points: erosion reduction through maintenance of small structural elements within landscapes
- Regional project of the province of Salzburg to protect groundwater and maintain pastures: maintenance of grassland instead of arable land
- Regional projects for preventive water protection: cover crops during winter and therefore reduction of winter erosion

Participation and costs
Participation of farmers in measures which explicitly account for soil erosion control has increased from 1998 to 2002. In 2002, an area of about 150,000 ha was under contract. This corresponds to about 34% of the area with a potential high erosion risk (Strauss and Klaghofer, in press). Actually an amount of between 93 and 113 €/ha (different schemes exist) is given as a subsidy for implementation of the measure “soil erosion control in farmland”, between 2000 and 4000 €/ha (depending on slope) is paid for the measure “soil erosion control in orchards” and between 2000 and 11000 €/ha (again depending on slope of the area) is paid for “erosion control measures in vineyards”. Adding up mean values for these contracts amounts to about € 143 million, which have been invested in 2001 into measures to reduce soil erosion risk on agricultural land. These numbers do not include measures which are detailed under heading “implicit erosion control measures”.

Since 1993 in **Switzerland**, there have been several legal regulations dealing with the protection of soil, rivers and lakes, hopefully leading to a reduction of soil erosion. The most important laws are listed in the following.

- In the Law on Agriculture (German abbreviation: LwG), the so called ecological subsidies are described (LwG, Art. 76): “With ecological subsidies the Federation encourages natural agricultural production forms, which are respecting the environmental and animal welfare, as well as their expansion.” The supported agricultural practices are described in the Ordinance on Direct Payments. For example a regulated crop rotation is prescribed (Art. 8): “The share of crops and the crop rotation have to be chosen in a way to avoid erosion, soil compaction and soil decline as well as leaching and losses of fertilizers and pesticides due to surface runoff as much as possible.” In Art. 9, soil protection is regulated: “The avoidance of erosion and of chemical soil pollution is an integral part of soil protection. Soil protection is promoted by an optimal soil coverage, measures against thalweg (concentrated runoff) erosion and by using soil friendly fertilizers and pesticides.” These measures are specified in the technical annex of this Ordinance: “Farms with more than 3 ha arable land must have on its arable acreage an average area-weighed soil protection index of at least 50 points for arable crops and 30 points for vegetables respectively.” The calculation of this soil protection index is explained in detail in the technical annex. Moreover: “No noticeable soil losses are allowed on areas where suitable measures to control erosion are missing. Suitable measures are considered to be in particular grass strips at least 3 m wide along ways on inclined arable fields or surface measures to drain off or to pass by water in order to avoid thalweg erosion.”

  Farmers must participate in this programme (so-called “ecological performance”) in order to receive these direct payments. In 2003, 88% of all farmers participated. 329,886,000 SFr. were disbursed to ecological direct payments 2001.

- In the Law on the Protection of Rivers and Lakes there is an article concerning soil management, as well (Art. 27): “Soils have to be managed according to the state of art in agricultural techniques, in order to avoid adverse effects on rivers and lakes, in particular by losses due to surface runoff and leaching of fertilizers and pesticides.”

- In the Law on the Protection of the Environment measures against soil pollution are regulated in Art. 33: “The soil may be physically affected only to the extent that its fertility is not permanently degraded; such shall not apply to building areas. The Federal Council may issue regulations or recommendations on measures against physical impacts on the soil such as erosion or compaction.” The “Ordinance relating to impacts on the soil” (German abbreviation: VBBo) specifies measures against soil compaction and erosion in Art. 6: “A person who constructs an installation or who exploits the soil shall choose and utilise vehicles, machines and tools such that compaction and other changes in soil structure which may threaten its long-term fertility can be prevented, taking into account the physical characteristics of the soil and its level of humidity. A person who intends to carry out modifications of the terrain or exploits the soil shall ensure that appropriate kinds of building and exploitation are used, in particular through anti-erosion building or cultivation techniques, rotation and adaptation of crop cultivation, so that the fertility of the soil is not threatened in the long term by erosion. If protection of the soil against erosion so requires, the cantons shall order measures to be taken jointly by several enterprises, particularly in the case of erosion caused by concentrated runoff (thalweg erosion).” In the annex to this ordinance the following guide values for soil erosion on arable land are formulated:

Guide values for erosion on arable land according to VBBo

Depth through which roots can penetrate	*Total mean erosion[1] (in tonnes dm per hectare and year)*
Up to 70 cm	2
More than 70 cm	4

dm = dry matter
[1] total mean erosion = sum of soil losses by sheet and linear erosion

These guide values were not only defined regarding onsite effects (soil loss), but also relating to potential offsite effects (ecological side effects).

Additionally to these national laws there are still different regulations by the different cantons. In order to promote and subsidize conservation agriculture, an "incentive programme" was adopted by the Bernese Office of Agriculture for regions susceptible to soil compaction, soil erosion, or nitrate leaching. Farmers willing to give up ploughing and to apply reduced or zero tillage techniques on their fields, can undertake a five-year contract with the Bernese Office of Agriculture. According to the contract, they will get yearly contributions which depend on the applied cultivation technique and on the crops they grow.

SWITZERLAND
Contributions for the transitional stage (Canton of Berne)
1 Euro = sFr. 1.55

Crops	**mulch tillage (transition)** Euro per ha & year	**zero tillage (target)** Euro per ha & year
1 winter grain	97	194
2 spring grain	97	194
3 winter/ spring rapeseed	194	323
4 strip tillage corn	290	
5 corn(silage/grain)	194	323
6 potatoes	323	387
7 sugar/fodder beets	226	355
8 peas, soya/ field beans	161	258
9 sown meadow, green fallow	0	129
10 sunflower	194	323
11 further crops as agreed with the Department of Environment and Agriculture		

Afterwards, a connecting contract, of which the conditions are stricter (payments will only be guaranteed for direct seeding) can be undertaken for a second five-year period.

The number of farmers participating in the programme has quadrupled since its beginning in 1996.
when a farmer is successful in direct seeding, this will encourage his neighbours to try out this new zero tillage technique as well ("snowball effect"). Table above indicates that in 2002, 5.4 % of the arable land in the canton of Bern was under contract, including 3.4 % with zero tillage, 1.2 % with mulch tillage and 0.8 % under temporary ley. For financial policy reasons, no more new contracts could be made for 2003.

In **France**, government support encourages the development of individual anti-erosive installations or of innovating agricultural practices through the law of 30 July 2003 with respect to 'the prevention of technological and natural risks and the repair of damage'. Article 49 of this law completes the rural code with a chapter on the delineation of erosion zones, i.e. zones where soil erosion on agricultural land may cause significant downstream damage.

The decree implementing this law defines the modalities of the delineation of soil erosion zones and de criteria for working out an action plan to be carried out for each of these zones. The action plan specifies the (agricultural)

measures to reduce erosion risks, some of which can be made obligatory. Amongst the agricultural measures are:

- periodic or permanent vegetative cover;
- grass strips along river sides;
- hedges, taluds or low stone walls;
- infiltration ditches and infra-structural measures to decrease runoff rates and volumes;
- soil management techniques reducing runoff;
- application of natural organic material to improve soil structure.

Contract area and financial costs for mulch tillage and zero tillage, time period 1996 – 2002 (Canton of Berne).

year	farmers with contract [-]	area under contract [ha]	main crops zero tillage [ha]	main crops mulch tillage [ha]	temporary ley[1] [ha]	payment total [Euro]	payment only zero tillage [Euro]	payment only zero tillage [%]
1996	92	337[2]	38	144	27	83,565	8345	10
1997	151	710[2]	276	298	20	171,575	62,695	37
1998	205	865	491	349	25	178,405	107,100	60
1999	265	1253	801	382	70	207,350	147,330	71
2000	355	1720	1081	501	138	265,975	191,335	72
2001	446	2289	1473	536	280	355,100	280,955	79
2002	446	2433	1563	533	337	388,935	317,300	82
	Total 1996 - 2002		5723				1,115,060	

[1] Temporary leys are compensated only in the first year.
[2] The contract area does not correspond to the sum of direct tillage and mulch tillage and temporary ley, since in the two first years part of the fields are plowed and seeded in autumn.

Territorial Exploitation Contracts (Contrats Territoriaux d'Exploitation: CTE) are 5 year contracts between a farmer and the state. This contract is in theory coherent with the environmental provisions of the CAP (Common Agricultural Policy). In compensation of financial support given by the state, the farmer commits to install economic and environmental devices. On the basis of a diagnosis of his exploitation, the farmer defines a total exploitation project which details the actions and the objectives. This project comprises an aspect devoted to engagement of the farmer in the field of arrangement, of the rural development of space and environment.

Other instruments are River Contracts. These contracts aim to improve the quality of water and to develop the river. They are signed by the departments or areas concerned and the ministry of environment. They lay down collective objectives which can integrate anti-erosive measures within the catchment basin. Subsidy rates vary from 10 to 40% (circular of the 24/10/1994).

The *Schéma d'Aménagement et de Gestion des Eaux* (SAGE) instituted by the article 5 of the law n° 92-3 of the 03/01/1992, lay down the general objectives for utilisation, development, quantitative and qualitative protection of surface water and groundwater resources, water ecosystems and wetlands. The interest of this SAGE is that it is a global and concerted solution, at the scale of the catchment basin, which integrates the protection and the economic uses. The control of soil erosion can form part of the objectives of the SAGE or of the River Contract, concerned with the reduction of the turbidity of surface waters and of their eutrophication related to diffuse pollution of agricultural origin.

The reduction of agricultural sources of water pollution is one of the objectives of this program. Other actions are envisaged within the same framework. They can also have a favourable impact on the control of soil erosion, in particular on the improvement of protection and management of fauna. This programme is established on the basis the EEC regulation n°2078/92 of the council of 30/06/1992 which envisages help to farmers applying environmentally respectful practices. A circular of the ministry of agriculture of the 26/03/1993 organises its setting up. Within this framework, objectives of protection of water are established and can result in the following measures:

- The protection of watercourses by the installation of grass buffer strips.
- The fight against erosion in areas with crops that are sensitive to this phenomenon.
- The conversion of arable lands into grasslands or the maintenance of non-productive meadows, aimed at the long term withdrawal through engagements of 20 years. In both cases, the level of support is 380 €/ha/year (data from 2002).
- The reduction of inputs, particularly nitrogen and plant protection products.

These measures considered also have an impact on soil erosion and its consequences.

Finally, the EEC regulation n° 2080/92 of the council of 30/06/1992 institutes a community system of support for forest measures in agriculture, to contribute to a management of the space more compatible with the equilibrium of the environment. The decree n° 94-1054 of the ministry of agriculture specifies the objectives of this support and fixed the conditions of its attribution. Among these objectives defined in the article 4 of this decree appears "the protection of the environment, in particular of water resources and the reduction of soil erosion".

Approximately 4% of the surface of **the Netherlands** is affected by wind and/or water erosion. Wind erosion involves some 97,000 ha (2.6%) in the Netherlands. The areas mainly occur in:

1. the coastal dunes,
2. sandy arable soils in South-Brabant and the North of Limburg,
3. central sections of the Netherlands (Veluwe) and
4. the arable raised peat bog soils in the North (Groningen and Drenthe).

Quantitative data on soil loss rates are lacking, mainly due to the nature of wind erosion. Economic costs are therefore difficult to estimate. There are no policy instruments to prevent wind erosion.

About 61,000 ha. (1.6%) is affected by water erosion, which occurs for the most part in the southern part of the province of Limburg. Regulations acting in the Netherlands are the following:

In July 2003, a *new erosion regulation* was enforced, which combines all the previously existing regulations. It obliges farmers to signpost occurrences of soil erosion on their farms to official authorities and to aim their farming activities at preventing erosion. In this regulation the agricultural commission (LLTB) firstly encourages farmers to prepare a farm erosion prevention plan on the basis of a set of guidelines or erosion prevention measures of the LLTB. . In this plan farmers have to take measures in order to attain 40 erosion control points per hectare. Each measure has a specific number of erosion control points (e.g. conversion into pasture 100 points per hectare, contour tillage 25 points per ha, non inversion tillage 35 points per hectare, etc.). If they do not prepare such a plan, the following regulations become obligatory.

The slope gradient, land use and the slope length determine which erosion control measures are necessary. Areas can be considered as sensitive to soil erosion if they have a high slope gradient and/or an unfavourable land use.

Table 2: The combination of slope length and gradient together determine the landuse allowed by the erosion-act 2003.

Slope gradient	landuse	Slope length
slope < 2°	Free	Free
2< slope <5°	Limited	Max. 400 m.
5< slope <18°	Limited	Max. 300 m.
18°< slope	Pasture	-

A limited land use means farmers have to apply cover crops in combination with f.i. direct-drilling.. Measures are only necessary if the land use consists of erosion sensitive crops, which are maize, potatoes, sugar beet and a few other less common row crops. Farmers are also restricted to transform existing grassland into cropland in a 100 m zone around build-up areas and infrastructure. These measures have mainly been taken to prevent muddy floods that cause damage to private properties and public infrastructure.

To conclude, it has been observed that the involvement of farmers in preventing erosion is (voluntarily or obligatory) generally increasing.

<u>SOUTHERN EUROPE</u>

In **Italy,** the policy options for prevention and remediation of desertification are put into effect through the correct use of the soil, for which an information data resource is necessary.

Currently, within the Interregional Programme "Agriculture and Quality" "soil" Measures 5, the Regions have resources to finance the production of the soil map of Italy in scale map 1:250.000. The Experimental Institute for the Study and the Soil Defense coordinates the plan "Soil Survey Methodologies" to the goal to conform criteria for the realization of a National soil map.

This map is a first step to characterize more vulnerable areas of desertification and soil erosion risk: it is currently limited to some pilot areas (Sardinia, Sicily and Puglia).

The main legislative references for protecting the soil from desertification are:

- Law n. 36/94, which governs the use of water resources and establishes that water use must be directed towards saving and resource renewal, so as not to harm available water resources, environmental liveability, agriculture, aquatic wildlife and flora, geomorphological processes and hydrogeological balances.

- Legislative Decree n. 152/1999, which generally reorganized the topic of protecting water from pollution by subdividing jurisdiction among the State (and within individual ministries), the Regions and the local authorities.

- Law n. 183/89, which led to the establishment of the river basin authorities and which calls for the drafting of hydrographic basin plans in order to implement a policy to prevent phenomena of hydrogeological instability, to protect soils, for water purification, and for the organisation, use and management of water resources. The hydrographic basin is defined by the law as a “unitary ecosystem”, that is to say a complex environment with its own homogeneity, where co-ordination and harmonisation of many functions related to different sectors of soil conservation can be put into practice, along with quantitative and qualitative management of water. The establishment of the “Basin Authorities”, at national, regional and interregional level is one of the major innovations brought about by the soil conservation reform. As for all aspects affecting control of soil erosion, the “Basin Authorities” are responsible for: stabilisation and consolidation of soils by means of both agrarian and forest hydraulic conservation structures; protection and consolidation of slopes against landslides and avalanches; prevention of both soil subsidence and sea-water intrusion in water table and rivers.

- The “Code of Good Agricultural Practices” approved in 1999 by the Ministry of Agricultural and Forestry Policies, putting the EC regulation 1257/99 into effect. The code contains standards and directions valid nation-wide, that could be integrated by regions and self-governing provinces to suit their local requirements. This regulation calls for agri-environmental measures to be taken in such a way as to finance actions which go beyond the Good Agricultural Practice defined as “normal” (GAPn), where the term “normal” stands for the whole of traditionally widespread agricultural practices considered rational from both a technical and an environmental point of view. The regions defined the local GAPn and came up with very detailed directions in order to prevent the risk of soil erosion. These directions can be put into practice mainly through a reduction in soil tillage and mouldboard ploughing, along with rotations that can ensure the soil covering during the rainy seasons.

- Law n. 97/1884, enforced in 1994, which determined the conditions to enhance soil protection in mountain areas through the development of farming activities effective to avoid soil erosion and to maintain the landscape and natural resources.

- The National Programme to Combat Drought and Desertification (NAP) of November 1999, which encourages Regions and Basin Authorities to identify areas vulnerable to desertification and the measures to fight this phenomenon, including the prevention and remediation of soil erosion and salinisation; the slope protection through low-impact environmental actions; the fire prevention actions and the adoption of farming, livestock and forestry management systems aimed at preventing physical, chemical and biological degradation of soil. Of the total 146.26 m. Euro to implement the NAP, 30 % of funding is devoted to soil protection actions; 15 % to reduction of the impact of production activities and 20 % to restore soil equilibrium. NAP measures will be mainly adopted through already existing funding instruments, such as rural development plans; water protection plans; river basin management plans; forest and forestation program; EU Structural funds (2000-2006) and CAP measures.

In **Spain**, due to the special significance of the agricultural sector in most regions, both from a socio-economic and environmental point of view, the main measures to control soil erosion have recently been set up in the framework of the agricultural policy.

Since joining the European Community, Spanish agricultural policy has been dominated by the Common Agricultural Policy (CAP). However, CAP implementation in southern Mediterranean European countries, and particularly in Spain, has had contradictory effects on soil erosion. One example is the set-aside policy, the main objective of which is to withdraw land from agricultural use to reduce production and diminish financial costs. The original regulation stated that abandoned land should not be used for any other purpose for five-years. Spontaneous vegetation had to be removed by tillage and other physical methods, excluding agrochemicals, to avoid weed invasion and phytopathogen blooms. The main consequence was a dramatic increase in the extent of bare soils, which were very vulnerable to erosion.

The reform of the CAP in the context of Agenda 2000 has signified the passage to a new era of integrated development of rural areas including soil protection and erosion control. In application of Council Regulation (EC) No 1259/1999 of 17 May 1999, the Spanish government has established environmental requirements to payments granted directly to farmers under CAP support schemes, financed in full or in part by the "Guarantee" section of the EAGGF. The '*eco-conditionality*' principle was adopted by Royal Decree 1322/2002. The following environmental requirements are compulsory for all CAP payments beneficiaries:

- Incorporate soil conservation practices to protect fallow land from erosion, including minimum tillage and maintaining an appropriate plant cover in order to minimise erosion risk;
- Avoid stubble burning; and
- Prohibition of tillage along maximum slope lines.

These requirements may be developed by Autonomous regions once special territorial situations have been taken into account. Furthermore, Autonomous regions may set a percentage of reduction for CAP payments without exceeding 20 per cent of the whole agricultural payments. Grants are reduced in accordance with the environmental risk or damage that may cause the inappropriate practice.

Soil protection from erosion is addressed in *agri-environmental schemes*. In application of Regulation (EC) No 1257/1999 of 17 May 1999, on support for rural development from the European Agricultural Guidance and Guarantee Fund (EAGGF), Spain has adopted a voluntary <u>grant system</u> for agricultural production methods designed to protect the environment and to maintain the countryside, and developed a <u>Code of Good Farming Practices</u>, through the National Decrees 4/2001 and 708/2002.

Agri-environmental measures aimed at soil protection are:

- Promote conservationist practices such as contour tillage and minimum tillage;
- Extensification of cereal production with use of traditional fallow periods and crop rotation;
- Establish maximum livestock rates to avoid overgrazing;
- Maintenance of isolated patches of natural vegetation for landscape protection and biodiversity conservation; and
- Planting woody crops on slopes in order to avoid soil losses caused by excessive tillage;

A public investment of € 1207 million (€ 827 million are covered by EU contribution) has been committed for funding the agri-environmental measures programme during the 2000-2006 period.

Moreover, beneficiaries of agri-environmental grants must fulfil for the whole of their exploitations with the requirements laid down by the Code of Good Agricultural Practices. These include, inter alia, *soil conservation and fight against erosion* measures, which involve

- Ban of tillage following maximum slope;
- Ban of straw burning;
- Restrictions of tillage (to be developed by regional governments).

Autonomous regions may establish slope limits and fix geometrical characteristics of plots to be excluded of the application of these practices according to soil, climatic or socio-economical factors of each area.

The *agricultural land forestation*, which establishes an Aid Programme for the afforestation of former agricultural lands, also purposes to enhance long-term forest resources and to combat soil erosion and desertification, by promoting forestry as an alternative use. The programme includes three types of aid: a) funding of afforestation costs, b) annual subsidy according to the forested surface for the first five-years, and c) compensatory subsidy for up to 20 years. Programme implementation is the responsibility of Autonomous Communities, but it is co-financed by Central Administration, Autonomous Communities and the EC (EAGFF). The total afforested area until 1998 was 400,893 ha, comprising predominantly slow growing rangelands (34.44%), herbaceous cropland (22.70%), pastures (14.58%) and fallow lands (9.87 %), as stated by Ministry of Environment (MIMAM, 2000). For the 2001-2006 period, the quantitative goal is set at 150000 ha of agricultural land been afforested with a total cost of € 880m (73% financed by EAGGF Guarantee).

Most responsibility for forest resources and nature conservation has been transferred to the Autonomous Communities. However, Central Government (through General Directorate for Nature Conservation (DGCONA) of the Ministry of the Environment) co-ordinates plans and programmes related to soil protection and desertification control, including:

1. Forest planning, Spanish Forestry Strategy and National Forest Plan, and Autonomous Forest Planning. The Spanish Forestry Strategy (EFE), which was drawn up in 1999, is a document discussing new Spanish forestry policy according to international resolutions on forest resources and aims to harmonize forestry responsibilities between Central and Autonomous administrations. Objectives include the design of new forestry policies, emphasizing multiple use of forests; organisation of forestry resources responsibilities within

Central Administration, co-ordination with Autonomous administrations and renewal of forest activity as a means of generating employment and economic activity. EFE promotes a mixed body formed by representatives of the Autonomous Communities, the State Secretariat for Water and Coasts, the Water Boards and the Directorate General for Nature Conservation, to prepare and apply the National Forest Hydrology Plan, whose priority shall be infrastructure initiatives in the territory when erosion is causing clear catastrophic effects, such as flooding in the cities, for example, soil degradation tending towards desertification or massive loss of work as the land has lost the capacity to regulate the water cycle, according to a system of duly agreed objective indicators. This Plan is included as part of the National Hydrological Plan, or within the Programme of National Action against Desertification.

In 2001, the Forestry Strategy was developed at national level by means of the National Forest Plan (NFP). Among other priority objectives, the NFP identifies the following: the reforestation of degraded plant covered areas, the wildfire protection and the application of silviculture treatments to improve forest quality. The Plan foresees the reforestation of 3.8 m ha affected by soil losses greater than 5 t/ha/y and the construction of 6.9 m m^3 of control structure to stabilize torrential water courses. In order to address the application of the programmes and actions to control soil erosion and combat desertification the NFP includes, the National Plan of Prioritised Actions to Hydrological and Forest Restoration, Soil Erosion Control and Combat Desertification (see below).

At regional level, some 13 Autonomous Communities have drawn up documents on forest policy and forestry master plans, of which seven have promulgated regional forest resource laws. Most documents point to the restoration of degraded lands affected by soil erosion by the means of revegetation and the need for sustainable forestry to control soil erosion and its off-site effects.

2. The National Plan of Prioritised Actions to Hydrological and Forest Restoration, Soil Erosion Control and Combat Desertification (MIMAM, 2001), was promoted by DGCONA in 1991 and its last version was included in the NFP. The Plan aims to control soil erosion and establishes the location and priorities for land rehabilitation in degraded river basins, according to both the use of the river basin as the operational unit and the severity of soil erosion problems. Target areas with high erosion rates (35,000 km^2) are prioritized. The Plan incorporates selected restoration measures: reforestation of degraded lands (11,00 km^2); construction of check dams and channel stabilization structures (10 m m^3); implementation of soil conservation practices in 8,000 km^2 and silvicultural treatments to improve forest quality (4,000 km2). The required investment is estimated to exceed €2,404 m for the first 20-years.

Despite these data, the Hydrological and Forest restoration activities developed under Co-operation Conventions with Autonomous Government over 1997-2001 period shows that the Plan is far from reaching its initial goals. In future, the National Plan of Prioritised Actions to Hydrological and Forest Restoration, Soil Erosion Control and Combat Desertification will be integrated in the National Actions Programme to Combat Desertification.

The National Action Programme to Combat Desertification (NAPD)

In 1996, Spain signed the UN Convention to Combat Desertification (CCD), which commits Spain to establishing a National Action Programme to Combat Desertification (NAPD). This NPAD is being prepared by a working party group co-ordinated by DGCONA, the main objective of which is the sustainable development of Spain's arid, semiarid and dry subhumid areas and, particularly, the prevention and reduction of land degradation, the rehabilitation of partly-degraded land and the reclamation of desertified areas.

In accordance with CCD (Article 1) or explicitly considered in the Regional Implementations Annex for the Northern Mediterranean, the NAPD will include the following desertification mitigation actions: a) Prevention and reduction of soil erosion, soil property degradation and long-term loss of natural vegetation; b) Rehabilitation of land affected by soil erosion and soil and vegetal cover degradation; c) Prediction of droughts and reduction of social and natural system vulnerability to water resource deficits; d) Sustainable water resources management; e) Protection against wildfires.

In **Portugal**, the National Rural Development Plan includes several agri-environmental measures to improve soil conditions and fight against soil erosion including Direct Drilling – see Table below for more details;

Support level of direct drilling (€/ha)

	Cash crops (basic subsidy)	**Irrigated cash crops** (basic	***Stubble conservation**	***Cover crops**	***Straw conservation on the soil surface**
<20 ha	45	75	59	61	69
20 – 100 ha	36	60	47	49	55
100 – 200 ha	18	30	24	25	28

* Only one of the options marked with (*) can accumulate with.

Minimum tillage

Minimum tillage: Applying conditions:

- At least 1 ha of sown crops;Crop rotations must include annual crops,Plant residues cannot be burn including straw and stubble;The area under no-tillage or reduced tillage cannot be grazed from 1st of October to 1st of March.

Reduced tillage is defined as tillage systems that only use implements that interact vertically with the soil. The use of the plough or horizontally rotating implements is forbidden. Disk harrow may be used once for the installation of the cover crop or if the straw was left on the field.

Support level of minimum tillage (€/ha)

	Cash crops (basic subsidy)	**Irrigated cash crops** (basic	***Stubble conservation**	***Cover crops**	***Straw conservation on the soil surface**
<20 ha	26	42	59	61	69
20 – 100 ha	20	34	47	49	55
100 – 200 ha	10	17	24	25	28

* Only one of the options marked with (*) can accumulate with.

Cover crops in orchards.

Cover crops in orchards: Applying conditions:

Farmers must present the following conditions to receive this compensation:

- A minimum area of 1 ha under permanent crops.
- The crop must be irrigated.
- The terrain cannot be flat, as it occurs in irrigation perimeters or at the lowlands.

The most representative perennial crops ***vineyards*** and ***olive groves*** are excluded from these measures

Support level of cover crops in orchards (€/ha)

	Cover crops in orchards
<5 ha	104
5 to 10 ha	63
>10 ha	42

The National Development Plan also includes the 'Afforestation of Agricultural Lands'. One objective of this measure is to “Contribute to the rehabilitation of degraded lands and desertification mitigation, with benefits to soil fertility and hydrological resources regulations.”
The afforestation of agricultural lands in areas highly susceptible to desertification, will have a maintenance support of € 175/ha.

The National Programme to Combat Desertification was approved in 17 June 1999 with the following specific objectives:

- Regional, rural and local development, as a determining factor in fixing the population in regions more susceptible to desertification and drought, and in reducing human pressure on more densely populated areas;
- Organisation of the agents for economic and social development around their professional, economic, cultural, sporting environmental interests, as way forward to active participation in decisions affecting the local population and in enhancing and improving the territory;
- Improvement of the conditions for an environment-friendly agricultural activity;
- Expansion and improvement of forests and their management, in order to reinforce the role of forestry in conserving soil and water;
- Identification of the areas most affected and allocation of the resources necessary to recover degraded areas;
- Water resources management policy designed to ensure its territorial integration, combining different water uses with the protection of the environment and the conservation of natural resources;
- Concerted research into phenomena which lead to desertification and how to fight them, experimentation and practical application of results;
- The creation of centres and demonstration fields to illustrate good techniques for soil and water conservation;
- Permanent information and public awareness campaigns aimed at different sections of the population, inhabitants and decision-makers, on the question of the fight against desertification and drought, and the contribution they make to the defence of Life on Earth.

In **Greece**, through the code of Good Agricultural Practice (Ref. No: 100949/2478/9.10.00) the Greek Ministry of Agriculture contributes to the implementation of the European Directives 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources and action plans for four areas have been adopted. The Ministries of Environment and Agriculture are also promoting relevant measures in the framework of the Habitats Directive 92/43/EEC. Moreover, in the frame of the European Regulations 1257/99, 1259/99, 92/43/EEC and 91/676/EEC, guidelines are given about irrigation practices, rotation management of natural ecosystems, biodiversity, and the protection of the soil from compaction and erosion processes, as well as guidelines to avoid overgrazing.

A National Desertification Action Plan for Combating Desertification has also been drafted and it describes the main guidelines and mechanisms to be followed in an effort to deal with the dangers and effects of desertification, both in agricultural and forestry land. This plan has been proposed by the National Committee of Greece, approved for application by a ministerial decree and adapted by the Ministers of Foreign Affairs, Finance, Agriculture, Environment and Development. More financial support is needed though, as well as basic institutional and legislative measures.

Apart from monitoring the compliance with these measures, it is necessary to be decided by the European Commission and incorporated in the environmental policies of the CAP subsidies to farmers who follow practices protecting the environment. Subsidies should be given to farmers as enhancing measures to follow techniques, which mitigate erosion.

The Ministry of Agriculture, as mentioned in the Rural Development Programming (2000-2006) Document, in the framework of agro-environmental measures, intends to implement the following actions:

1. Sustainable Management of Pastures
2. Extensification of Animal Husbandry
3. Sustainable Management of lakes and lagoons and protection of sensitive areas under the network of NATURA 2000
4. Preservation and reconstruction of terraces for the protection of soil erosion

The Ministry of Environment is promoting the harmonization of the Water Framework Directive 2000/60 in collaboration with the Ministries of Agriculture and Development. Moreover, the Ministry for the Environment has completed the General Framework for Spatial Planning in the framework of which natural environment protection and specifically desertification and soil erosion represent challenges to be taken into account.

EASTERN EUROPE

Bulgaria

The Forests Act and the Regulation on its Enforcement - this act arranges relations between forest owners, forest management, reforestation and forest protection. It addresses, inter alia, forest protection (soil protection facilities, combat soil erosion, forest prevention facilities, forest roads building, measures against insects, weeds).

The Agriculture Lands Preservation Act and the Regulation on its Enforcement - this act arranges prevention of agricultural lands, restoration and improvement of land fertility, and condition and order of land use changing. It addresses:

- ✓ Protection of agricultural lands from damages – land use, fertilizers and pesticides use and restriction for using, quality of water for irrigation usage, crop rotations and cultivation schemes, soil erosion prevention techniques;
- ✓ Land re-cultivation – re-cultivation projects, humus moving and storage; and
- ✓ Land purpose change and fees – methods and rules for change of land categories in connection with land fertility.

Ordinance for combating soil erosion and landslide in forest areas - with this ordinance are regulated:

- ✓ Conditions and sequences for implementation to combat soil erosion and landslide in forest areas;
- ✓ Projection of fortifications and forest shelter belts in areas with high erosion risk, and afforestation measures in burnt out areas accounting of completed hydrotechnical measures for soil protection.

Main action directions for afforestation are (i) the sustainable ratio between natural and unnatural forest reproduction; (ii) afforestation with priority of areas with high soil degradation risk. In order to combat soil erosion, build up a high erosion risk places data base and maintenance of fortification equipments are main actions taken.

National forest policy and strategy – Sustainable Development of Forest State in Bulgaria 2003-2013

Forest management – Increase of forest stability with cultivation of local deciduous species in natural places. Adaptation of forest cultures to climate aridity. Prevention of soil erosion.

Table 3: Overview of inventoried national policies

Country	Legislation	Economic instruments	Social Instruments (awareness raising / education & training)	Other
Austria	S(12)	AES (ns + s)	0	
Belgium				
– Flanders	S (in prep.)	AES (ns + s(7)) / S(8)	M / GAP	
– Wallonia	N	AES (ns)	0	PLUIES(22)
Bulgaria	NS + S(21)	AES(24) (s)	0	
Denmark	NS + S(1)	AES (ns) / S(2)	0	
Finland	0	AES (s)	0	
France	S(35)	AES(16) (ns) / NS(17)	0	
Germany	S(9)	AES(11) (s)	GAP(10)	
Greece	0	AES (ns)	GAP(19)	NDAP(20)
Hungary	NS(26) / GAP(26bis)	AES (ns + s in prep.)	SCS	
Iceland	0	CC	SCS	
Italy	NS(27) + S(28) / GAP(6)	AES (ns + s)	0	NAP(23)
The Netherlands	S	0	0	
Norway	N	AES (s)	M & ES	
Portugal	0	AES (ns + s)	0	NPCD(18)
Slovakia	S (in prep.)	AES (ns + s(7))	0	
Spain	NS(29) / GAP(6)	CC / AES (ns + s)	0	NAPD(30) / INES(31) / EFE(32) & PFE(33) / MIMAM(34)
Sweden	NS + GEC	N	NS	

Continued...

Country	Legislation	Economic instruments	Social Instruments (awareness raising / education & training)	Other
Switzerland	NS[13] + S[25]	NS[14] / AES[15] (s)	ES[15] & SCS[15]	
UK				
– England	NS / GFP[3]	AES (ns[4] + s[5])	0	
– Wales	NS / GFP[3]	AES (ns)	0	
– Scotland	GEC[6] + GFP[6]	AES (ns)	0	

Legend
0 = Lack of data.
N = No instrument available.
S = Specific instrument available, directly dealing with soil erosion.
NS = Non-Specific instrument available, with an indirect effect on soil erosion.
AES = Agri-Environment Scheme with specific (s) or non specific (ns) measures.
CC = 'Cross Compliance': production subsidies tied to environmental requirements.
GFP / GAP = Code or Standard of Good Farming / Agricultural Practice.
GEC = General Environmental Conditions.
SCS = Soil Conservation Service.
ES = Extension Services.
M = Municipalities.

The following categories are used:

- **Legislative**
  e.g. Soil Protection Act (Germany), Water Resources Act (England), Code of Good Agricultural Practice (several countries), etc.
  This legislation may deal with soil erosion either specifically or non-specifically.
  Legislative means BINDING.

In some cases, it is not clear whether a Code of good agricultural practice is legally binding or not. If not, it can be considered as a social instrument (to be checked by members of the AF).

- **Economic:**
  e.g. agri-environmental scheme (several countries); subsidies for small scale erosion prevention and combating measures (Belgium);…

- **Social:**
  To what extent member countries support extension services or specific awareness raising actions with respect to soil erosion (or less specific)?

Specifications
(1) Specific legislation focused on coastal erosion.
(2) Subsidies for windbreaks.
(3) Obligatory in Less Favoured Areas and conditional to be eligible for grants from the AES.
(4) Countryside Stewardship.
(5) Entry Level Stewardship, expected by 2005.
(6) Conditional to be eligible for grants from the AES.
(7) Expected to be operational from mid 2004.
(8) Subsidies for municipalities through the Erosion Decree of December 2001.
(9) Federal Soil Protection Act.
(10) Principles for the Application of Good Professional Practices in Agricultural Soil Use (BMVEL, 1999).
(11) Different schemes for several Federal States.
(12) Soil Protection Laws of the different Austrian provinces.
(13) The 'Law on Agriculture' and the 'Law on the Protection of the Environment' provide a high degree of soil protection, in part. against soil erosion.
(14) Ecological subsidies, i.e. direct payments through the 'Law on Agriculture.
(15) Different schemes for the different cantons, e.g. Berne.
(16) 'Shéma d'Aménagement et de Gestion des Eaux'.
(17) Territorial Exploitation Contracts (farmers - state) and River Contracts (departments - state).
(18) National Program to Combat Desertification, 1999.
(19) Status not known.
(20) National Desertification Action Plan for Combating Desertification.
(21) Ordinance for combating soil erosion and landslides in forest areas.
(22) 'Prévention et Lutte contre les Inondations et leurs Effets sur les Sinistrés': a regional plan for preventing floods and erosion in Wallonia.
(23) National Program to Combat Drought and Desertification.
(24) Agri-environment pilot actions within the SAPARD program.
(25) Ordinance relating to impacts on the soil. Guide values for erosion on arable land.
(26) Act on arable land.
(26bis) Good Agricultural Practice under the Gov. Decree transposing the Nitrate Directive.
(27) Law n. 36/94 and Decree n. 152/1999.
(28) Law n. 183/89 and Law n. 97/1884.
(29) Forest Law (Ministery of Environment, 2003).
(30) National Action Programme to Combat Desertification (in preparation, Ministery of Environment).
(32) National Inventory of Soil Erosion (Ministery of Environment).
(32) Spanish Forest Strategy (Ministery of Environment).
(33) Spanish Forest Plan (Ministery of Environment).
(34) National Plan of Prioritised Actions to Hydrological and Forest Restoration, Soil Erosion Control and Combat Desertification (Ministery of Environment).
(35) Law of 30 July 2003 with respect to 'the prevention of technological and natural risks and the repair of damage'.

4.2.2 COMMUNITY POLICIES WHICH CAN BE USEFUL TO PROTECT SOIL AGAINST EROSION

***Mandate –** to consider existing community policies for the implementation of soil erosion measures, being able to address and recognize the rights of use of land owners, as well as the protection of a common resource – e.g. integration of soil thematic strategy into the CAP, Structural and Cohesion funds and the Water Framework Directive.*

WATER FRAMEWORK DIRECTIVE

The Water Framework Directive (WFD) requires the "good status" of all waters in the EU by 2015 in terms of both ecological and chemical status. Good status has yet to be defined but it is clear that diffuse pollution (pollution arising from urban and rural land-use activities that are dispersed across the catchment, and do not arise as a point source effluent) adhering to soil particles must be adequately managed to achieve "good status" in water. Diffuse pollution is closely linked to land use and management - e.g. construction of new roads, agricultural and forestry activities, and the increasing extent of impermeable surfaces in urban areas. In cases where (contaminated) soil is eroded from the land and reaches a water course, the implementation of the WFD should go a fair way towards controlling soil erosion and sediment delivery.

Sediment derived from diffuse sources such as soil erosion and erosion of rivers banks is relevant to the implementation of the WFD in two main ways.

(1) Sediment QUANTITY. Rivers need a certain amount of sediment naturally to function in a sustainable way. They also need this for good ecological functioning. For example, salmonids need a certain amount of sediment in order to create redds for breeding. Similarly a lot of riverine habitats (wetlands etc) are constructed of sediment. Thus sediment is good for habitat diversity and biodiversity. So a certain amount of sediment within a river (derived from soil erosion, channel bank erosion etc.) is needed. However, too much sediment can be detrimental to how a river behaves (for example, excessive channel migration across its floodplain, degradation of the channel bed etc) and detrimental to ecology by, for example, blocking pores in the channel bed gravels with fine-grained sediment, which is bad for salmonids.

(2) Sediment QUALITY. Sediment in rivers may be contaminated when it is derived from the erosion of contaminated soil, or may become contaminated after entering the water course by fixation of dissolved pollutants. Contaminated sediment is likely to be problematic for achieving good chemical status, and will also have effects on stream ecology. The report on "Link between soil erosion and the diffuse contamination of water and air" by the STS working group on soil erosion describes this in more detail. Although a certain amount of nutrients, metals etc are needed within the river, the problem is having these chemicals in excess, above a certain threshold.

Therefore, there is a very clear and real link between soil management and water quality (quality in the broadest sense – chemical, ecological, aesthetic, health, recreation etc). The implementation of the WFD implies that all impacts on water quality (chemically and ecologically) will have to be analysed. If necessary, actions will have to be taken within river basin management plans, including soil erosion prevention and combating measures (i.e. source reduction measures). Thus there is an important link between the WFD and the STS. The connection seems obvious when probably > 90% of the surface area of most river basins in Europe is land and therefore mainly soil; < 10% is surface water. As such, *sediment quantity and quality issues (and the link to soil erosion and soil management) must play a significant role in both the STS and WFD.* However, at the moment these issues are not being given the appropriate consideration, especially in the WFD. If sediment quantity and quality issues are not addressed through effective soil management (and especially the reduction of excessive soil erosion), then it is likely that rivers (and lakes etc.) may not achieve good chemical and ecological status by 2015. It is, therefore, important that the STS and WFD address these needs.

Furthermore, soil functioning has important implications for flooding issues covered within the WFD. Compaction can result in reduced infiltration, increased runoff, and an increased potential for flooding. Consequently, *soil protection is needed in order to minimise the risk of flooding.*

Currently, however, the implementation of the WFD seems to be problematic, and the holistic approach, which potentially includes the tackling of soil erosion, is not being translated into national laws. Therefore, there is still a long way to go. Also, it is difficult to see how effectively the WFD would deliver all its benefits to other environmental policies. But to start from other policies demanding deliveries from the WFD could bring about the necessary push to move in a better direction.

In theory, the WFD could deliver:

1) Hydrological and morphological data on rivers, lakes and coastal waters (substrate conditions, structure and condition of the riparian zone, flow regime, chemical quality of the substrate); and
2) Environmental Quality Standards (EQS) for the 33 priority substances, partly for the water, sediment and/or suspended particulate matter.

In reality, current focus is on things which have always been used to assess water quality – invertebrates in rivers and chlorophyll in lakes. There is a huge lack of hydromorphological data, which would be needed to assess good status, and the resistance to include wetlands/floodplains into the assessment is strong. Furthermore, it seems difficult to set EQS for suspended particulate matter or sediment, with quite a number of MS resisting.

Thus, all the data and standards, which would be useful for the development of soil policies, are difficult to get moving at the moment. On the other hand there is no legal way to escape the collection of data under point 1. Therefore it would be justified and supportive if the soil policy developers would assume that this data will be available from Dec 2006 on when the monitoring programmes must be operational. *The soil strategy should:*

i) identify the relevance of WFD data for soil protection measures – E.g. data on suspended sediment transport in rivers could provide information on soil erosion; and data on diffuse contaminants could give an indication on soil quality, etc.;

ii) identify which soil data are important but not delivered by WFD (to be delivered by SFD) – E.g. data on soil erosion status and risk, diffuse sediment and contaminant delivery from land to rivers, soil compaction, and soil hydrological parameters;

iii) identify which soil data, soil functions and measures are important to support the achievement of the WFD objectives – Thus any soil data/functions (compaction, structure, hydrological parameters, erosion potential, soil quality etc) that determines the fluxes of water, sediment, and dissolved and particulate contaminants and nutrients from the land to waters is relevant for implementation of the WFD.

An interdisciplinary evaluation of land use (agriculture and forestry), soils, geosphere, and hydrosphere is needed to properly implement the WFD. Agreement with respect to nomenclature and methodology is needed, particularly in the last three fields. A considerable amount of information that can be used for this purpose is available in the national soil and geological surveys and institutes of the MS. For example, maps of erosion rates provide information about the vulnerability of soil to erosion. River-basin management plans and measures programmes often require site evaluations. The German Geological Surveys, for example, have extensive experience with such evaluations. Thus, in Lower Saxony, management measures for water protection are carried out in co-operation with others. These measures are monitored in a soil monitoring programme. The experiences from these could be used as an example for the implementation of the programmes of measures conducted within the framework of the WFD. On the other hand, the WFD could make available data on suspended solids as well as morphological data, that could be integrated into a soil erosion monitoring programme, as described in the recommendations on monitoring soil erosion in Europe by the Working Group on Soil Erosion.

HABITATS DIRECTIVE

The Habitats Directive is particularly relevant for the protection of some terrestrial habitats that depend on specific soil characteristics, such as dunes, peat lands, calcareous grasslands and wet meadows. In Denmark, for instance, coastal protection is ensured by a Nature Protection Law, including rules about sand-dune preservation and lower sand drift. An area of 300 m by the water's edge is included in the dune protection to prevent sand drift. The National authorities in Denmark have the obligation of achieving this protection. It might give sudden limitations in the use of land for the owner. Coastal protection cases are administrated by the counties and the state authorities function as advisers.

ENVIRONMENTAL IMPACT ASSESSMENT DIRECTIVE (97/11/EC)

Applies to those private and public projects that are likely to have significant environmental impacts. One of the potential impacts to be examined is the impact on soil. Given that soil erosion is an important threat, the assessment could be focussed, inter alia, to soil degradation by erosion processes.

In particular, there are provisions for protecting “uncultivated land or semi-natural areas”, including those posed by intensive agriculture.

STRATEGIC ENVIRONMENTAL ASSESSMENT DIRECTIVE (2001/42/EC)

Requires the assessment of certain plans and programmes, such as land use development plans, to ascertain potential significant environmental effects. This will include impacts on fauna, flora and soil.

In the next phase of the Working Group activities, a more extended analysis of concrete possibilities to integrate soil erosion control measures in the different directives will be carried out.

COMMON AGRICULTURE POLICY (CAP)

The CAP reform agreed in 2003 (Council Regulation 1282/2003) will have substantial impacts on farming in Europe, mostly resulting in benefits for the environment.

The main element of the reform package is that CAP payments will no longer be based solely on levels of production. The support will be an income support and not a production support. This is known as ‘decoupling’. Farmers will receive a single farm payment (SFP) on the condition that they:

✓ meet certain regulatory standards based on specified environmental, food safety and animal welfare legislation ("*statutory management requirements*" as laid out in Council Regulation 1782/2003: 18 current Directives - those which could have an influence on soil erosion include the Birds and Habitats directive).

✓ maintain their land in "*Good Agricultural and Environmental Condition*" (GAEC) by addressing issues relating to soil erosion, soil structure, declines in organic matter and biodiversity across the agricultural landscape as set in Council Regulation 1782/2003, see Table below.

Issues that have to be addressed under GAEC]

Issue	Standards
Soil erosion: *Protect soil through appropriate measures*	Minimum soil cover Minimum land management reflecting site-specific conditions Retain terraces
Soil organic matter: *Maintain soil organic matter levels through appropriate practices*	Standards for crop rotations where applicable Arable stubble management
Soil structure: *Maintain soil structure through appropriate measures*	Appropriate machinery use
Minimum level of maintenance: *Ensure a minimum level of maintenance and avoid the deterioration of habitats*	Minimum livestock stocking rates or/and appropriate regimes Protection of permanent pasture Retention of landscape features Avoiding the encroachment of unwanted vegetation on agricultural land

According to Art. 5, "Member States must define, at national or regional level, minimum requirements for GAEC, taking into account the specific characteristics of the areas concerned, including soil and climatic conditions, existing farming systems, land use, crop rotation, farming practices and farm structure."

If farmers do not meet these standards they risk losing payments (otherwise known as 'cross-compliance'). Decoupling should be good news for the environment because there should be less incentive to have intensive production. This is expected to reduce over-stocking of livestock and over-production of crops – both of which can be associated with an increase in soil erosion. In addition, soil management as the basis of GAEC provides a tool for managing erosion risk and the soil degradation processes that can lead to erosion. GAEC also aims to prevent land abandonment, which it is feared could be quite widespread in Mediterranean regions following CAP reform, because land abandonment in these areas could lead to even worse soil erosion and degradation problems.

Additionally, the CAP agreement requires that Member States maintain the area of *permanent pasture*, which should prevent the wide-scale ploughing up of land for arable cultivation and potential problems with soil degradation often associated with arable farming in some areas.

The agreement also fixes a ceiling of 5% *modulation*, i.e. a 5% transfer of funds from direct farm payments to rural development and this should provide additional funds for agri-environment schemes, some of which could be used to address soil management and resource protection issues.

There is also an option to use set aside (Art. 54). The text states that "*Set aside areas shall not be less than 0.1 ha in size and 10 m wide. For duly justified environmental reasons, member states may accept areas at least 5 metres wide and 0.05 ha in size."* There is a possibility that set aside strips could be used along the borders of water courses and across fields which have a high risk of erosion.

Finally, Member States are required to introduce a *farm advisory system* by 2007. At a minimum, this system must provide advice for farmers on cross-compliance and could be used to improve farmer knowledge and understanding of soil management issues.

Within the second pillar of the CAP, rural development programmes foresee a large number of further specific measures to prevent soil erosion via agri-environmental commitments, which sets up a voluntary and higher level of soil protection at the farm level. *Recommendation: to promote resource protection, especially direct specific measures to tackle soil erosion in agri-environment schemes.*

Effect of CAP reforms on soil protection

The latest CAP reforms and the growing importance of environmental criteria through the establishment of cross-compliance appear to offer considerable potential for soil protection measures. No other existing community policy implies such a high degree of soil awareness. There remains, however, some uncertainty as to the exact nature and extent of these measures in the different Member States.

Whilst the proposed reforms will deliver environmental benefits in the medium to long term, the implications for farming, and hence, for the environment in the short term are still far from clear. This is because some Member States are not fully decoupling in 2005 and, also, there will be a degree of variation in the way the different member states pay the SFP, implement cross-compliance and use modulation. In the short term, there may be sudden structural change in farming that could have negative effects but it is clear that the impacts of decoupling on the whole pattern of European land use will be significant and difficult to predict.

For example, if payments will be based on historic receipts (2000-02) and farmers will be paid for their entire cultivated area, regardless the type of crops grown, the production of the more profitable and formerly not subsidised crops will tend to increase. In Flanders, for instance, this would cause an increase of the area with vegetables and potatoes, and a decrease of the area with small grains, silage maize and protein crops. Economically, this would lead to distortion of competition between farmers receiving payments and farmers who always produced these profitable crops without subsidies and are therefore excluded from payments under the reformed CAP. The potential environmental effects of such evolution with respect to soil protection could be detrimental, given that both potatoes and vegetables are highly sensitive to soil erosion. The economic benefits of these crops would trigger farmers to extend their production into the less suitable and/or the more erodible areas (erodible soils, steep/long slopes). This would highly increase erosion risks in certain regions. In order to avoid mainly the economic effects, Flanders decided to grant payments only to the area grown with formerly subsidised crops, hence excluding potatoes and vegetables. This will equally avoid the damaging environmental effects of a rapid increase in production of these highly erosion sensitive crops. In MS where payments are not restricted to formerly subsidised crops, more guidance of farmers and perhaps stringent regulations regarding the allocation of land to certain crops (sensitive to soil erosion) would be needed in order to fulfil the cross compliance requirements with respect to soil erosion.

It is clear that *the reforms offer the real opportunity to make improvements, but relies on Member States to take advantage and introduce meaningful controls under cross-compliance.* The WG on Soil Erosion recommends that *MS investigate, prior to the implementation of the reformed CAP, potential impacts on the environment of the different policy options.*

In order to succeed in reaching the environmental requirements laid down by actual and future CAP regulations, MS should be aware of the importance of farmers' support when implementing new measures in the framework of this policy. *The Commission should stimulate this process of change by the promotion and establishment of technology transfer programmes, structure modernisation plans, training programmes and research and development actions.*

CARBON SEQUESTRATION

There is a gap here for proposals, possibly through the Kyoto Protocol, for polices to encourage soil carbon sequestration which would have a beneficial effect on reducing soil erosion. One of the measures to reduce soil erosion is to improve soil structure and increase organic matter in the top soil. In this, the role of agriculture coincides with the role agriculture can have in reducing the impact of climate change, by binding the carbon to the soil. Improving soil structure and increasing organic matter is stimulated by reduced soil tillage methods including conservation agriculture (need to cross reference to Commission climate change soil working group**).** A special problem is the management of peat soils in Europe. Intensification of agriculture and drainage systems causes the breakdown of peat soils and the release of carbon into the atmosphere. A land management system could be devised to prevent further breakdown or even simulate building up new peat areas.

INTEGRATED COASTAL ZONE MANAGEMENT

The European Commission adopted this document (COM(2000)547) in September 2000 based on the results and conclusions of the EC Demonstration Programme on Integrated Coastal Zone Management (ICZM).

The EC Coastal Strategy highlights the importance of coastal zones acknowledging that *our coastal zones are facing serious problems of habitat destruction, water contamination, coastal erosion and resource depletion*[7] but also recognising that an important factor which is affecting coastal zones can be identified in socio-economic and cultural problems, including damage to property due to erosion.

The Coastal Strategy also includes a proposal for European Parliament and Council Recommendations where eight principles of good coastal zone management have been identified (more details will be given in the Communication document).

Principles of Integrated Coastal Zone Management [8]:

- A Broad “Holistic” Perspective (Thematic and Geographic)
- A Long Term Perspective
- Adaptive Management
- Local Specificity
- Working with Natural Processes
- Participatory Planning
- Support and Involvement of all Relevant Administrative Bodies
- Use of Combination of Instruments

In the EC Coastal Strategy, coastal erosion is specifically tackled. The Commission states:
“The basic bio-physical problem in the coastal zones is that development is not kept within the limits of the local environmental carrying capacity. Some of the most common manifestations of this problem are: Widespread coastal erosion, often exacerbated by inappropriate human infrastructure and development too close to the shoreline; Loss of property and development options, as the coast erodes; Coastal erosion is locally perceived as the most significant threat to maintaining income in many areas that live from tourism.”[9]

4.2.3 –OTHER POLICY OPTIONS TO PREVENT/ REMEDIATE SOIL EROSION

Mandate – *Identification of policy options specifically designed for the prevention and remediation of soil erosion and its consequences. For these policy instruments, the most appropriate level of intervention (local, regional, national, EU) should be assessed. Different policy options should be recommended and accompanied by a justification, estimates impacts and costs and timelines.*

RECOMMENDATION TO DEVELOP A SOIL FRAMEWORK DIRECTIVE
Justification

To reach a more coherent and a more visible soil policy, a soil framework directive could be developed, rather than linking soil items up with several other policies. Such a soil framework directive should be as flexible as possible as regards the criteria that will be developed or applied to reach or maintain soils of good quality, such as soil type, climate and land use. In addition, local conditions should be taken into account.

To develop coherent policies and soil management practices, the following steps are recommended:

1. Develop a concept to determine the optimal soil quality and to assess soil threats, taking into account soil type, climate, land-use and local conditions at the local or sub-national level (subsidiary principle)
2. Determine the state of the soil (quality, threats)
3. Develop a policy framework

For soil erosion, the quality and amount of data on the state of the soil are sufficient, and can facilitate the development of a soil protection policy.

This policy option is recommended by the majority of the members of the WG on Soil Erosion, however not necessarily supported by all stakeholders. Some stakeholders do not see the need to develop a SFD at this stage, given that current policies can be identified that already deliver effective soil protection, and further linking of Strategies can be undertaken to reinforce soil protection.

Impacts

- MS need to make regulations, but are free to make a choice in the way they want to develop regulations and/or Environmental Schemes. Regulations could be obligatory in exposed areas.
- Information for farmers and landowners needs to be written which is relevant to local circumstances. Measures against soil erosion and land degradation may vary from technical measures to changes in the agricultural production system.
- Educational programmes need to be developed to update Extension Services.

RECOMMENDATION TO ENCOURAGE EROSION ACTION PLANS IN AREAS AT RISK OF SOIL EROSION

Justification

In areas at risk of soil erosion, every farmer, group of farmers or local authority should be encouraged to write an Erosion Action Plan for their farm(s). Active prevention of erosion and land degradation should be an important part of the Plan. This means that the farmer is made aware of their role in preventing erosion/ land degradation and that they need instruments to be able to do this. Every farmer should get access to existing information on soil and land quality from their farm (via internet and/or

[7] Communication from the Commission to the Council and the European Parliament on Integrated Coastal Zone Management: A Strategy for Europe
[8] European Commission: Proposal for a European Parliament and Council Recommendation concerning the implementation of Integrated Coastal Zone Management, (Brussels: 08.09.2000, COM(2000) 547 final
[9] Communication from the Commission to the Council and the European Parliament on Integrated Coastal Zone Management: A Strategy for Europe

via the municipality) and support – advice and information.
MS should be free to decide whether the plans are to be drawn up by individual farmers, e.g. in MS with large farms, or by groups of farmers or by local authorities. Later on, technical guidance can be provided to assure comparable working methods and levels of accuracy.

The challenge is to let the farmers realise that they have an economic interest in preventing land degradation and erosion.

To best use these initiatives there is need for:

- ✓ Development of maps based on land and soil quality showing the possibilities for sustainable production systems and for the best soil treatment (for example the introduction of direct drilling).
- ✓ Making available local/regional results from trials by the Extension Services. These results may also be of interest for other regions/countries and should be made widely available (for example via internet).
- ✓ Gathering experiences with new methods for soil treatment (for example direct drilling).

In other words: existing and future policy options could be used much more effectively if the farmers are able to access information about the possibilities that are available to them and if local networks are established.

RECOMMENDATION TO PROVIDE A POLICY MEASURE TO ADDRESS IMPROVED SOIL WATER RETAINING CAPACITY OF SOILS IN AREAS PRONE TO FLOODING

Jusitification

There is a link between soil quality and structure and the risk of downstream flooding. The potential for flooding is not only dependent on the amount and intensity of precipitation but is also dependent on the extent and type of land cover and soil properties such as soil structure. Today, agricultural and forestry activities are characterized by a high degree of mechanization and the structure of fields and forests has been adapted to the use of large machinery. In many areas, stonewalls and vegetation strips (such as hedges) have disappeared. Furthermore, the drainage of fields has been artificially improved and the overall hydrological system of the land has changed considerably, with a tendency for water to be transferred from the land to rivers as fast as possible. The use of heavy machinery, often under wet conditions (overhead watering), also causes soil compaction, which further exacerbates the situation. All of these developments can lead to an increase in downstream flooding. Land-based options to reduce the risk of flooding include:

- ✓ Improve the soil structure by using the most appropriate soil treatment and equipment. Direct drilling is friendlier for some soils in relation to structure and organic matter content and the soil is often able to absorb more water. Investment in the right equipment for superficial soil treatment is expensive. Buying of this equipment could for instance be stimulated by **tax reduction** (VAT freedom) or by **direct subsidizing.** Improvement of soil structure has also a direct positive effect on the amount of soil erosion. *Research is needed to establish the relation between soil type, soil structure and soil hydrology.*
- ✓ Forest vegetation is generally capable of holding water for long periods. Today, forest logging operations are more efficient and mechanized. The cutting area has increased and the forest road network is extensive. During logging, both during thinning and clear felling of wood, the deep tracks made by the heavy logging machinery (e.g. harvesters and forwarders) change water flow paths and can accelerate run-off. Clear cuts especially can dramatically decrease the amount of transpiration from vegetation in an area, and hence can increase surface run-off, a rise of the groundwater level and an increase in pore water pressure. The impact of these changes is that the water retaining capacity of forests is reduced. To change this situation, it is necessary to get an overview of which forested areas in Europe are vulnerable to downstream flooding, and to give **support** (e.g. direct subsidizing, tax reduction, VAT freedom) **to forestry** in these areas to reduce the cutting area and adapt the forest road network so as to improve the hydrological system. Furthermore, support could be given to forest management plans highlighting these elements. Forest planting to improve the hydrological situation and reduce erosion/land degradation should also be assessed. In very vulnerable areas it should be possible to develop integrated land management systems to keep water on the land for as long as possible without causing detrimental effects downstream. This approach will also have a positive effect on landscape structure and biodiversity.

Policy measure – regulations /economic instruments

These should identify the parts of river basins that are likely to cause downstream flooding in sensitive areas (such as important environmental and agricultural land, towns, cities etc.) and concrete measures should be formulated to address this, including support. Support options include the subsidising of forest and land management methods and equipment.

Impacts

- MS should be encouraged to develop their own regulations to stimulate farmers and foresters to buy equipment for better soil quality and structure in basins prone to flooding.

- Information is needed to inform farmers/forest owners about the importance of improving soil structure and how they can contribute.

- Education programmes need to be developed to update Extension Services and Forest Organizations.

- Costs are related to the reduced VAT for buying equipment in designated areas.

RECOMMENDATION TO GIVE ECONOMIC INCENTIVES TO FARMERS TO USE SUSTAINABLE PRODUCTION SYSTEMS
Justification

A development, which can have a negative impact on erosion and land degradation, is the role of the retail industry in the choice of production systems at farm level. More and more, the retail industry is making contracts with farmers about market products. A consequence of this development is that the farmer can start growing the most profitable crops, which may not be adapted to the local soil and climate conditions. This development can be decreased by giving economic incentives to the farmers if they use sustainable production systems, such as tax benefits or subsidies, etc. This requires the development of an information system at European, national and regional levels indicating which production system should be considered as sustainable (see part above under CAP) and this should be part of both EU and national regulations. Member States can develop their own policy to encourage sustainable production systems at a national or regional level, making use of economic incentives adapted to the local conditions.

In Spain, there are tax benefits for farmers practicing certain farming techniques such as organic farming. Given the importance of soil degradation processes, incentive practices that allow protection of the soil are also needed.

Impacts

- Development of a system dividing Europe in ecological land management zones (agro-ecological zones) giving an indication which land management systems are sustainable under the given soil and climate conditions. Within the recognized regions, MS should develop subregions in which more specific land management practices can be applied.
- Farmers/Forest owners in areas especially exposed to land degradation /soil erosion should get an economic incentive to introduce sustainable systems. MS should be free to develop incentive programmes adapted to the local situation.
- Education programmes need to be developed as well as local advisory bodies.
- Costs are related to the support given to farmers and foresters in designated areas.

RECOMMENDATION FOR ALL MEMBER STATES TO HAVE A SOIL CONSERVATION SERVICE
Jusitification

Today Iceland and Hungary are the only European countries having a Soil Conservation Service. Slovenia has an organisation with similar tasks. Every MS should be obliged to establish a (small) Soil Conservation Service to ensure that soil policies are fully addressed. MS should have the freedom to organise this in a way adapted to their local situation, for example, regional competence. Furthermore, this entity can be an independent "service" or can be part of a ministry, an administration, an agency, a research institute.

The task of the national Soil Conservation Services should be:

- ✓ To investigate in which areas soil erosion and land degradation are a problem.
- ✓ To develop national/regional strategies as to how this situation can be improved.
- ✓ Be responsible for developing/supporting regulations to avoid soil erosion / land degradation.
- ✓ The investigation of the best land management practice and technical measures to reduce soil erosion and land degradation.
- ✓ The development of information and education material for land users.

The establishment of a European Soil Conservation Service would be desirable. A European Soil Conservation Service should be in charge of co-ordinating the national Soil Conservation Services: the implementation of the EU soil protection policy and related directives and programmes needs harmonised information, harmonised concepts and methods and an operative network.

The functions of the potential European Soil Conservation Service, would be:

- ✓ To provide a bridge between EU political decisions and the practical execution of soil survey and soil protection programmes on national and regional levels.
- ✓ To provide a harmonized methodology for soil survey, data collection and problem evaluation.
- ✓ To provide the co-ordination of the development of conservation programmes and practices as well as information, advice and technical guidance (through training programmes, published guidelines and brochures).
- ✓ To provide a bridge between scientific results and practices.

Impacts

- Both on national and European level the Conservation Services should be kept small and effective. Costs are primarily related to salary of the involved officials.

RECOMMENDATION TO IDENTIFY THE SOIL RESOURCE MORE CLEARLY AS AN OBJECTIVE OF THE AGRI-ENVIRONMENT SCHEMES, UNDER THE RDR.
Justification

Soil is addressed in agri-environment schemes in many European countries. However it is not directly addressed, as it is often an indirect consequence of a measure to create a habitat food source. For soil protection to be addressed seriously in these schemes it requires stand-alone measures and to be an objective of the schemes.

Impacts

- MS should include the soil as a specific chapter in existing and new Agri-Environmental Schemes. For forest owners separate schemes should be developed.
- Education material needs to be developed.

RECOMMENDATION TO EXPLORE THE MERITS OF IFM, ORGANIC FARMING AND CONSERVATION AGRICULTURE AS A WAY TO PROTECT SOIL THROUGH SUSTAINABLE FARM MANAGEMENT..

IFM - integrated farm management is a whole farm policy providing the basis for efficient and profitable production which is economically viable and environmentally responsible. IFM integrates beneficial natural processes into modern farming practices using advanced technology. It aims to minimize environmental risks while conserving, enhancing and recreating that which is of environmental importance."

Many of the principles of Integrated Farm Management can help to reduce soil erosion. They are:

- ✓ a commitment to good husbandry and animal welfare
- ✓ efficient soil management and appropriate cultivation techniques
- ✓ the use of crop rotations
- ✓ minimum reliance on crop protection chemicals and fertilizers
- ✓ careful choice of seed varieties
- ✓ maintenance of the landscape and rural communities
- ✓ enhancement of wildlife habitats
- ✓ a commitment to team spirit based on communication, training and involvement.

Soil conservation measures should be included in the protocols of IFM, including conservation agriculture techniques, as they have been included in the National Regulation in Spain *(Real Decreto 1201/2002*)

Organic Farming - Organic farming provides a whole set of management measures and factors besides those for production directly. The farm is part of the ecosystem and is taking advantage of natural processes and a dynamic ecological balance. Organic farming does not only means omitting chemical-synthetic pesticides and fertilisers, but also optimising the whole farm with respect to interactions of the crop and its natural environment. Since the 1970's organic farming has developed special soil tillage techniques in order to reduce the problems linked to ploughing, and to overcome problems with weeds. Through the use of diverse crop rotations, including grass-clover, legumes and legume mixtures, intercrops and intracropping, organic farming provides a more permanent plant cover, thus conserving the soil. The potential role of organic farming in reducing soil erosion should be further investigated and improved where possible.

Conservation agriculture (CA)- CA is an effective way to prevent soil erosion. The main strength of CA is that the soil is permanently covered with living or death plant material through a variety of techniques, such as no-till, non-inversion tillage, etc (see also report on WP 4.1). Secondly, where intensive soil tillage is detrimental to soil structure and therefore induces soil erosion, CA can provide an alternative soil management system that contributes to the development of a proper soil structure. Soil structure formation is enhanced by

- the presence of soil organisms, taking advantage of the increased OM content of the upper soil layer and of not disturbing the soil;
- the continuous development of plant roots;
- the lower number of passes by heavy farm machinery (reducing subsoil compaction)

Impacts

- Actions to include soil as an implicit element in IFM and Organic Farming protocols
- Research or an objective compilation of existing science on the application potential of CA in different agro-ecological zones and on the overall environmental effect of CA (including the use of herbicides and pesticedes, greenhouse gas production, nitrate leaching, etc.). These results should be used by regional or local authorities as a sound policy basis.
- Development of related information and education material at national level for farmers and landowners.

SOIL EROSION

Task Group 5 on
LINKS WITH ORGANIC MATTER AND CONTAMINATION WORKING GROUP AND SECONDARY SOIL THREATS

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Executive Summary

Salt-affected soils occur both naturally and as a result of irrigation practices which permit the mobilization of salinity within the soil body and the transport of salts and/or Sodium (Na) to new locations. Salinity also poses a major management problem in many non-irrigated areas where cropping relies on limited rainfall.

The most commonly identified driving forces inducing salinization and sodication in Europe are: increasing demand for irrigation water, increasing use of low quality waters, groundwater overexploitation and marine intrusion into freshwater aquifers. Associated impacts derived from climatic change may exacerbate soil salinization and sodication in some regions of Europe.

Within Europe, 26 countries are more or less affected by salinization and sodication, However, information about the current status of salinization and sodication in Europe is both not complete and contradictory depending on the sources used.

Salinity usually has negative direct effects on crop yield by reducing the ability of plant roots to absorb water. It also affects the structural and hydraulic characteristics of soil with subsequent loss of aggregate stability and reduction in infiltration rate. As a consequence, soil erodibility increases as well as runoff and soil loss by erosion.

We recommend:

- The urgent implementation of a network in European countries affected or potentially affected by salinization and sodication, in order to collect updated and reliable information on the status of salinization and sodication in Europe, to identify areas threatened by salinization and sodication, and to monitor indicators of salinization and sodication (link with Research and Monitoring WGs).
- The application of models predicting transport of water and solutes for a selection of management strategies (i.e. alternative irrigation methods and scheduling, calculation of leaching requirement, conjunctive use of different irrigation waters, amendments, etc.) leading to environmental protection, to the rational and sustainable use of soils and water resources through prevention of the hazard of soil salinization/sodication is also necessary.
- To increase knowledge of the soil hydraulic parameters/functions is necessary to validate and calibrate simulation models and to develop reliable management scenarios (link with WG Research).

Soil compaction induced by large-scale equipment in agriculture is of growing concern. The demand for tractive power and machine power increase with intensified production practices. As higher tractive power or bigger bunker capacities often result in higher wheel loads, heavy wheel traffic under wet conditions increases the risk of irreversible harmful damage to the soil structure to greater depths.

Soil compaction directly affects plant growth and yield capacity as it has an impact on water and air storage capacity, oxygen supply to roots, and rootability. Also soil functions related to the environment e.g. soil air- and water conductivity and heat balance are affected. Changes in nutrient cycles due to altered soil chemistry and increased greenhouse gas emissions can also arise from soil compaction. The reduced infiltration capacity e.g. for precipitation water may also lead to a higher erosion susceptibility. Especially subsoil compaction occurs to be very persistent and is difficult to alleviate. To safeguard the ecological soil functions and the functions linked to human activities on a sustainable basis, measures against harmful soil compaction are required.

About 32% of the subsoils in Europe are estimated to be highly vulnerable to subsoil compaction and approximately another 18% moderately vulnerable, but no precise data are available.

We propose that the key responses to compaction problems are effective precautionary measures for prevention of compaction, which should be addressed by policy instruments. For the avertion of harmful changes to the soil, concrete measures should be selected in accordance with the competent agricultural and environmental advisory bodies, together with the farmer.

We recommend that Community policies should increase the focus on the compaction problem, and simultaneously work out further guidelines to prevent traffic-induced subsoil compaction, and develop guidelines for good agricultural practice in relation to soil compaction. Further research should emphasise on improvements of prevention techniques and applicable practices in arable cropping. In general a more holistic approach in soil compaction research would be needed, bringing together soil scientists, agricultural engineers, agronomists, economists, industries and field practioners, to improve the on-farm practices and the rural ecosystems.

Floods are climatological phenomena that are influenced by geology, geomorphology, relief, soil and vegetation condition. Certain threats (erosion, sealing, compaction) to soils have an impact on the occurrence of flooding. Flooding can wash out enormous quantities of fertile topsoil and deposit the sediments in other parts of the environment, at great cost to socio-economic and environmental resources. Thus, soil protection measures and flood protection schemes can have huge benefits beyond the simple protection of soil.

Landslides are major natural hazards, claiming thousands of lives and millions of Euro in lost property each year in almost all mountain, river basin and coastal areas. Environmental degradation caused by human interference with nature and by climatic change increases the hazard potential. Growing population density and mobility associated with urbanisation, expanding infrastructure and industrial facilities and tourism expose more people and more property to hazardous events and thus generate increasing risks. These hazards also pose the biggest challenge to developing and maintaining a sustainable infrastructure.

We recommend that the strategy to meet these threats should be based on two principles:

- Society has to become better prepared for the impact of disasters.
- Society has to proceed from reaction to and protection against hazards, to the management of risk by integrating risk prevention strategies into sustainable development programmes.

In order to achieve these objectives, significant progress in hazard and risk assessment, risk reduction and capacity building is considered essential.

We recommend the adoption of land use planning schemes in river basins preventing rapid runoff both in

rural and urban areas, and determining land use restrictions on flood-prone areas. A transnational effort should be made to restore the natural flood zones of rivers leading to flood mitigation and to ecological benefits. An important step could be the harmonisation of soil protection, flood prevention and spatial planning policies. This is an essential output of the Water Framework Directive that must be integrated with Soil Protection objectives.

Soil organic matter is degraded by erosion processes. The organic matter loss is mainly correlated with the removal of the topsoil by water erosion, its oxidation through excessive aeration caused by intensive soil tillage and also with the degradation of soil structure through soil compaction. Declining soil organic matter contributes to higher level of soil erosion that, in turn, hampers the establishment of plant cover and the replenishment of organic matter.

Soil management practices that are good for organic matter conservation and to combat erosion have to be identified and integrated into agri-environmental measures. Conservation practices and sustainable farming management systems will play an important role in stabilizing and increasing organic matter.

The application of exogenous organic matter (EOM) may improve the resilience of soils against degradation processes. Long-term improvements, however, can only be achieved if the soils are managed in accordance with the precautionary principle to maintain soil functions on a sustainable basis. Exogenous organic matter should only be applied if there are no detrimental impacts on soil functions or harmful off-site effects.

Soil erosion and the delivery of contaminants to water and air influence the quality of surface waters, groundwaters and air, and, in turn, freshwater ecosystems and human health. In this respect, soil erosion on land and the erosion of river banks have important implications for the ability of Members States to implement and comply with the EU Water Framework Directive (2000/60/EC). Although there is a moderate amount of information to suggest a strong link between soil erosion and the diffuse contaminant of water and air, we are, however, lacking detailed information in Europe on:

- Accurate fluxes of sediment and associated-contaminants *between* the land and rivers;
- Estimates of the contribution of soil erosion to river sediment and contaminant loads;
- Detailed information on the contamination of the atmosphere from surface erosion processes; and
- The link between the application of wastes to land and the effect of this on soil biology, hydrology and erosion potential.

We recommend that, in order to address the role of soil erosion and sediment delivery in the contamination of water and air, integrated soil-sediment-water-air policies need to be developed.

TASK 5 Links with organic matter and contamination working group and secondary soil threats

Recommendations for a Soil Protection Policy from Salinization and Sodication, Compaction, Floods and Landslides (with indications of links with Monitoring and Research actions and Working Groups)

Soil quality has been defined as “the capacity of a soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health”. Soil quality degradation can result from declines in organic matter content, salinization, sodication, compaction, acidification, nutrient depletion, chemical or heavy metal contamination, or reduced diversity and activity of soil organisms. Thus, a complete assessment of soil conservation must go beyond estimating soil erosion and should consider other soil qualities that may be degraded. Because of its importance, a quantitative assessment of soil quality is needed to determine the sustainability of land management systems as related to agricultural production practices, and to assist government agencies in formulating and evaluating sustainable agriculture and land use policies.

1. A network should be urgently implemented in European countries affected or potentially affected by salinization and sodication, in order to collect updated and reliable information on the status of salinization and sodication in Europe, to identify areas threatened by salinization and sodication, and to monitor indicators of salinization and sodication (*link with Research and Monitoring WGs*). Application of models predicting transport of water and solutes for selection of management strategies (i.e. alternative irrigation methods and scheduling, calculation of leaching requirement, conjunctive use of different irrigation waters, amendments, etc.) leading to environmental protection, to the rational and sustainable use of soils and water resources through prevention of the hazard of soil salinization/sodication is also necessary. Knowledge of the soil hydraulic parameters/functions is necessary to validate and calibrate simulation models and to develop reliable management scenarios (*link with WG Research*).
2. Community policies should increase the focus on the compaction problem, and simultaneously set up research programmes to improve models for stress propagation in real soil and to collect data on soil strength. Maps with the carrying capacity of subsoils loaded with a specific tire can be an effective way to bring the problem under the attention of the general public, policy makers and farmers. The carrying capacity concept provides a means of identifying management thresholds in relation to subsoil compaction.
3. Improving river basin land use, preventing rapid runoff both in rural and urban areas, and a transnational effort to restore the natural flood zones of rivers leads to flood mitigation and to ecological benefits in the form of maintaining biodiversity. Such measures often result in the recharging of underground aquifers and cleaner water for drinking, increased areas for recreation, opportunities for touring and so on.

Figure 1 shows the driving forces and pressures determining these threats on the soil and related processes. The Figure also lists some parameters to be monitored and used as **indicators** together with some **recommendations** to be followed in the frame of a Soil Protection Policy.

Recommendations for a Soil Protection Policy from Salinization and Sodication, Compaction, Floods and Landslides (with indications of links with Monitoring and Research actions and Working Groups) Giuseppina Crescimanno, *Università di Palermo,Dipartimento ITAF, Viale delle Scienze, 9012*

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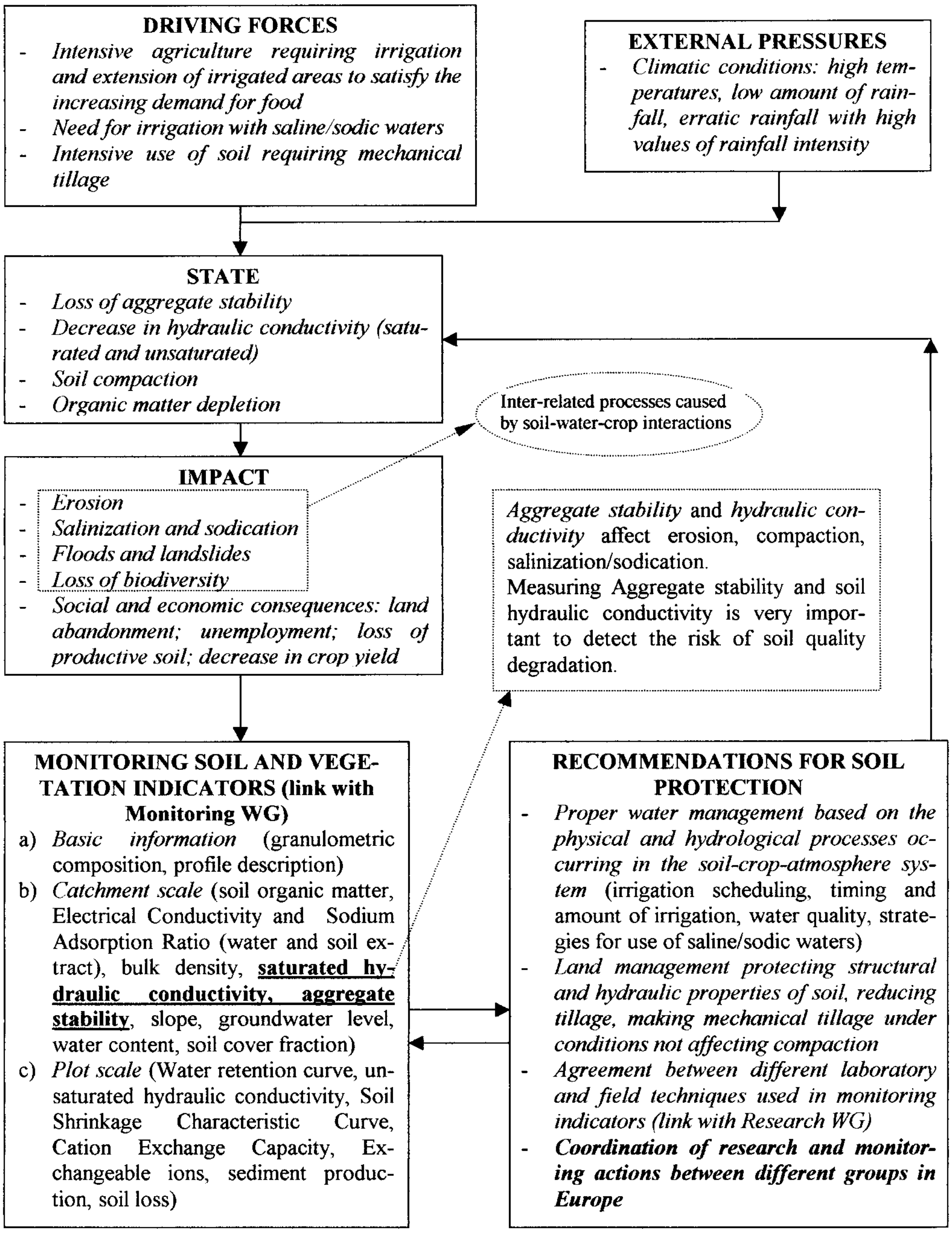

Figure 1.- Overview of the causes and pressures determining soil erosion, salinization and sodication, compaction, floods and landslides, of the indicators to be monitored and of the strategies and policies to be adopted to prevent the extent of these threats in Europe (with indication of links with Monitoring and Research actions and WGs)

Chapter 1 – Introduction

"It can be stated without exaggeration that no other problems exist, except the threat of nuclear war, which is so crucial for the future of mankind as the deterioration of global environment." (I. Szabolcs, 1994)

Soil quality has been defined as "the capacity of a soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (*Doran J.W. and T.B. Parkin 1994. Defining and assessing soil quality. P. 3-21. In J.W. Doran et al. (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. SSSA and ASA, Madison, WI.*).

Soil functions that soil quality influences include the ability (i) to accept, hold, and release nutrients and other chemical constituents; (ii) to accept, hold, and release water to plants and surface and groundwater recharge; (iii) to promote and sustain root growth; (iv) to maintain suitable soil biotic habitat; and (v) to respond to management and resist degradation. Degradation can result from declines in organic matter content, salinization, sodication, compaction, acidification, nutrient depletion, chemical or heavy metal contamination, or reduced diversity and activity of soil organisms. Thus, a complete assessment of soil conservation must go beyond estimating soil erosion and should consider other soil qualities that may be degraded. Because of its importance, a quantitative assessment of soil quality is needed to determine the sustainability of land management systems as related to agricultural production practices, and to assist government agencies in formulating and evaluating sustainable agriculture and land use policies (Doran and Parkin, 1996).

Two problems hinder a regional-scale assessment of soil quality. First, soil quality cannot be measured directly, but must be inferred by measuring soil attributes or properties that serve as indicators. Changes in these indicators can be used to determine whether soil quality is improving, stable or declining with changes in management, land use, or conservation practices. Second, many of the soil attributes that contribute to soil quality are highly correlated, functioning in concert with other soil attributes. Identification of indicators integrating different and important soil quality attributes is fundamental to the development of management strategies and policies preventing soil quality degradation. The soil communication (Soil Thematic Strategy) identified eight soil threats:

- erosion
- contamination
- organic matter
- salinization
- compaction
- floods and landslides
- sealing
- biodiversity

Of these threats, salinization,/sodication, compaction, floods and landslides have been linked to the Erosion Working Group, and are discussed in the following chapters.

Chapter 2 – Salinization and Sodication *(extent, causes, pressures, strategies and actions that should be adopted to prevent and to combat salinization and sodication in Europe)*

Objectives: to analyse the situation of salinization and sodication in Europe, to examine the causes and pressures enhancing these processes, both leading to desertification, and to provide suggestions for policies and actions finalized to prevention of this threat in Europe.

2.1 Saline and sodic (alkali) soils

Salt-affected soils occur both naturally and as a result of irrigation practices which permit the mobilization of salinity within the soil body and the transport of salts and/or Sodium (Na) to new locations. Salt-affected soils are usually separated into two groups, namely saline soils on the one hand, and alkali or sodic soils on the other (Bresler, 1982; Sumner, 1993; Szabolcs, 1989).

Generally, saline soils have received more attention than sodic soils, because firstly saline conditions often rise from anthropogenic causes such as irrigated agriculture, and secondly because of the much larger areas of agricultural soil which have been salinized through the world.

Salinization of water and soil represents a pre-condition for desertification, defined as "degradation of land in arid, semi-arid and dry sub-humid areas resulting mainly from adverse human impact" (UNEP, 1991).

Salinity also poses a major management problem in many non-irrigated areas where cropping relies on limited rainfall. Dry land salinity has been a threat to land and water resources in several parts of the world, although only in recent years has the seriousness of the problem become widely known.

2.1.1 Salinization and sodication in Europe

Within Europe, 26 countries are more or less affected by salinization and sodication, while no problems have been so far recognized in Austria, Belgium, Denmark, Finland, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Poland, Switzerland, Sweden and UK.

Table 1 shows some information concerning the distribution of saline and sodic soils in Europe according to different sources of data and information (Szabolcs, 1989; Fao, 1997; Correia, 1999; FAO and ISRIC, 2000) and to data collection carried out by sending a questionnaire to researchers involved in this issue within and outside Europe (Crescimanno, 2003).

Table 1 also reports some additional information collected in the different countries (land area, irrigated area).

Analysis of Table 1 clearly shows:

- The lack of information concerning the extent of saline and sodic areas (as well as other information) in many countries;
- The large discrepancies existing in the different collected data;
- The only reliable information in the Table appears to be that related to the irrigated areas in the various countries.

This analysis demonstrates that a survey is necessary in Europe to assess the current status of salinization and sodication, as well as other useful information. Only for Austria, Belgium, France, Germany, Norway, Hungary, Portugal, Russia, Spain, Slovakia, Switzerland, and U.K was it possible to obtain updated information from answers to questionnaire (Crescimanno, 2003), but in some cases these appear contradictory and need further verification.

EUROPE	Total land area (FAO, 1997)	Total land area (Correia, 1999)	Total land area (Crescimanno, 2003)	Irrigated area (FAO, 1997)	Irrigated area (Correia, 1999)	Irrigated area (Siebert-Doll, 2001)	Irrigated area (Crescimanno, 2003)	Saline soils (Szabolcs, 1989)	Saline soils (FAO, 1997)	Saline soils (FAO and ISRIC, 2000)	Saline soils (Crescimanno, 2003)	Sodic soils (Szabolcs, 1989)	Sodic soils (FAO, 1997)	Sodic soils (Crescimanno, 2003)
	1000ha	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*	*1000ha*
Albania	n. a.	707,0	n. a.	n. a.	423,0	340,0	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Belgium	n. a.	n. a.	863,0	n. a.	n. a.	400,0	30,0	n. a.	n. a.	n. a.	0,6	n. a.	n. a.	n. a.
Bulgaria	n. a.	n. a.	n. a.	n. a.	n. a.	800,0	n. a.	5,0	n. a.	770,0	n. a.	20,0	n. a.	n. a.
Cyprus	n. a.	156,0	n. a.	n. a.	35,0	40,0	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Czech Rep.	n. a.	n. a.	n. a.	n. a.	n. a.	24,0	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Ex Czechoslovakia	n. a.	n. a.	n. a.	n. a.	n. a.	198,0	n. a.	6,2	n. a.	n. a.	n. a.	14,5	n. a.	n. a.
Ex U.S.S.R.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	7.546,0	n. a.	n. a.	n. a.	21.998,0	n. a.	n. a.
Ex Yugoslavia	n. a.	7.766,0	n. a.	n. a.	168,0	119,0	n. a.	20,0	n. a.	n. a.	n. a.	235,0	n. a.	n. a.
France	n. a.	19.119,0	29.898,0	n. a.	1.160,0	2.000,0	1.576,0	175,0	n. a.	n. a.	225,0	75,0	n. a.	250,0
Greece	n. a.	3.924,0	n. a.	n. a.	1.190,0	1.422,0	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Hungary	9.200,0	n. a.	7.729,6	200,0	n. a.	210,0	237,7	1,6	500,0	4.030,0	150,0	384,5	1.800,0	850,0
Hungary			8.200,0				135,0				20,0			1.400,0
Italy	29.400,0	12.033,0	n. a.	2.700,0	3.100,0	2.698,0	n. a.	50,0	400,0	n. a.	n. a.	n. a.	0,0	n. a.
Malta	n. a.	n. a.	n. a.	n. a.	n. a.	2,0	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
Moldova Rep.	n. a.	n. a.	n. a.	n. a.	n. a.	307,0	n. a.	n. a.	n. a.	2.290,0	n. a.	n. a.	n. a.	n. a.
Portugal	n. a.	3.771,0	3.800,0	n. a.	634,0	632,0	700,0	n. a.	n. a.	n. a.	150,0	n. a.	n. a.	50,0
Romania	23.000,0	n. a.	n. a.	3.100,0	n. a.	2.880,0	n. a.	40,0	500,0	n. a.	n. a.	210,0	1.100,0	n. a.
Russia (Eur. Part)	n. a.	n. a.	1.707.500,0	n. a.	n. a.	3.983,0	5,08	n. a.	n. a.	2.450,0	n. a.	n. a.	n. a.	n. a.
Slovakia	n. a.	n. a.	2.438,3	n. a.	n. a.	174,0	311,0	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	4,9
Spain	50.000,0	20.345,0	13.838,0	3.500,0	3.360,0	3.268,3	3.400,0	n. a.	2.400,0	600,0	1.050,0	n. a.	0,0	n. a.
Spain			50.599,0				3.640,0				728,0			
Switzerland	n.a.	n.a.	1.487,0	n.a.	n.a.	25,0	n.a.	n.a.	n.a.	n.a.	0,7	n.a.	n.a.	0,0
Turkey	77.000,0	27.885,0	n. a.	4.200,0	2.220,0	4.185,9	n. a.	n. a.	2.000,0	n. a.	n. a.	n. a.	500,0	n. a.
United Kingdom	n.a	n.a	6.850,0	n. a.	n. a.	142,7	n.a.	n. a.	n. a.	n. a.	50,0	n. a.	n. a.	0,0
Ukraine	n. a.	n. a.	n. a.	n. a.	n. a.	2.454,0	n. a.	n. a.	n. a.	40,0	n. a.	n. a.	n. a.	n. a.

Ex U.S.S.R.: Belarus, Ukraine, Moldova Rep., Russia, Latvia, Estonia, Lithuania
Ex Yugoslavia: Slovenia, Croatia, Bosnia-Herzegovina, Serbia, Macedonia
n. a. not available

Table 1. Status of salinization and sodication in Europe according to different sources of data

2.1.2 Mediterranean countries within Europe

An increasing attention is being given to salinization and sodication problems in Mediterranean countries within Europe. Problems existing in these Mediterranean countries can be considered particularly interesting as these countries (i) represent environments characterized by very extreme conditions with respect to fluctuations in water availability and needs and (ii) many of the approaches to deal with these problems and some of the solutions currently adopted, or to be adopted in the near future, can be very useful elsewhere in the future. An example of a study carried out in a Mediterranean country is reported in par. 2.5.2.

2.2 Factors inducing salinization and sodication

2.2.1 Climatic conditions

Salinization and sodication may have a different genesis in the different countries and according to different climatic conditions (Kertez et al., 2000). In arid regions, the scarcity, variability and unreliability of rainfall and the high potential evapotranspiration affect the water and salt balance of the soil. Low atmospheric humidity, high temperature and wind velocity promote the upward movement of the soil solution and the precipitation and concentration of the salts in the surface horizons. Various types of Na, Mg and Ca salts are concentrated following this process, mainly chloride and sulphate: this determines salinization. In less arid climates, salts are less concentrated and Na dominates in carbonate and bicarbonate forms which enhance the formation of sodic soils. The sodication process involves the presence of soluble sodium salts in the soil solution and their adsorption in the exchange complex.

2.2.2 Irrigation and Management

Poor soil and water management, including insufficient water application, irrigation with saline/sodic waters (Oster, 1994; Crescimanno, 2000), and water without proper agronomic practices, have been identified as being the main drivers of salinization/sodication in several salinity projects (FAO, 1997; Crescimanno 2001).

Analysis of some of the different situations in Europe has made it possible to identify some common driving forces inducing salinization and sodication, i.e. increasing demand for irrigation water, deterioration of water quality, inappropriate management of irrigation (e.g. use of sprinkler irrigation systems instead of drip systems), lack of drainage systems, increasing use of saline and wastewaters, groundwater overexploitation and marine intrusion in coastal areas.

2.2.3 External pressures enhancing the risk of salinization and sodication

External pressures common to countries within and outside Europe (Australia, Mexico, Argentina, Iran), and enhancing the processes of salinization and sodication, are represented by climatic conditions characterized by increasing temperature and evapotranspiration, with dry seasons during which irrigation is necessary to keep acceptable levels of a crop's yield, erratic rainfall, intensive use of soil, increase in irrigated areas and increasing use of low quality waters.

2..3 Consequences of salinization and sodication

2.3.1 Crop yield

Salinity may have negative direct effects on crop yield by reducing the ability of plant roots to absorb water: the reduced availability of water to a plant is due to soluble ions and molecules causing an osmotic pressure effect (Rhoades, 1989). Threshold relationships between the electrical conductivity (EC) of the saturated extract and crop yield have been empirically determined for several crops and can be used to evaluate the influence of saline irrigation waters on agricultural production (Maas, 1990).

2.3.2 Soil structural and hydraulic properties

Sodium (Na) dissolved in irrigation water and adsorbed in the exchange complex affects the structural and hydraulic characteristics of soil (Crescimanno et al., 1995). The deleterious effect of Na on soil structure (Rengasamy and Olsson, 1991) can be attributed to swelling and/or dispersion of clay particles (Abu-Sharar et al., 1987) and migration of clay into the soil pores with subsequent occlusion, slaking of aggregates and loss of aggregate stability (So and Aylmore, 1993). Soil erodibility increases as a consequence of loss in aggregate stability (Baiamonte and Crescimanno, 1997).

2.4 Large scale impact of salinization/sodication

2.4.1 Sealing, crusting, soil loss, biodiversity

At the large scale, soil sealing and crusting (Agassi et al., 1981) determine reduction in infiltration rate (Agassi et al., 1985) with subsequent increase in surface runoff and soil loss by erosion. Reductions in hydraulic conductivity affect water transport in the vadose zone (Crescimanno and Provenzano, 1998), decreasing the amount of water available for crops and evapotranspiration (Crescimanno and Iovino, 1995), and indirectly affect the growth of plants, also determining a loss of biodiversity.

2.4.2 Economic and social impact of salinization/sodication

Economic consequences common to salinized/sodicized areas are represented by changing crops towards more tolerant ones, sometimes with less economic advantage, additional costs for farmers in order to build drainage systems or to use more water to perform salt-leaching. The main social impact of salinization is represented by unemployment and land abandonment, with extreme consequences such as suicides in some countries (e.g. in Australia).

2.5 Indications for a policy for soil protection against salinization and sodication

2.5.1 The key role of water management

Water management has a key role in developing policies to protect soil against salinization and sodication. Since salinization and sodication (but also sealing, crusting, erosion) are processes deriving from the interaction between soil and water (Fitzpatrick et al., 1994), soil protection can be achieved only through an accurate description of the physical and hydrological processes occurring in the soil. Physically based simulation models (Wagenet and Hutson, 1992; van Dam et al., 1997) make it possible to examine different combinations of existing field conditions (soil, climate and water) and to define viable management options leading to sustainable land use in areas susceptible to salinization and sodication.

2.5.2 Results of a EU-funded pilot study carried out in Sicily (Italy) in order to explore methodologies and tools to assess and prevent the risk of salinization (Project n. ENV4-CT97-0681)

A pilot-area (Delia-Nivolelli catchment) was selected in Sicily (Italy) in order to perform investigations to delineate strategies for soil protection against salinization and sodication. The investigation, carried out from 1998 to 2001, showed that (Crescimanno, 2001):

1. Irrigation with saline water, often performed without adequate drainage, is the main cause of salinization in the area; 2. A greater risk of salinization is associated with the use of high-pressure systems (e.g. sprinkler), compared to drip systems; 3. Due to the presence of clay soils with low hydraulic conductivity and lack of drainage systems, application of leaching fractions can determine a greater hazard of salt accumulation instead of removing excess of salt from the soil profile; 4. Blending or cyclic strategies (Rhoades, 1990; Crescimanno et al., 2002) can be suggested to reduce salinization in these situations, but attention needs to be paid to deterioration of soil structural and hydraulic properties due to a decrease in cationic concentration (Abu-Sharar et al., 1987); 5. Crop transpiration and yield are the result of the combined effect of the amount of water available and of the level of salinity. Models accounting for the two factors are needed for accurate prediction of a crop's yield in a saline environment; 6. Salinization has caused desertification in previously productive fields.

In conclusion, this investigation evidenced that a proper management of irrigation, based on selection of different possible options using simulation models accounting for soil-water interactions, represents the only possible strategy for soil protection against salinization and sodication.

2.5.3 Irrigation scheduling and salt-reclamation

Irrigation scheduling (amount and timing of irrigation) is the only viable strategy for optimization of water use by crops with minimization of soil degradation, especially in countries where insufficient rainfall occurs and irrigation is necessary to achieve acceptable levels of production. Accurate calculation of leaching fractions (van der Molen, 1973; Cote et al., 2000), as well as a proper use of amendments (Keren and Miyamoto, 1990), should be based on description of the physico/chemical/hydrological processes occurring in the soil, also accounting for cracking and bypass flow (van der Task and Grismer, 1987; Crescimanno and De Santis, 2003). Improper calculation of leaching fractions can increase salt-accumulation in clay soils without adequate drainage.

2.6 Prevention of salinization and sodication in salt-affected and potentially affected countries in Europe

A network should be implemented urgently in European countries affected or potentially affected by salinization and sodication, in order to take the following actions:

- Collection of updated and reliable information on the status of salinization and sodication in Europe, and of other information related to the process of salinization and sodication.

As shown in Table 1, there are large discrepancies in the different information reported by the different sources, and many gaps which need to be filled in terms of information for the majority of the listed countries.

- Identification of areas threatened by salinization and sodication in different countries for monitoring purposes (link with WG Monitoring).
- Monitoring of indicators of salinization and sodication for identification of the threatened areas (link with WG Monitoring). These indicators should be: electrical conductivity of the soil saturated extract (ECs), Exchangeable Sodium Percentage (ESP) or Sodium Adsorption Ratio (SAR) of the saturated extract (see par. 2.7).
- Application of models predicting transport of water and solutes for a selection of management strategies (i.e. alternative irrigation methods and scheduling, calculation of leaching requirement, conjunctive use of different irrigation waters, amendments, etc.) leading to environmental protection, to the rational and sustainable use of soils and water resources through prevention of the hazard of soil salinization/sodication (*link with WG Research*).
- Accurate determination of soil hydraulic properties is a key step for application of simulation models and selection of appropriate management strategies (Stolte et al., 1994; Crescimanno and Baiamonte, 1999; Crescimanno, 2001). Since large-scale results are necessary, research (*link with WG Research*) should be developed to find methods combining an acceptable accuracy in inputs with accuracy of model predictions and results of management scenarios.

Since no actions or policies specifically dealing with prevention of salinization and sodication exist in European countries, while these policies have been implemented in other countries (as an example, a National Plans for Salinity exists in Australia, and a National Water Commission exists in Mexico to deal with soil protection against salinization/sodication), these and possibly other countries facing these problems should be included in these monitoring/research actions in order to explore a wider range of situations and to develop a wider range of management actions/plans.

Institutions from Australia, Mexico, Argentina, Iran, Israel and Malaysia could be available for these monitoring/research actions. Helpful information was provided by colleagues working in these countries in response to my request of answering the questionnaire giving an overview of the situation. The contribution of researchers involved in salinity/sodicity issues in these countries is acknowledged in the specific section.

2.7 Monitoring salinization and sodication: indicators

2.7.1 Indicator of salinization

Soil salinity is generally measured on an aqueous extract of a saturated soil-paste by measuring the electrical conductivity, ECs. Because the ECs and the total salts concentration of an aqueous solution are closely related , ECs is commonly used as an expression of the total dissolved salt concentration of an aqueous sample.
In order to determine ECs, a saturated soil-paste is prepared by adding distilled water to a sample of air-dry soil while stirring and then allowing the mixture to stand overnight to permit the soil to fully imbibe the water and the readily soluble salts to fully dissolve. A conductivimeter is then used to measure the electrical conductivity, Ecs.

2.7.2 Indicator of Sodication

The *Exchangeable Sodium Percentage* (ESP), represents the amount of exchangeable Sodium expressed as a percentage of the Cation Exchange Capacity (CEC).
The ESP is defined by the relationship:

$$ESP = (exch.Na^{+}/CEC)\times 100$$

The exchangeable sodium is determined by difference from leached Na^{+}, determined using a flame photometer, and the amount of soluble Sodium, determined from the saturation extract.
An useful and easier to measure index for predicting the tendency of an incoming soil solution to bring the soil at a value of ESP in equilibrium with the SAR of the applied solution is the Sodium Adsorption Ratio (SAR), defined by the relationship:

$$SAR = [Na^{+}]/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$$

where all the concentrations are in meq/l. SAR is expressed in terms of ion concentrations rather than of ion activities. The SAR of the saturated extract of the soil can be considered a measurement of the hazard of soil sodication.

2.8 Concluding remarks

A greater awareness of the threat represented by salinization and sodication is necessary. Salinization and sodication represents a huge environmental problem of which other countries outside Europe are aware, but so far it has been considered a secondary threat in Europe. With the increasing external environmental pressures this threat is likely to become bigger and bigger even in Europe. Degradation in those soil properties that ensure fertility and productivity is bound to transform our cultivated land into a desertificated area.

2.9 Acknowledgments

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Chapter 3 – Subsoil compaction

Per Schjønning, Holger Böken, Jan Van den Akker and Ole H. Jacobsen. *The text is to a large extent based on a recent review by van den Akker and Schjønning (2004) and a German contribution at the OECD 'Expert Meeting on Farm Management Indicators', in Palmerston North, New Zealand by Lebert et al. (2004).*

Chapter 3 – Subsoil Compaction

Introduction

Soil compaction induced by large-scale equipment in agriculture is of growing concern. The demand for tractive power and machine power increase with intensified production practices. As higher tractive power or bigger transport capacities often result in higher wheel loads, heavy wheel traffic at high inflation pressures and wet conditions increases the risk of irreversible harmful damage to the soil structure to greater depths.

The compaction problem has been extensively reviewed in a number of publications (e.g. Håkansson, 1994; Soane and Van Ouwerkerk, 1994; Van Ouwerkerk and Soane, 1995; Van den Akker *et al.*, 1999, 2003; Birkas *et al.*, 2000; Horn *et al.*, 2000; Canarache *et al.*, 2002; Chamen *et al.* 2003, Van den Akker and Schjønning, 2004). It is well described how compaction influences soil, at least in terms of the physical conditions. An important conclusion from these investigations is that subsoil compaction appears to be rather persistent if not permanent, i.e., the resilience regarding subsoil compaction is extremely low. Factors generally considered to alleviate compaction are wetting/drying, freezing/thawing, biological activity and tillage. The efficiency of freezing in alleviating subsoil compaction has previously been overestimated (Håkansson and Petelkau, 1994). Furthermore, soil compaction becomes more persistent the deeper it penetrates because the frequency and intensity of the factors above decrease rapidly with depth. This effect will be further accelerated because reduced root growth in compacted soil will reduce oscillations in water content (Whalley *et al.*, 1995) and biological activity. Soil compaction affects the whole range of soil functions because the soil structure influences nearly all processes in the soil.

Extent and development of the subsoil compaction problem

Fraters (1996) estimates that about 32% of the subsoils in Europe are highly vulnerable to subsoil compaction and another 18% are moderately vulnerable, but no precise data are available. Subsoil compaction is a hidden form of soil degradation that affects all of the agricultural land. It results in gradually decreasing yields and gradually increasing problems with soil air- and water conductivity. The impact of subsoil compaction is primarily prominent in years with extreme dry or wet periods - another reason why it is hardly recognized. In fact, all agricultural soils in developed countries display compacted subsoils.

In the field experiments initiated in the early 1980's (Håkansson *et al.*, 1987), wheel loads of 50 kN were used for the initial subsoil compaction action. This was considered a very high wheel load at that time. Van de Zande (1991) considered 35 – 40 kN as the highest wheel load class in an investigation in 1984 on traffic intensity on fields in the Netherlands. Nowadays self-propelled slurry tankers with injection equipment have wheel loads of 90 – 120 kN and are used in early spring on wet soils. Arvidsson (2001) investigated the impact on subsoil compaction of wheel loads of 90 kN exerted by self-propelled, six-row sugar beet harvesters, which were introduced in Sweden in 1993. Van der Linden and Vandergeten (1999, cited by Poodt *et al.* (2003)) reported maximum wheel loads of 130 kN for sugar beet harvesters. Although wheel loads are not *per se* responsible for subsoil compaction, the development described here indicates the extreme demands on modern tyres for carrying these loads with low contact area pressures.

The British Soil Code mentions that large agricultural machinery is not necessarily a greater risk for normal work on undisturbed soils. Since faster work rates allow the work to be completed under better soil moisture condition by making better use of workable days. However, the higher trafficability obtained by the use of wide, low-pressure tyres puts an increased responsibility to the farmer: the higher efficiency should be used for decreasing the number of work days and not for running a higher acreage at wet conditions.

Sustainability criterion

Although it has been shown in recent decades that compacted subsoil is not at all or only extremely slowly ameliorated by natural processes (e.g. Voorhees, 2000), it might be claimed that the soil resource could be reconstituted by other means. However, as reviewed by Larson *et al.* (1994) and Håkansson and Reeder (1994), several studies have shown that mechanical subsoiling is not able to fully remedy the malfunctions created by compaction. Further to that, it appears that the mechanical loosening effect seems to persist for only a few years (e.g. Bishop and Grimes, 1978; Kooistra *et al.*, 1984). To a large extent this is due to the loosened soil being extremely vulnerable to recompaction from traffic (Soane *et al.*, 1986). Another potential means of ameliorating compacted soil is through the action from actively growing plant root systems. However, Cresswell and Kirkegaard (1995) reviewed the literature and concluded that it is still not clear whether "biological drilling" is an effective process for ameliorating dense subsoils. In conclusion, we judge subsoil compaction so severe that <u>no subsoil compaction</u> should be the criterion for sustainability.

The compaction problem in the DPSIR context

The <u>driving force</u> leading to soil degradation through soil compaction is the intensification and mechanization of modern agriculture. This in turn relates to efforts of reducing the cost of production. The <u>pressures</u> exerted on the soil resource when speaking of compaction are very direct in terms of increased frequencies and levels of physical loads put on the soil. The <u>state</u> of the soil as a consequence of these pressures has changed in terms of reduced volumes and continuities of soil pores. This in turn has a dramatic and significant <u>impact</u> on a number of soil functions. The <u>responses</u> that may be identified and activated should be directed towards the pressures and perhaps even the driving forces. The key term for responses regarding the compaction problem is <u>prevention</u> of compaction. It is an important recognition that it is not advisable for policy implementations regarding subsoil compaction to include concrete measures of repairing the damage created by subsoil compaction. I.e., responses directed towards the state of the soil (e.g. mechanical loosening of the subsoil) in order to reduce the impact of the compaction are not expected to be successful without significantly changing the cropping system. The following text primarily addresses the impact of (sub)soil compaction and the potential responses to be used in reducing the problem.

Impact of subsoil compaction on soil functions and processes

Subsoil compaction exerts a pronounced effect on soil functions. Basically, compaction influences the state of the soil in terms of a reduction in void volume. Pore continuity may be affected as well. This reduces the ability of the soil to conduct water and air. A poor saturated hydraulic conductivity may trigger surface runoff and eventually water erosion. It may also induce preferential flow in macro pores, which has been shown to facilitate transport of colloid-adsorbed nutrients and pesticides to deeper horizons. A poor aeration of soil may yield non-optimal plant growth and induce loss of soil nitrogen and production of greenhouse gases through denitrification in anaerobic sites. Plastic deformation of soil aggregates and higher bulk density resulting from compaction increase the mechanical strength of the soil matrix. This may limit root growth and crop exploitation of soil water and nutrients. Accordingly, this may increase leaching of nutrients. These and other compaction effects on soil functions are described in a number of scientific reports and reviews (e.g. Soane and Van Ouwerkerk, 1994; Van Ouwerkerk and Soane, 1995).

The potential impact of subsoil compaction on crop yield and environmental aspects may be much more severe than deduced from average results of even long-term field trials. Therefore, in addition to field trials, models run with different scenarios of weather conditions may increase the understanding of the impact of soil compaction (e.g. Feddes *et al.*, 1988; Simota *et al.*, 2000; Stenitzer and Murer, 2003; Lipiec *et al.*, 2003). The most common soil physical parameter is the dry bulk density (g cm^{-3}). This as a sole parameter is not suitable for the identification of harmful soil compaction, since it is not directly related to soil functions. Although it is correlated to soil functions, there is no classification for general use, which would allow for an assessment of soil health based on dry bulk density values.

Table 1: Soil functions and sub-functions that are directly affected by soil compaction, and soil parameters as possible indicators (after Lebert et al., 2003).

Soil function	Soil sub-function	Indicator: Single Parameter	Indicator: Aggregated Parameter
Air regime	Air storage	Air capacity Bulk density	For all sub functions: Visual classification of soil morphology by: Effective bulk density Packing density Spade diagnosis
	Air flow	Air permeability O_2-Diffusion Bulk density	
Water regime	Water storage	Available water capacity Bulk density	
	Water flow	Water conductivity (saturated/unsaturated) Bulk density	
Plant production	Rootability	Root length density Bulk density Penetration resistance	

The same applies for the parameters "pore volume" and "void ratio" which are derived from bulk density. In contrast, the evaluation of soil compaction should address soil functions like air- and water conductivity. Lebert et al. (2003) qualified 5 parameters as suitable for detecting harmful compaction in the subsoil: the soil physical properties air capacity and saturated water conductivity and the three methods of visual soil valuations: effective bulk density, packing density and spade diagnosis[1] (Table 1). Please consult paragraph 3.6.2 for a discussion on the potential implementation of these procedures in the identification of allowable stresses in the subsoil.

Due to the direct influence of compaction on the soil's hydraulic conductivity, it may be relevant to specifically mention the interaction between soil compaction and soil erosion. Water erosion may be triggered if the capacity of the soil to infiltrate and conduct water to deeper horizons is lower than the rate of precipitation. Often the focus is mainly on the infiltration capacity as this directly will induce surface runoff that in turn exerts a shearing force on the soil matrix. However, erosion may be initiated also due to a limiting hydraulic conductivity of some soil horizons below the surface. A poor hydraulic conductivity in compacted subsoil has been shown to trigger horizontal movement of water above the limiting soil layer (Kulli *et al.*, 2000). Another consequence is ponding on the soil surface and hence the initiation of surface runoff on sloping land. Measurements of runoff from Danish field experiments on soil erosion indicated that this process may be active in periods with moderately intense but continuous rain (Schjønning *et al.*, 1995, 1996). In conclusion, soil compaction may play a key role in the soil erosion problem.

Recommendations to prevent subsoil compaction

3.6.1 Adjusting loads to the soil carrying capacity

The international research has identified the following factors as essential for the risk assessment of subsoil compaction (a.o. Söhne, 1958; Barnes et al., 1971; Koolen and Kuipers, 1983; Soane and van Ouwerkerk, 1994; Alakukku et al., 2003):

a) Soil stability and soil strength;
b) Soil moisture;
c) Soil vehicle data;
d) Soil stress distribution.

The factors a) and b) together build the bearing capacity of the soil. The factors c) and d) together characterise the compressive stresses reaching the subsoil. The vertical stress on the subsoil must be lower or equal to its bearing capacity, in order to maintain the soil structure and the respective soil functions. When the stress reaching the

[1] Method for visual soil classification with a special spade (Görbing and Sekera, 1947; Preuschen, 1983).

subsoil exceeds the precompression stress or the shear strength, soil structure will change and a disruption of soil functions may occur due to further compaction.

In the work by Jan Van den Akker (e.g. Van den Akker, 1997) it has been shown that it is possible to quantitatively relate soil stress exerted by loading by wheels with the strength in the subsoil (Van den Akker & Schjønning, 2004). This wheel load carrying capacity concept allows the identification of the maximal loading exerted by a specific tyre type and tyre inflation pressure, without exceeding the strength of that subsoil. As the strength of the subsoil is soil type specific and further influenced by the water content, the carrying capacity identified by this stress and strength matching concept is a dynamic parameter even for a specific loading situation. However, a potential measure in combating soil compaction is the quantification of this parameter for a number of soil types at different water contents and for a number of tyre inflation pressures and tyres. Van den Akker and Schjønning (2004) showed how this could be done for four German soil types at two water contents. The example pointed out that the wheel load carrying capacity may be high enough to carry out several tillage and traffic operations even at a water content of field capacity. However, a necessary prerequisite is the use of the best tyres currently available. If using standard tyres, the carrying capacity may well be too low to allow traffic even with medium size machinery. The thresholds identified (~40-60 kN wheel-load) were, furthermore, too low to allow traffic with high-capacity slurry tankers and self-propelled harvesters used in modern agriculture.

The carrying capacity calculated from the stress and strength matching concept may serve as one tool for farmers and extension officers. Modern information technology allows for several ways of bringing this information to the end user. However, data on soil strength is scarce and the predictions obtained for this scale thus have to be based on pedotransfer functions relating soil texture and strength. Such relations are uncertain, which emphasizes a high demand for more data on soil strength in order to create reliable maps for larger areas.

3.6.2 Identification of allowable stress values from soil functions

It has been a general premise for most studies on subsoil compaction that – due to its persistence – it should be avoided. However, our knowledge on soil functions allows idenfication of key parameters that could be used as indicators for a healthy soil (Table 1). The idea is that subsoil compaction is allowable, given that some threshold values of these indicators are not exceeded. Werner & Paul (1999) defined the bearing capacity of some subsoil as the stress on the virgin compression line, which corresponds to a compaction level giving rise to some specific threshold indicator values. The approach was labelled the 'loading quotient' concept because the stress identified can be given as a quotient of the precompression stress. Lebert et al. (2003) claimed that a volumetric air capacity of 5% and a saturated hydraulic conductivity of 100 mm d^{-1} were suitable indicator thresholds.

The 5% v/v air capacity threshold is somewhat lower than often reported in literature (e.g. Grable & Siemer, 1968; Schjønning et al., 2003). Renault & Sierra (1994) concluded from a comprehensive work with modelling aeration in soil, that more studies are needed on the effects of soil structure on local anaerobiosis. The critical limit of air capacity and - diffusivity may also be soil type specific (Schjønning et al., 1999, 2003) and further will depend on the soil function in question. As an example, denitrification may be triggered at another threshold of air-filled pore space than reduction in plant growth. The 100 mm d^{-1} threshold for saturated conductivity corresponds to ~4.2 mm h^{-1}. Given the intensity of precipitation commonly observed, this seems a rather low value. It is advisable that more investigations are carried out to verify the threshold level of these indicators on the European scale.

Hence, the approach with soil function related indicator thresholds in decision tools for avoiding harmful soil compaction is interesting but its implementation is not straightforward and needs more studies.

3.6.3 General measures to prevent subsoil compaction

The principles for the application of best management practice in agricultural soil use to safeguard against soil compaction are based upon a system of four principles according to Sommer (1998):

- Adaptation of cropping methods
  (e.g. the adaptation of row width to enlarged tyre size)
- Further development of technical solutions
  (e.g. low pressure tyres)
- Improvement of the soil bearing capacity
  (e.g. by conservation tillage, reduced tillage or no tillage)
- Limiting the mechanical loads
  (e.g. no complete filling of harvestors or trailers under wet soil conditions)

A detailed, international review of practical options to lower the risk of subsoil compaction in farming systems are given by Chamen et al. (2003). The particular state of the soil and the required level of action to safeguard against compaction are assessed and determined by the competent agricultural advisory bodies together with the farmer. In Germany, a code of good farming practices for the prevention against soil erosion and soil compaction in agricultural land-use has been published, which also provides practical on the spot solutions against soil compaction (BMVEL 2001).

The carrying capacity approach discussed above may generally be explained as a matching of machine operations to the conditions of the soil. With a lack of specific soil data for most conditions, it is a great challenge to implement this in practice. A number of precautionary measures should be regarded in order to decrease the risk of compaction. Below, we summarise some of the most important management tools to consider in this context.

Soil stresses in the subsoil can be decreased by decreasing tyre inflation pressures, wheel loads and rut depths and by using wider, larger and flexible tyres. Wheel loads can be decreased by lowering the payload or weight of the equipment or by increasing the number of wheels (e.g. dual wheels or tandem). A very effective way of decreasing soil stresses is to reduce the average ground pressure on the rut bottom by using wide tyres with low inflation pressures. This was the basis for guidelines suggested by Tijink (1998) in terms of limits for inflation pressure, average ground pressure and vertical soil stresses at 50 cm depth in spring or in summer/autumn. However, these guidelines neglect the effect of high wheel loads on subsoil compaction. Håkansson and Petelkau (1994), on the other hand, mentioned recommended axle load limits of 60 kN (30 kN wheel load) in Sweden and 30 – 40 kN (15 – 20 kN wheel load) for machines with standard tyres in the former German Democratic Republic. These axle load limits are very simple, however, neglecting the considerable benefits of low tyre inflation pressures. The use of limits for axle load or inflation pressure as generalised management thresholds will often imply under- or overestimation of allowable wheel loads leading to subsoil compaction or too low, uneconomical wheel loads. Summing up, wheel load, tyre inflation pressure, average ground contact pressure and speed are interrelated.

The complexity discussed above makes it controversial to introduce strict legislation on maximum allowable wheel loads or inflation pressures. However, the carrying capacity concept makes it possible to determine whether a certain combination of wheel equipment, machinery and payload causes subsoil compaction and should not be allowed. This would enable certification of allowable agricultural machinery when data on subsoil strength become available.

Conventional mouldboard ploughing is one of the most vigorous means of compacting the subsoil. A substantial part of the tractor weight is loaded on the rear wheel running on top of the subsoil in the furrow. Recent research indicates that subsoil stresses may be significantly reduced by using ploughs allowing the tractor to drive with all wheels on the untilled land (on-land ploughing) (Anken *et al.*, 2000; Weisskopf *et al.,* 2000; Munkholm *et al.*, 2003ab).

Many studies indicate that tracked vehicles are less vigorous regarding compaction than wheeled vehicles (e.g. Soane, 1973). In theory, the contact pressure below tracks is much lower than under wheels. However, recent studies have revealed non-uniform distribution of the weight of the machine below the tracks creating peaks of stress even higher than under wheels. Soil stresses can therefore only be reduced with well-designed tracked vehicles. An important advantage of tracked vehicles versus wheeled tractors is the superior tractive power and steering stability making them very suitable for on-land ploughing.

Umbilical systems for slurry application are effective in avoiding unnecessary traffic on wet soils. A significant part of (sub)soil compaction in humid areas is due to traffic by heavy slurry wagons in early spring. Paradoxically, this problem has increased dramatically in several countries due to environmental legislation because autumn applied slurry results in nitrate leaching and has been banned. Slurry separation in order to allow spreading the high amount of water in the manure by irrigation equipment is one means of reducing the need to traffic the soil with heavy equipment.

An effective way of reducing traffic on wet soil is to use cable traction of tillage implements. The system takes use of traction device located outside the field and thus avoids traffic with heavy tractors in the field.

Another promising alternative is the use of light, unmanned tractors with low ground contact stresses (Alakukku *et al.*, 1997). This system would fit very well into precision farming and further implementation of high technology into modern agriculture.

Other ways to prevent subsoil compaction are limiting the wheeled area. In the zero or controlled traffic concept, mostly wide span vehicles (gantries) are used for permanent separation of wheeled and cropped areas (Chamen *et al.*, 1992; Taylor, 1994). Thereby soil conditions for both crops and tyres can be optimized. A typical width of a gantry is 12 m, hence per 12 m width of the field the width of one wheel way is sacrificed for traffic. In most cases the increase in crop production compensates the loss of cropped area.

Taking care that every year the same traffic lanes are used and strictly avoiding traffic outside these lanes can also reduce the compacted area. To find and follow these lanes, high technology systems like Global Positioning System (GPS), computer steering, or sensor technology are available or can be developed.

Research needs

The soil water content is decisive for (sub)soil strength and knowledge of the soil water content is thus a prerequisite for decisions on allowable stresses. If the carrying capacity of the (sub)soil as a function of water content is known, this may be combined with the soil water content to decide if a certain machine operation is allowable. A water balance model may interactively predict the water content for the subsoil. Arvidsson *et al.* (2000, 2003) demonstrated how this approach may point out the risk of compaction at a given time of the year for a specific combination of climatic region and soil type. The same procedure may be used for assessing soil vulnerability at a given date for a given soil grown with a given crop.

At the moment, due to the lack of quantitative data on (sub)soil strength for most soil types, the above scenario is unrealistic. Hence, there is a strong demand for more data on soil strength as related to the water content. The establishment of a European database for information on subsoil strength has already been started (Trautner et al., 2003). The analytical determination of the precompression stress is expensive and time consuming. To simplify the procedure, Lebert (1989) proposed a model of regression analysis. Based on that research, a number of different pedotransfer functions for the prediction of the precompression stress were worked out and proposed (DVWK, 1995, 2002; DIN, 2001; Horn et al., 2002; Horn and Fleige, 2003). More studies should be performed to further improve these pedotransfer functions. The development of a comprehensive in situ measuring method for the strength of soils should be encouraged.

Concerning models, the deviation between model assumptions and the actual soil conditions may lead to a high variance of prognosis and assessment, depending on soil type and regional soil properties (e.g. Trautner, 2003). Thus the development of soil compaction models and the determination of soil strength should be validated and possibly further improved (Lebert et al., 2003; Keller et al., 2004). In Germany the models are currently being tested in Saxony and Thuringia (Stahl et al., 2001; Schmidt et al., 2003; Paul, 1999).

Improved methodologies in stress measurements in soil will also provide a highly needed tool for quantifying the stress distribution in the soil/tyre contact area. This may next facilitate the construction of tyres with a better distribution of the load across the contact area.

More studies on critical limits for soil quality indicators should be performed. This is crucial as decisions on management based on indicator values may induce stresses beyond the precompression stress and hence increased subsoil compaction. The fact that subsoil compaction is persistent calls for precaution before implementing this approach. Based on more studies, however, a set of indicators may be suitable as trigger values to determine harmful changes to the soil through compaction in fine textured soils (clays, silts, loams). For sandy soils and for a number of specials soils, where the limits are exceeded by natural processes of soil geology and pedology and not by anthropogenic use, as in stagnic soils, extra solutions should to be worked out, as shown by Lebert et al. (2004).

Improved prevention techniques need research and more efforts in engineering to become economically viable. Examples are: systems to adjust automatically the inflation pressure to the surface trafficked (low inflation pressure in the field and high inflation pressure on the road) and on-land ploughing for small ploughs on sticky soils.

Policy options to prevent subsoil compaction

The key response to subsoil compaction is prevention. Policy instruments should focus on prevention rather than on remediation. Community policies should increase the focus on prevention of soil compaction, and simultaneously set up research programmes to improve prevention techniques, models that support this, and data collection data on soil strength. The carrying capacity derived from the stress and strength matching concept provides a means of identifying management thresholds in relation to subsoil compaction. Management thresholds could be adapted for the implementation in good agricultural practices and hence become a valuable tool in optimising soil quality (Schjønning et al., 2004). Existing limits for tyre inflation pressures, ground pressures and wheel loads are in many cases not adequate and universal and neglect either the effect of wheel load or the effect of inflation pressure. New limits must be developed that include wheel load as well as inflation pressures and are adapted to the kind of subsoil and climate considered. Accordingly, we do not see the option of regulating traffic on agricultural land by legislation on loads and / or tyre inflation pressures as realistic. Instead, efforts should be directed towards development of decision support systems that require limited input and have the wheel load carrying capacity as output. Simultaneously, designers of farming gear should be encouraged to improve farm technology in order to be able to adjust the stresses exerted by machinery to the actual soil bearing capacity.

The policy also should include the implementation of the general measures to prevent subsoil compaction discussed in paragraph 3.6.2. Reiterating, these could be technical, such as reducing tyre inflation pressure, ploughing on-land, different wheel arrangements, tracks instead of wheels or automated low-weight machinery. They could also be management measures, such as choice of crop rotation or adjusting traffic to soil water content. An increased awareness among farmers is also necessary alongside with the continuous rationalisation in agriculture. This can be promoted by the development of user-friendly decision support systems to assist the farmer and his advisors in the selection of ways and equipment to prevent over compaction

Chapter 4 – Floods

4.1 Drivers and pressures

Floods are climatological phenomena influenced by among others geology, geomorphology, relief, soil and vegetation conditions Flooding may also be anthropogenic, in many cases in combination with natural conditions, for example land use (building, tourism etc.), agriculture, deforestation, constructions (roads, railways, dams etc.), terracing or water table regulation.

The storage effect of vegetation, soil, ground and wetlands has an important mitigating effect particularly in minor or medium-scale floods. Rivers and lakes also have a important storing capacity to a certain level. Each of these storage media is capable of retaining certain quantities of water for a certain length of time. A large natural storage capacity provides slow rises in water levels and comparatively minor floods. Retaining water on the natural media should have priority over swift water runoff. In some cases, in the event of heavy and lasting rainfall, natural storage impact is less relevant as regards the reduction in flow, but is still extremely beneficial when it comes to reducing sediment yield.

4.2 State/Extend of the problem

This section mainly concerns flood events in Southern Europe and Central Europe. The characters of these flood events differ. Many floods in Southern Europe are so-called flash floods, which are sudden floods in upstream or headwater areas where mitigating risks involve a wide range of small-scale solutions. Flash floods in general cause transport of a lot of sediment (varying from small sediments to rocks). The floods in Central Europe were more like fluvial floods: low land floods where warning periods and duration of the events are longer and large-scale measures have to be taken. These differences in flood events imply that the measures which need to be taken and the interaction with soil protection will differ as well.

Next to river flooding coastal flooding can lead to erosion. Land use is then not the driving force, but storm surges are. The other way around is also possible: erosion causes flooding

Flooding is a natural occurrence but magnitudes and frequency may be exacerbated by land use and climate changes. In addition there is an increase in the development of floodplains leading to increasing flood hazard. Compilation of historical evidence of the chronology and frequency of flooding show considerable variation over time. The historical analysis shows the high sensitivity of flood magnitude and frequency to climatic variation and this variability calls into question the use of standardized flood frequency and extreme event analysis. Almost all the compiled chronologies show a marked increase in frequency in recent years. For instance, 11 catastrophic floods occurred during the last 50 years in Catalonia and six of them were recorded in the 1980's (Llasat and Puigcerver, 1994). This is probably an artefact of increased reporting but questions are arising, when examining the gauged flows as well as historic records as to whether the frequency of large floods is increasing and to what extent it may be due to climatic change or to land use and management changes or both (Poessen and Hooke, 1996).

Over the last few years Southern Europe has suffered regularly from catastrophic floods (two of the most recent and dramatic events were those that occurred in Tuscany 19 June 1996 and in Biescas, Huesca Spain, with several tens of casualties). Many of these floods have occurred in the mountainous area of the general Mediterranean region and have characteristics relating to both types of environment, e.g. floods in the N. Italian Alpine piedmont, and in the Pyrenees. Most of the descriptions and analyses of individual extreme floods in the Mediterranean exist as local or institutional reports and have been produced to evaluate damage, making it difficult to assess the extent of flood hazards at regional and national scales.

In recent years Central Europe has suffered from vast floods, and the population are becoming increasingly aware of this problem. Besides the impacts associated to flooding, the areas of Central Europe that are affected by extreme flood events often suffer from severe droughts later in the same year.

4.3 Impacts of the problem

The European Land and Soil Alliance has recognised that certain threats (sealing, compaction and crusting) to soils have an impact on the occurrence of flooding. It is also recognised that flooding can wash out enormous quantities of fertile topsoil and deposit the resultant sediment in other parts of the landscape. Thus, soil protection measures and flood protection schemes can have huge benefits beyond simple protection of soil.

Soil is an essential resource for water protection, as it serves as a buffer and filter for water, cleaning water as it moves through the soil biota.

Soil characteristics should be more carefully considered in flood risk assessment and modelling. Better communication between experts on flood control and soil science has to be supported to refine models and planned measures.

Flooding may cause loss of land by erosion due to the destabilising effects of the water. Soil may be transported from slopes of rivers and adjacent areas by running water. Flooding may also cause erosion on hillslopes, which can undermine the slopes leading to mass movements by landslides.

Another severe effect could be the redistribution of pollution by flooding. The water may include pollutants which will be deposited on previously uncontaminated areas. On the other hand, pollutants in contaminated areas exposed to flooding water could be released and transported to nearby or downstream rivers and lakes.

4.4 Response/possible measures

The following measures are favourable for flood protection, risk prevention and soil conservation: Reducing soil compaction and strengthening natural soil functions:

- A location specific management of flood plains by agriculture and forestry
- Using agricultural practices reducing erosion retaining as much water as possible
- Strengthening water storage capacity of soils and vegetation by nature-oriented agriculture and forestry
- Consideration of flood effects on land consolidation procedures, especially in flood prevention-relevant areas

Revitalising the soil as a water reservoir promoting a nature-oriented rainwater management:

- Creation of space in built-up areas where rainwater is able to seep away thus it can be retained in a natural way
- A network of separate sewers in the canalisation where waste water can be drained to water treatment systems and rainwater can seep away in a natural way or into retaining reservoirs
- A revitalisation of marshlands and moors, a deconstruction of land drainages
- A decentralised, nature-oriented rainwater management in new residential areas as well as in commercial areas
- A general improvement of the water balance of the soil by taking groundwater protection measures.

Soil-oriented building and the stopping of building activities in flood-prone areas:

- Stop further settlement, commercial and traffic infrastructure plans in flood-prone areas
- Investigate areas prone to loss of land by flooding and give recommendations for proper land use
- A strategy to manage floods in a ecological manner should be based on improving river basin land use, preventing rapid runoff both in rural and urban areas, and improving a transnational effort to restore the natural flood zones of a river. It tends to reactivate the ability of natural wetlands and floodplains to alleviate flood impacts. Besides flood mitigation, this leads to ecological benefits in the form of maintaining biodiversity, often recharging underground aquifers and cleaner water for drinking, creating areas for recreation, opportunities for touring and so on.

All forms of soil compaction and sealing have to be avoided and to be reduced to an environmentally compatible minimum. Unsealing measures should become as natural as previous sealing. Maintaining the local natural vegetation, planting deeply rooting trees and a permanent soil cover in agricultural areas optimise the water absorption capacity of soils and reduce the removal of soil. Preventing and reducing flood damages, measures to protect and revitalise flood plains and near-natural riversides have to be taken. Furthermore, a well directed revitalisation of existing sealing in flood and flood-prone areas has to be introduced. Therefore, in preparing soil protection, the local authorities should also be supported by superior planning for flood prevention.

An important step could be the harmonisation of soil protection, flood prevention and spatial planning policies. Land use planning can be very effective by determining land use restrictions on flood-prone areas. The responsibility of this planning should be organised on a regional or municipal level. The EU Water Framework Directive should be taken into account.

Chapter 5 – Landslides

5.1 Introduction

Landslides are major natural hazards, claiming thousands of lives and millions of Euro in lost property each year in almost all mountain, river basin and coastal areas. In Europe, landslides form an increasing threat due to population growth, increasing summer and winter tourism and to intensive land use change and climatic change. These hazards also pose the biggest challenge to developing and maintaining a sustainable infrastructure. The form and scope of landslides - which is a generic term for all slope movements, including slides, falls and debris flows- are very diverse.

This is because of the multiplicity of initiating mechanisms (erosion, deformation, dissolution and rupture under static or dynamic load), combined with topography (height and gradient of the slope etc.), lithology (characteristics and susceptibility of materials – solid, plastic, viscous, liquid), structure (overhang, fracturing, superimposed layers), characteristics of the water table and relative proportion of water and solid materials.

There is also a link between landslides and bank erosion in rivers and lakes. In clayey banks, the erosion in the toe of the bank (above and under the water surface) undermines the slope and a slide may be triggered, and in sandy banks erosion also undermines the slope but in this case only a surface slice will be lost.

When landslide is used in the following text, this includes all these aspects of landslides given above.

If the velocity of movement is chosen (which indirectly expresses risk level because it determines the possibility to escape at the onset of the phenomenon) two types of landslides can be distinguished*:*

- Slow-moving landslides *(rotational*, *translational*) corresponding to mass displacements of more or less coherent soil, with limited internal deformation. The displacement is progressive and may be accompanied by rupture, but in general with no sudden important acceleration. These movements can be monitored and controlled and are not a direct threat to personal safety but can be an important threat to human infrastructures;

- Fast-moving landslides that may accelerate suddenly. They can be subdivided into two groups, depending on whether the material is propagated as more or less individual particles

  (*rockfall, rock avalanche*) or as reworked mass (*mudslides, earthflows, debris flows).*

5.2 Drivers and pressures

In general, drivers and pressures for landslides are natural or anthropogenic, in many cases in combination. Natural conditions – and prerequisites for landslides - are geology (soil properties) and inclining topography. Forces of nature are working to adapt cliffs and slopes to equilibrium by natural processes like snowmelt, heavy rainfall, earthquake, action of the sea etc. Anthropogenic drivers are, for example, land use (building, tourism etc.), deforestation, constructions (roads, railways, dams etc.) terracing, mining, deforestation, exploitation of materials or water tables.

Landslides are associated with a gravitational displacement of a mass of destabilised earth and/or rock. Causes are generally multiple, a conjunction or superimposition of several factors, including predisposition and triggering factors (i.e. rainfall, earthquake).

Water is an important driving force acting on the dynamics of movements, whatever their extend and its action is amplified according to the geomechanic parameters of the soils. The knowledge of areas temporarily or permanently saturated by waters and their evolution is a key understanding of the phenomena. Heavy rainfalls causing high groundwater levels and high pore-water pressure together with increased erosion results in low soil stability. Global climate change will increase the risk of landslides due to changed groundwater levels based on increased precipitation etc. The increased number and intensity of heavy rains is likely to lead to increased surface runoff and hence to a higher debris flow risk in mountainous and hilly regions.

In many European regions, ongoing land uplift and shore-level displacement results in unstable conditions especially for clay and silt deposits. The frequency of landslides has in fact increased during the last hundred years of industrialisation.

5.3 State/Extend of the problem

Landslides are widespread on steep slopes in mountainous and hilly regions and areas close to rivers and lakes. Landslides are brought about chiefly by combinations of natural conditions such as high relief, weak strata, erosion, seismic shaking, high groundwater, deforestation and past periglaciation but also by human activities. Within the European area, the main mountainous regions are the Alps and the Apennines, the Pyrenees and the Sierra Nevada, the Massif Central, the Norwegian-Swedish mountain chain and, to a lesser extent, the high ground of the NW British Isles. These are prone to rockfalls, debris flows and large landslides as a result of glacial erosion and, more recently, glacial retreat and thawing of permafrost. Away from the mountains, erosion is most active on the coast and in certain river basins. Earthquake activity is generally modest, with the notable exception of that affecting the Apennines. Deforestation, sometimes associated with the development of skiing areas, has led to an increased activity of shallow mass movements, particularly debris flows, and consequent aggradation of rivers. A dominant feature of clayey areas of gentle relief in much of central Europe is a mantle of weak relict solifluction material, emplaced by repeated freezing and thawing during cold periods of the Pleistocene, which is very prone to reactivation by human interference. Damaging sub-aqueous landslides occur off the coast of southern France, in the Rhine delta and in some Swiss lakes.

Data on the social and economic effects of landslides is now available from numerous countries. In several European countries, this problem is being increasingly recognised and landslides are one of the primary hazards being mapped by the different civil authorities. These mapping programmes, however, are not always carried out in an appropriate way because of their diversity, frequency and wide geographic distribution, and because they are often not well understood by decision-makers.

Furthermore, hazards posed by landslides are dynamic. As European mountains, river basins and coastal areas are increasingly developed, the potential costs of landslides also increase. As a result of this threat insurance claims are steadily rising. In addition, the result of development increases the incidence of landslides by changing their topographic, soil and vegetation controls. Consequently, there is an increasing concern related to landslides because of the urbanisation, construction of infrastructure, development of leisure and recreational areas, changes in agricultural practices and forest management, all factors leading to an adverse effect. Additionally, climate changes can similarly increase the incidence of landslides. Landslide hazard has clearly a European dimension, and concerns mountain and river basin areas as well as coastal environments.

5.4 Impacts of the problem

Landslides result directly in death and injury to humans, damage to buildings and infrastructure, loss of arable land and degradation of the environment. Indirect effects, such as interruption of transport routes, can also be considerable.

Above the consequences of lost human lives, landslides cause extensive costs for measures to repair and rebuild buildings, infrastructure and other constructions. For example, the damage and rebuilding costs for the Swedish population is ca. 10 million Euro every year due to erosion caused by rock falls, landslides and gullies. After heavy rainstorms and flooding in summer 1997 numerous landslides in the Polish Carpathians were activated. The serious damage of houses and communication infrastructure has been continuously reported since that time. The rough evaluation of costs is tens millions of Euro.

5.5 Response/possible measures

It is now increasingly recognised that landslide hazard assessment forms an important part of land use planning in mountain, river basin and coastal environments. Policy instruments and activities should focus on prevention rather than on remediation. A proper land use planning is the best way to prevent these types of natural hazards. The main task for authorities with the responsibility for protecting livelihood and infrastructure from the threat of landslides should be to identify risk areas both for resident areas and exploiting areas. For residential areas, such risk mapping should focus on preventing measures in order to achieve safety for the population and existing investments. For future exploiting areas, risk mapping should be a basis for land use planning and an instrument to avoid risk areas. In both cases, future climate changes must be taken into consideration.

Generally, mitigation measures are hazard and risk mapping, creating public awareness, reforestation / grassing of steep slopes, obligation of detailed geotechnical investigations and installation of warning systems (weather radar, local systems in well-known debris-flow channels). All available modern mapping technologies are applied during the realisation of a project, including remote sensing, GIS and GPS measurements.

Mitigation measures in landslide risk areas can be made by:

- √ Revetments by quarry stones, concrete blocks or gabions;
- √ Vegetation can be established on the slopes, e.g. grassing, reforestation and afforestation;
- √ Soil counter weight embankments could be applied in the lower parts of the slopes or unloading by excavation of the slope crest.
- √ Soil nailing, ground water control etc

In many cases the measures are combined to achieve the most effective result.

To protect against debris flow it is important to maintain existing vegetation to prevent a fast runoff of surface water. Also revetments by stones or concrete can be used. Dams (control dams, reflecting dams and sedimentation dams), energy absorbers and drainage systems for groundwater are common preventive measures.

Measures for mitigation and protection against bank erosion are:

- √ Revetments (like landslides);
- √ Nailing vegetation;
- √ In rivers where dams are situated it is important to avoid large outflows from dams in order to avoid damages downstream;
- √ Diverting the watercourse may be applicable in some cases.

5.6 Policy options to prevent landslides

In January 2000, a great number of representatives of science, industry, the public sector and governmental agencies met as a final point of the EC approved project CALAR (Concerted Action on Forecasting, Prevention, and Reduction on Landslide and Avalanche Risks). The meeting was held in Vienna under the auspices of the United Nations International Decade for National Disaster Reduction / International Strategy for Disaster Reduction (IDNDR / ISDR), the International Association for the Study of Insurance Economics (the Geneva Association) and the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE).

The following declaration was agreed by the participants and could be a basis for formulation of a policy on landslides:

The significance of risks related to mountain hazards (such as avalanches, debris flow, landslides and rock falls) is growing on the worldwide scale. Environmental degradation caused by man's interference with nature and by climatic change increases the hazard potential. Growing population density and mobility associated with urbanisation, expanding infrastructure and industrial facilities and tourism expose more people and more property to hazardous events and thus generate increasing risks.

The strategy to meet these developments has two principles:

- Society has to become better prepared for the impact of disasters.
- Society has to proceed from reaction to, and protection against hazards, to the management of risk by integrating risk prevention strategies into sustainable development programmes.

These goals are in accordance with those of the UN ISDR.

In order to achieve these objectives, significant progress in hazard and risk assessment, risk reduction and capacity building is considered essential.

High priority should be given to the following goals:

HAZARD AND RISK ASSESSMENT

- Improve the scientific understanding of mass movements on slopes.
- Establish, manage and co-ordinate national and international databases on hazardous events and damage to the natural and built environment. Access to these databases should be unrestricted.
- Understand and quantify the vulnerability of people and society, the environment, buildings and infrastructure, and develop methods of reducing vulnerability.
- Improve hazard maps with unified methodologies.
- Develop risk assessment tools, such as risk maps and socio-economic impact studies for the prognosis of potential damage, as indicators for changing risk and in order to increase public awareness.

RISK REDUCTION

- Implement and enforce land use planning based on acceptable risk levels.
- Apply appropriate engineering techniques to reduce hazard impact on human life, environment and property.
- Monitor hazard-prone sites (with sensors, satellites and human observations), develop and apply early warning systems.
- Promote integrated crisis management.
- Consider insurance as integral part of risk reduction strategies.

CAPACITY BUILDING

- Develop cross-disciplinary networks, that include all stakeholders, such as geoscientists, engineers, urban-planners, political authorities, insurance and tourist industry staff and risk managers, and develop public-private partnerships.
- Improve public awareness of hazards and risks.
- Promote multidisciplinary education, training and exchange of information.
- Foster the exchange of experience, knowledge and technology between the developed and the developing world.
- Promote the involvement of local communities in disaster reduction approaches and encourage appropriate educational processes.

The conference participants are convinced that the general objectives and the specific action items listed in this declaration can reduce the risks poses by mountain hazards to an acceptable level, which in turn will help us to live with natural hazards in the 21st century.

Chapter 6 – Organic matter and relationship to other soil protection measures

The importance of soil organic matter (SOM) as an indicator of the sustainability of agro-ecosystems has been widely recognised (Pariente and Lavee, 2003). The different functions of organic matter are reviewed in detail by the Working Group on Organic Matter. Organic matter is usually positively associated with good soil structural stability (its action as a bonding agent between primary and secondary mineral particles leads to enhanced amount, size and stability of aggregates) and good soil water retention characteristics (as a water adsorbing agent it enhances water acceptance and availability) and, hence, promotes infiltration and percolation. At the same time, SOM controls nutrients that affect biomass. Both bonding and adsorption processes explain why SOM has often been found to be positively correlated to soil structure. On the contrary, agricultural soils with low organic matter content are prone to slaking, surface sealing and erosion.

An extensive bibliography about aggregate stability and the positive relationship with organic matter are available (Oades, 1993; Tisdall and Oades, 1982; Mataix-Solera and Doerr, 2003) and the positive relationships between soil organic carbon and microbial biomass, and the influence of microorganisms on soil structure and aggregate stability have been extensively documented (Insam & Domsch, 1988; Harris et al., 1964; Allison, 1968). Tisdale and Oades (1982) developed the notion of hierarchy in soil aggregation processes. Whereas the fine micro-aggregates were bound by polysaccharides that survived in small pores out of the reach of bacteria coarser aggregates were bound by mainly fungal hyphae and very fine roots. Soil structural stability is therefore not really influenced by the amount of organic matter but by specific types of organic matter that bind the soil (see Allison 1968).

The relationships between SOM and high structural stability were studied in detail as part of an EU project ERMES (1999 but the results are not widely available) which looked at the spatial patterns and monthly variations in soil structure in relation to organic matter, micro-climate, soil biological activity (Boix-Fayos et al., 1998; Imeson et al., 1988; Lavee et al., 1988; Imeson and Lavee 1998). It did this along climatological gradients in Alicante Crete and Israel. Some of the results contradict the assumptions that are normally made about relationships between organic matter, climate and erosion. For example, although the total amount of organic matter present is low in terms of kg per m^2, it is not unusual for 70 to 90% of the subsoil to be composed of rocks and stones. This means that the small amount of soil present has a very humid and has a high organic matter content. Where there is a patchy vegetation cover, the maximum amount of organic matter is found at a depth of say 5 to 20 cm on the bare patches. It is on the surface under the plants. The low aggregate stability of the surface horizon on the bare areas is positive because it helps prevent evaporative loss and enables plants to practise rainwater harvesting.

Two other conclusions from the ERMES project are relevant. Firstly, aggregate stability is at a maximum where there is the greatest amount of biological activity (number of degree days of growth) because this is where the greatest production of binding agents occurs. In Israel this is where the annual temperature of 17 degrees, Lavee et al. (1988) showed how the zone of maximum stability shifted seasonally in relation to climate.

The second conclusion is that there is a climatological threshold below which organic matter is the main factor controlling erodibility and aggregate stability. Where there is less than 350 mm of annual rainfall, the effects of salt on clay dispersion is the main process. This threshold (when organic matter is secondary to the influence of water soluble salts on dispersion) is reached in Europe not only during dry years but also during the summer. The authors recognised different process-response systems.

There is general agreement with regard to the role of erosion in soil organic matter losses. The organic matter content in the soil expresses the relationships between the sources of organic materials and the decomposing factors (soil biota). The main source of SOM is litter. So the degradation or destruction of plant cover leads to a disruption of carbon cycle, reducing organic matter stored in a soil and degrading soil physical properties. On the other hand, removal of vegetation strongly increase surface runoff and sediment yield (Castillo et al.,1997). The organic matter loss is mainly correlated with the removal of the topsoil related to runoff. The loss of soil by erosion has the consequence that the resulting soil after erosion normally has worse conditions (less organic matter content for example) to develop a good vegetation cover and this soil, in turn, is more susceptible to erosion, leading to a negative feedback.

Soils rich in organic matter, such as those of many rainy regions, are more resilient, more capable to recover from the damage, than soils with low organic matter content from Mediterranean region. The vulnerability of these soils means that the effects of climate change upon these environments will be exacerbated (Albaladejo et al., 1998; Martínez-Mena et al., 2002). An understanding of the dynamics of soil organic carbon is required to better appreciate the ability of soils to stabilize carbon and any implications for global change.

Soil management practices that are good for organic matter conservation and to combat erosion have to be identified and integrated into agri-environmental measures. Conservation practices and sustainable farming management systems could play an important role in stabilizing organic matter. The situation is more complicated when it is necessary to change the existing land-use system fundamentally. Special interest must be paid to farming systems which diminishes the losses of organic matter due to mineralisation by reduced tillage (Kern and Johnson, 1993).

As processes influencing runoff must therefore play an important role in any analysis of soil erosion intensity, measures reducing runoff are critical to effective soil conservation.

6.1 The importance of patterns and structures in organic compounds and matter and the relationship of these to resilience and erosion.

Most studies of SOM have not looked at the spatial patterns of organic matter in the soil and on slopes, how these originate and how they function. Plants and organism in interacting with the soil transform the mineral soil into a habitat which is to their collective advantage. Organic compounds that promote water repellent behaviour have a positive influence in preventing erosion (Imeson et al., 1992). For example in case few runoff exists a 1 cm storm in July might wet a soil that has no stones or water repent layer to a depth of 5 cm and this water would be lost to evaporation in a few days. In contrast if 80 per cent of the surface is stones or 95 per cent of the surface is hydrophobic, water will penetrate to a depth of 30 to 50 cm. The large pores between the stones and the hydrophobic layer, trap the water in the soil because they prevent capillary rise. Patterns in different types of organic matter promote resilience and should be protected as they may take tens of years to develop fully. They assist for example in post fire seed germination.

6.2 Recommendations for the Use of Exogenous Organic Matter for Enhancement of Soil Organic Matter Contents

Addition of organic compounds can increase the soil's organic matter content and electrolyte concentration and reduce the physical disintegration of soil aggregates by raindrop impact and chemical dispersion, thus preventing surface sealing, increasing infiltration and the water holding capacity and improving soil structure while reducing runoff generation and soil erodibility (Stocking and Albaladejo, 1994).

The improvement of soil structure by organic amendments can be classified in different mechanisms: (i) amendments aimed to increase organo-mineral adsorption, based on persistent stabilising agents; and (ii) amendments based on increasing microbial activity, thereby generating coating effect and physical aggregation due to microorganism binding effect. Regarding nutritional aspects, organic amendments might influence soil fertility in two ways: first, the amendment itself entails nutritional input; secondly the amendment can increase soil biomass and, therefore, increase the availability of nutrients. Amending effects must be divided in short and long term. In short-term, amendment quality affects directly soil fertility status, but in long-term nutrient availability is conditioned by organic matter input rates, which are directly to plant growth and roots development.

Although there is widespread agreement in relation to overall importance of organic matter, there is less agreement as regards as the most effective individual components. The restoration of organic matter levels and soil structure is highly dependent on soil type, climate and actual land-use but could be influenced by the amount and nature of organic matter added, maintaining the limits of the respective site. Sources of organic matter can be placed into three distinct categories:

- The fresh organic matter which has an major but very short lived impact
- The stabilised organic matter, which has a much longer term effect
- The very stable organic matter

Fresh organic matter is easily degraded and thus stimulates the microbiological activity. The secretions of the microorganisms reduce the wettability of the pores surfaces and so increase the resistance to disaggregation by water. However, fresh organic matter is quickly degraded.

The stabilised organic matters have a longer effect for two reasons:

- First, because they are longer to degrade, they regularly provide decomposition products, that stimulate the microbiological activity,
- Second, they favour the aggregation of the soil particles (Linères, 1993).

The carbon threshold beyond which structural stability may increase is subject to discussion. On loamy soils most studies give a range of 1% to 1.5% of carbon (De Ploey and Poesen, 1985; Le Bissonnais and Arrouays, 1997). Similar result were obtained by Albaladejo et al. (2000) in Mediterranean semiarid areas, in that areas the increase of 1% of soil organic carbon yielded a reduction of 95 and 98% in total runoff and soil loss, respectively. It should be clear that such thresholds are highly dependent on soil type and organic matter type.At the moment, there are not enough reference to give a carbon threshold value.

Despite recognizing the potential benefits derived from the increase of organic matter to reduce soil erosion the technical group expresses its concern over the likely consequences of the application of wastes to land (LABO, 2004). A previous and rigorous characterization of organic wastes is necessary to use them and more research about the effects on different type of soils and doses to apply is necessary. Attention must be drawn to not only heavy metals, but also to other environmentally hazardous substances and potential pathogen bacteria. Particularly important is the need to consider the timing of waste application in relation to soil type and to the management of the land. Thus, for example, if a soil needs to be ploughed to incorporate certain wastes, then this must be done so as not to increase the risk of erosion. On the other hand, the application of contaminated wastes may increase the risk of diffuse contamination of waters (and air), by altering the susceptibility of the soil to erosion and by lateral transport with the soil particles or as dissolved nutrients and contaminants in the surface water run-off.

Chapter 7 – The link between soil erosion and diffuse contamination of water and air

7.1 Soil erosion and the diffuse contamination of surface waters

There are a variety of different point and diffuse sources of nutrients and contaminants in river basins and many of these are shown in Figure 1. Figure 1 illustrates that certain types of land use, land management, and land activities tend to be dominated by either point (i.e. direct industrial discharges, sewage treatment works) or diffuse (agriculture, urban road network) sources of sediment and contaminants to surface waters. In consequence, it has long been known that there is a direct link between erosion of the land surface and the diffuse contamination of surface waters (Salomons and Forstner, 1984; DEFRA, 2003). Thus, it has been documented since the 1960s that there is a direct link between soil erosion on agricultural land, phosphorus delivery from land to waters, and eutrophication of rivers and lakes (Vollenweider, 1968; Omernik, 1977). The MONERIS (Modelling Nutrient Emissions in River Systems) model has estimated that 22% of the phosphorus emissions into the main river basins of Germany for the period 1993-1997 were derived from (diffuse) erosion pathways (Scherer *et al*., 2003). Similarly, it is well known that pesticides and other micro-organic contaminants have deleterious effects on water quality and aquatic habitats, and that soil erosion (and surface runoff) can be a major source in agricultural areas (Warren *et al*., 2003). Once within the aquatic environment, sediment-associated contaminants derived from the land surface by erosion processes may persist within rivers and surface water bodies (such as ponds, lakes and reservoirs) for long periods of time, and/or they may be exported towards the coastal zone (estuaries, harbours etc.) and seas and oceans. Thus, for example, the erosion of soil ultimately supplies a large proportion of the sediment (Owens and Batalla, 2003) and associated contaminants entering the North Sea (Neal and Davies, 2003; Scherer *et al*., 2003). Contaminants delivered to surface waters by erosion in particulate form may change to dissolved form once in the aquatic environment, and may be more bioavailable and/or more hazardous to aquatic ecosystems and human health than contaminants in particulate form.

There are a variety of different nutrients and contaminants that can be supplied to waters (both surface and groundwater) that derive from the erosion of soils (Table 1). Many of these nutrients and contaminants do not occur naturally within the soil (such as ^{137}Cs – which is derived from the atom-bomb tests and the Chernobyl incident) or are present in soils in elevated concentrations due to applications of wastes (e.g. sewage sludges or biowastes) or artificial inputs associated with farming and forestry practices (such as the application of phosphorus-based fertilisers).

Most of the nutrients and contaminants listed in Table 1 tend to be elevated in the surface layers of the soil profile: often in the upper 0-5 cm. This reflects either atmospheric deposition (as in the case of fallout radionuclides) or artificial inputs to the soil surface, and the fact that many chemicals are sediment-associated and thus sorb tightly to soil particles (both mineral and organic) in the top layers (Owens *et al*., 1996; Haygarth *et al*., 1998). Surface erosion processes such as rain-splash detachment, overland flow and associated rill, inter-rill and gully erosion, then export the contaminated sediment to the river system. Certain land management operations such as ploughing may, however, alter the depth distribution of contaminants (Owens *et al*., 1996; Haygarth *et al*., 1998) and this will have an effect on the delivery of contaminants to waters due to soil erosion.

It is important to recognize that studies (e.g. Russell *et al*., 2001; Chapman *et al*., 2003) have shown that there are also subsurface pathways by which eroded sediments and contaminants (both sediment-associated and in dissolved form) move through the soil and are delivered to surface waters (and groundwaters), and some of these are shown in Figure 2. In addition, the erosion of channel bank material is also a major source of sediment-associated contaminants in rivers, and should not be neglected. Work in the UK has demonstrated that typically between 10 and 40% of the suspended sediment load of rivers may be derived from channel bank sources (Owens *et al*., 2000), even in large urbanised river basins (Carter *et al*., 2003). Material eroded from channel banks is delivered directly into the river channel and thus often represents an immediate problem. The relationship between soil erosion on land and the contamination of surface waters is more complex due to sediment deposition and uncertainties associated with sediment delivery ratios.

Contaminant	Sources
Metals (Ag, Cd, Cu, Co, Cr, Hg, Ni, Pb, Sb, Sn, Zn, As).	Geology, mining, industry, acid rock drainage, sewage treatment, urban runoff, agriculture.
Nutrients (P, N).	Agriculture, forestry, urban runoff, wastewater and sewage treatment.
Organic compounds (pesticides, herbicides, hydrocarbons).	Agriculture, industry, sewage, landfill, urban runoff.
Xenobiotica and antibiotics	Sewage treatment works, industry, agriculture.
Radionuclides (^{137}Cs, ^{129}I, ^{239}Pu, ^{230}Th, ^{99}Tc).	Nuclear power industry, military, geology, agriculture.

Table 1 - *Some of the main sources of sediment-associated contaminants to waters that can be derived from the erosion of soils and river banks (modified from Taylor, 2003).*

Some of the eroded material that is delivered to rivers in agricultural and forested catchments is relatively "uncontaminated" and *becomes* contaminated within the river by dissolved discharges from point sources (such as sewage treatment works), which subsequently sorb onto the "clean" sediment. Indeed, most river systems require a certain amount of uncontaminated sediment, nutrients and certain trace elements for sustainable geomorphological and ecological functioning.

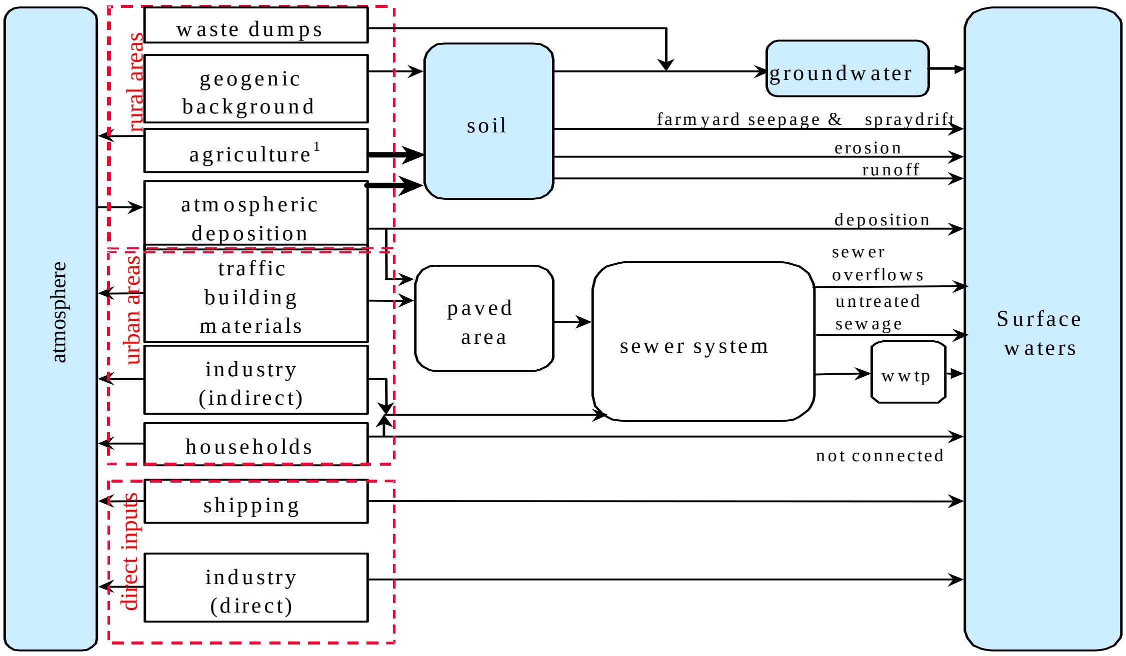

Figure 1 – *Fluxes of materials from point and diffuse sources in a river basin* (modified from Vink et al., 1999; Eisma, 2003).
[1]Includes application of fertilisers, sewage sludges and biowastes onto agricultural land and the resultant discharges into surface waters (e.g. through erosion processes).

Figure 2 – *Pathways of sediment and contaminants to rivers based on the MONERIS model (Eisma, 2003).*

Once the sediment-associated contaminants enter the river there are many opportunities for deposition and storage, such as on the channel bed, on floodplains (see Table 2) and in lakes and reservoirs. Thus, Kronvang *et al*. (2003) document the presence of 19 pesticides (old and modern) and nine heavy metals in the channel bed-sediments of 30 lowland streams in Denmark. Further downstream, these contaminants may be deposited in harbours, estuaries and oceans (Power, 2002; Scherer *et al*., 2003). Important here is not only the fact that the contaminated sediment may have implications for water quality and habitat/ecological quality (Adami *et al*., 1997; Power, 2002; DEFRA, 2003) within the river corridor and further downstream, but also that such deposition on floodplains during overbank flooding results in the *creation* of contaminated soils: contaminated soils that were derived from the erosion of the land upstream and subsequently transported (perhaps with a subsequent increase in contaminant content from point sources) and deposited on the floodplain surface. In time, channel bank erosion may reintroduce this material into the river channel.

Material	Mean annual load ($t\ year^{-1}$)		Mean annual floodplain deposition flux ($t\ year^{-1}$)		Mean annual conveyance loss to floodplain storage (%)	
	River Swale	River Aire	River Swale	River Aire	River Swale	River Aire
Suspended sediment	45158	18462	16894	8604	27	32
Cr	1.17	2.51	0.33	0.25	22	9
Cu	3.66	2.76	0.86	0.38	19	12
Pb	29.40	3.66	24.49	1.30	45	26
Zn	32.51	9.99	17.50	2.43	35	20
Total-P	62.54	120.21	9.83	11.48	14	9

Table 2 – *Estimates of the deposition and conveyance losses of sediment and associated contaminants on the floodplains bordering the main channels of the River Swale (1346 km^2) and River Aire (1002 km^2), Yorkshire, UK (from Walling and Owens, 2003).*

An important consideration in the link between soil erosion and the contamination of waters is the well-documented relation between particle properties and size, and contaminant concentration, and the fact that sediment erosion and transport processes are particle size dependent. It is known that, for many contaminants, concentrations increase with a decrease in particle size or increase in specific surface area (Horowitz, 1991) (see Figure 3). Clay minerals have negative residual charges and this results in their ability to adsorb cations. Thus, most contaminants are concentrated in the <63 µm fraction, and particularly the <2 µm fraction. Equally, fine sediment particles are generally more easily transported than sand-sized material. In consequence, during the soil erosion-sediment transport process, fine (and consequently more contaminated) material is transported preferentially compared to contaminant-poor coarser material.

However, the situation just described is complicated by the fact that there is an increasing body of evidence for freshwater systems that demonstrates that most sediment it transported as composite particles (a mix of mineral particles, organic material, air and water, bound together) and not as primary individual grains (Droppo, 2001). This has important implications for sediment-associated contaminant transport and deposition within rivers.

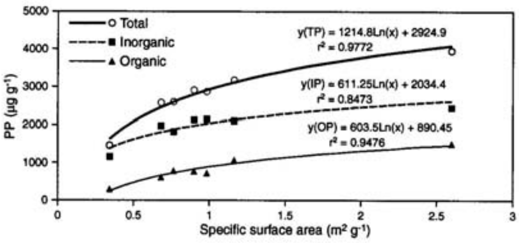

Figure 3 – *Relation between particulate phosphorus content and specific surface area based on a fractionated suspended sediment sample (from Owens and Walling, 2002).*

Both soil erosion and the delivery of sediments and contaminants from land to waters are highly variable in both time and space. This spatial and temporal variability makes it difficult to predict and model with certainty the precise link between soil erosion and the contamination of surface waters. It also makes the development of appropriate management strategies more complex. However, the literature on the general causes and processes of soil erosion and sediment delivery within Europe is reasonably substantive (e.g. Boardman *et al*., 1990; Rickson, 1994), and we know conceptually most of the main sources of those pollutants associated with diffuse contamination of waters due to erosion processes. Thus, broad recommendations could be made to reduce soil erosion and the associated diffuse contamination of surface waters in European river basins.

7.2 Soil erosion and links to air quality and contamination

Several studies carried out in different European countries during the last few years have clearly demonstrated the significance of wind erosion as a predominant land degradation process (U.K.: Davies, 1993; Belgium: Poesen *et al*., 1996; Netherlands: Eppink and Spaan, 1989; Germany: Schäfer and Neemann, 1990, Schäfer *et al*., 1994; Denmark: Hansen, 1983; Poland: Podsiadlowski and Walkowiak, 1999; Sweden: Jönsson, 1992; Hungary: Kertesz *et al*., 1990). For a useful review see Gross (2002). As with soil erosion by water, wind erosion is particle size selective so that finer soil particles are preferentially eroded and transported greater distances, often tens or hundreds of kilometres (Harrison *et al*., 1996), than coarser material. Also, as described earlier, finer sediments tend to have higher concentrations of contaminants compared to parent soil due to their affinity for contaminant sorption. For example, the amount of pesticides can be up to ten times higher in the fine particle fraction than in the topsoil as a whole (Fritz, 1993).

Apart from on-site effects, emitted soil dust also causes significant off-site damages from deposition in adjacent ecosystems and is suspected to have impacts on human health. The chemical substances contained in the fine particle fraction contaminate surface waters and groundwaters and cause eutrophication in these ecosystems. This process is becoming increasingly important in Northern Europe, which is characterised by (1) the use of large amounts of fertilisers, manures and pesticides and (2) the increasing contamination of arable soils by the atmospheric deposition of various pollutants (heavy metals, dioxins, radionuclides, organic pollutants, xenobiotica, etc). The spread of pollutants via fine particle erosion of contaminated arable land has not yet been fully quantified, but must be considered important. Schulz (1992) proposed a value of 100 ng TEQ kg^{-1} for dioxin-contaminated arable land due to wind-induced emission of fine soil particles.

The impact of soil-derived aerosols on human health has not yet been thoroughly studied. However, recent research by Norton and Gunter (1999), Prospero (1999), Pope *et al*. (1999) and Rutherford *et al*. (1999) showed a clear link between atmospheric soil dust and the occurrence of respiratory problems (e.g. asthma). In the northern part of the Netherlands, an increase in health problems during and shortly after dust storms has been reported by Knottnerus (1985) and Nijf (1987). Fine soil particle emission may also play an important role in the spread of plant and animal diseases (Bout 1987, Pimentel *et al*., 1995).

7.3 Information and needs

There is probably a reasonable amount of evidence in Europe to suggest a strong link between soil (and channel bank) erosion and the subsequent delivery of contaminated material to surface waters (and probably groundwaters). Similarly we have plenty of evidence relating to the existence of contaminated sediment (transported and deposited) in European rivers. We also have evidence from tracing and fingerprinting studies to show that much of this sediment is derived from the erosion of the land surface. We are, however, lacking detailed information in Europe on:

- Accurate fluxes of sediment and associated-contaminants *between* the land and rivers;
- Estimates of the contribution of soil erosion to river sediment and contaminant loads;
- The role of aggregation and flocculation on sediment and contaminant transport;
- Accurate estimates of basin-scale storage of sediment and contaminants in river systems;
- The role, design and location of topographic and buffering features for controlling delivery;
- Detailed information on the contamination of the atmosphere from surface erosion processes; and
- The link between the application of wastes to land and the effect of this on soil biology, hydrology and erosion potential.

7.4 Conclusion

Clearly, soil erosion, by water and wind processes, has implications for the quality of soils and their ability to perform important soil functions, in particular the ability to sustain agricultural and forestry production. As such, soil erosion represents a key component of the EU Soil Thematic Strategy and national policies and initiatives (DEFRA, 2004). In addition, soil erosion and the delivery of contaminants to water and air influence the quality of surface waters, groundwaters and air, and, in turn, freshwater ecosystems and human health. In this respect, soil erosion on land and the erosion of river banks have important implications for the ability of Members States to implement and comply with the EU Water Framework Directive (2000/60/EC).

7.5 Sources of information and acknowledgements

Some of the ideas presented in this chapter stem from the EU-funded European Sediment Research Network (SedNet), and in particular SedNet Work Package 2 - *Sediment management at the river basin scale* - and thanks are due to Ramon Batalla, Marc Eisma, Heinz Glindemann and Kevin Taylor for inputs. Further information on SedNet and WP2 can be found at www.sednet.org. Thanks are also extended to Arnold Arnoldussen, Holger Böken, Olaf Düwel, Rob Jarman and W. Schäfer for helpful advice and information.

Appendix A

The application of exogenous organic matter (EOM) to soil can improve the soils resilience against degradation processes. Its effect, however, is less important in preventing erosion than soil cover and land management practices. Long-term improvements can only be achieved if the soil is managed in accordance with the precautionary principle to maintain soil functions on a sustainable basis.

For the improvement of a soil's erosion resilience, the Working Group Erosion recommends the application of site specific land management practices and effective soil cover, together with appropriate tillage practices, some of which are also specified in the codes of good agricultural practices of some Member States. To preserve soil in good agricultural and ecological condition on a long-term and sustainable basis and to effectively protect neighbouring water bodies and other ecosystems, soil organic matter levels should be maintained by appropriate cropping practices for the respective land-use, climate and soil type. To safeguard against detrimental impacts on soil functions or harmful off-site effects, exogenous organic matter (EOM) which originates from a range of biowastes or biodegradable wastes, should only be applied in line with the following principles:

(a) The application of such EOM shall not introduce new pollutants or other hazardous substances into the soil nor shall it lead to a long-term accumulation in the soil.

(b) When EOM which originates from biowastes or biodegradable wastes is applied, a parallel analysis for hazardous substances must be established for every applied batch. Since hazards to soil-borne organisms may occur although active substances are not detectable/traceable in the soil, a 'start-of-pipe' solution for example for xenobiotics and antibiotics will be required.

(c) To avoid over-fertilisation and the diffuse contamination of surface waters in some areas of Europe, the phosphorus levels in soils may also limit the applicability of EOM.

(d) Since wind and water erosion processes may lead to the transfer of nutrients and pollutants, certain sources of EOM which originate from biowastes or biodegradable wastes shall not be applied to soils at risk of erosion, or in the immediate vicinity of sensitive environments, so as to minimise the risk of contamination of surface water, groundwater and air.

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SOIL EROSION

Task Group 6 on DESERTIFICATION

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Executive Summary

Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. European Mediterranean countries have been identified as sensitive areas to desertification because of the occurrence of particular conditions over large areas:

- Semi-arid climatic conditions affecting large areas, seasonal droughts, very high rainfall variability and high-intensity rainfall.
- Poor and highly erodible soils, prone to develop surface crusts.
- Uneven relief with steep slopes and very diversified landscapes.
- Extensive forest coverage losses due to frequent wildfires,
- Crisis conditions in traditional agriculture with associated land abandonment by rural populations and deterioration of soil and water conservation structures.
- Overgrazing
- Unsustainable exploitation of water resources leading to serious environmental damage including chemical pollution, salinization and exhaustion of aquifers.
- Concentration of economic activity in coastal areas as result of urban growth, industrial activities, tourism and irrigated agriculture.

Land degradation has not spatial and temporal confinement. In Northern Europe under northern boreal and subarctic climate conditions there are examples which are similar with desertification known from Southern Europe.

The drivers of desertification always include both the human and the biophysical factors. Neither dimension can be regarded as the sole triggering factor. Land management practices and land use changes leading to overgrazing, deforestation, forest fires, overexploitation of water resources, and secondary salinization are among the most recognized causes of land degradation and desertification

Assessing desertification is a complex task and there is a lack of a holistic methodology that enables this to be done at the global and regional level Assessment methods currently being used by the National Action Programmes (NAPs) have looked at a hypothesised sensitivity to desertification but this is different from detecting and assessing actual current trends in desertification. At present, most evaluations rely on soil erosion estimates, which are a relevant desertification symptom, but not the only one

The assessment of sensitivity to desertification and actual desertification itself is an issue addressed by European scientific research projects whose importance increased after the United Nation Convention to Combat Drought and Desertification (UNCCD) committed affected countries to elaborate and approve a National Action Programmes (NAPs).

Desertification is a complex process of simultaneous degradation of soil, water resources and vegetation, which can affect natural, semi-natural and agricultural systems, as well as other human activities. Collectively, this degradation leads to a loss in resilience, soil quality and in ecosystem integrity and health. This results in a loss of both ecological and social capital

Desertion and desertification are related problems in rural areas. Whether causes of land abandonment are natural or socio-economic is still subject to debate. Land abandonment occurs because of external driving forces, such as market changes, or as a consequence of land degradation which lead the system to cross some irreversible threshold, such as the critical soil depth for plant growth.

Aridity, drought and desertification are distinct, but closely related, concepts. In addition to natural irregularities on water supply associated to climatic conditions, the public perception of desertification in Mediterranean areas has been heightened by water resources shortage arising from the human induced water problems

Successful programmes to address desertification should encompass all the complexity of this problem, including its physical, ecological, sociological and economical components. Moreover, they require reliable instruments of diagnosis and forecast, allowing for the application of the right treatments at the right places

Combating desertification includes the application of sustainable systems of exploitation of land resources and ranges from the prevention and/or reduction of land degradation to the restoration of degraded/desertified lands.

Prevention and reduction of land degradation should be tackled through linked forecast and integrated land use planning actions. The implications for management of these actions should be refined at the local scale.

Once some thresholds are exceeded, even if desertification-driving forces are reduced, degradation can only be reversed by restoration actions. Since degraded systems are characterised by net losses of resources, restoration in desertification-prone areas is conceived to increase the conservation and capture of such resources. These goals should be achieved by restoring ecosystem functioning.

To avoid, reduce, limit and mitigate land degradation and desertification it is needed to adapt both research and policies to the many variable scales at which socio-natural landscape dynamic operate. More recognition should be given to the importance and responsibilities of all social sectors involved in the study and control of the desertification processes.

Collaboration and co-operation between European organisations and institutions should be established in order to promote initiatives concerning joint programmes, financial aspects and technology transfer for developing pilot research projects on soil degradation processes and on mitigation measures.

6.1 Introduction

Desertification is a land degradation problem of major importance in the dry regions of the world. The international community has long recognized that desertification is the most important economic, social and environmental problem of concern to many countries in all regions of the planet. The World Atlas of Desertification (UNEP 1997) which summarizes the current state of scientific knowledge on the dry lands of the globe, assesses that more than 6.1 billion ha, 47.2 % of the Earth's land surface, is dry land. Nearly 1 billion ha of this area are natural1y hyper-arid deserts, with very low biological productivity. The remaining 5.1 billion ha are made up of arid, semiarid and dry sub humid areas, part of which have been degraded since the dawn of civilization whilst other parts of these areas are still being degraded today. These lands are the habitat and source of livelihood for about a fifth of the world's population. They are areas experiencing pressures on the environment caused by human mismanagement, problems that are accentuated by the persistent menace of recurrent drought.

Desertification adversely affects nearly 3,100 million ha of rangelands (80 % of their total area in drylands), 335 million ha of rainfed croplands (60 % of their total area in drylands), and 40 million ha of irrigated croplands (30 % of their total area in drylands), in all, up to 3,475 million or 70 % of total area of drylands (Dregne, 1991).

For over decades the European Commission has recognised desertification as a major environmental problem in southern Europe. Most of the Mediterranean countries have been identified as having "very high", "high" or "medium" levels of soil degradation severity. This includes the southern and eastern parts of the Iberian Peninsula, parts of Mediterranean France, most of the Mezzogiorno in Italy, Sardinia and Corsica and most of Greece, including the islands, especially Lesvos. Furthermore, The United Nation Convention to Combat Desertification (http://www.unccd.int) identified Portugal, Spain, Italy, Greece and Turkey as countries with a marked problem of desertification because of the occurrence of particular conditions over large areas:

- Semi-arid climatic conditions affecting large areas, seasonal droughts, very high rainfall variability and high-intensity rainfall.
- Poor and highly erodible soils, prone to develop surface crusts.
- Uneven relief with steep slopes and very diversified landscapes..
- Extensive forest coverage losses due to frequent wildfires,
- Crisis conditions in traditional agriculture with associated land abandonment by rural populations and deterioration of soil and water conservation structures,
- Unsustainable exploitation of water resources leading to serious environmental damage including chemical pollution, salinization and exhaustion of aquifers.
- Concentration of economic activity in coastal areas as result of urban growth, industrial activities, tourism and irrigated agriculture.

One of the main problem which scientists and policy makers must face is the evolving nature of the meaning of desertification and its adaptation to a European context. A great deal of confusion or deliberate obfuscation about desertification reflects poorly defined or incorrect use of terms, the failure to identify the various combinations of processes at different times and spatial scales and ignorance or lack of data, and this confusion may even be politically, economically, socially and scientifically motivated (Thornes, 1996).

The more widely accepted definition of desertification is, at present, that one given by the United Nations Convention to Combat Desertification. It defines desertification as "*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities"*. Land is defined as the terrestrial bio-productive systems that comprise soil, vegetation, other biota and the ecological and hydrological processes that operate within the system. Land degradation means the reduction or loss of the biological and economic productivity and complexity of irrigated and non-irrigated agricultural land, pastures, rangeland, forest and woodland.

Definition given by UNCCD was established by consensus of scientists of more than 150 countries, including European Commission as a signatory partner. According to this definition, desertification is a process confined to areas affected by drought. On the other hand, some authors claimed that land degradation has no spatial and temporal confinement and it may take place under a variety of physical conditions including more humid areas. In Northern Europe under northern boreal and subarctic climate conditions there are examples which are similar with desertification known from Southern Europe. Unfavourable climate conditions reduce the possibilities that damaged vegetation recover after disturbance. In Northern Scandinavia overgrazing by reindeer causes disappearance of the lichen vegetation and a process of land degradation and soil erosion starts. Overgrazing during historical times in Iceland caused the disappearance of forest- and vegetation cover. The volcanic soils are very susceptible for wind erosion and on that moment large areas are degraded and more or less desertified.

However, it is important to stress that desertification cannot simply be relegated to questions of diminishing productivity, and thus conceives as a purely physical phenomenon driven by processes such as erosion, salinization, overexploitation of water resources or pollution; rather, it is a perceptional question embedded in value systems and other social criteria, reflecting cultural, political and economic aspirations.

In searching for a definition, desertification can be seen as an extreme case of degradation which result in a permanent decline of land's productivity and desertion of an area. This extreme case of degradation would require a certain conjunction of natural and social circumstances. It occurs whenever one or more variables in a socio-natural dynamical system accelerate or slow down out of proportion and do not allow the other ones to keep up with them, initiating a search for a different dynamic equilibrium. In this new equilibrium the life and diversity support capacity of the system is sequentially diminished (van der Leeuw, 1996; Yassoglou, 2000).

6.2 Land degradation and desertification: driving forces and direct causes

Land degradation and desertification has evolved over time influenced by socio-economic, cultural and institutional forces (the drivers of desertification) that promote activities and resource management practices (the direct cause of desertification) with harmful effects. The relative role and influence of driving forces and proximate causes has varied in each historic period and with particular geographic area.

Analysing degradation and desertification from a long-term perspective, it can be concluded that degradation is nothing new. Each human occupation identifies particular resources and develops particular techniques for exploiting them; the continued presence of a group of people must inevitably lead to the destruction or exhaustion of the resources on which it relies most. Indeed, studies on the evolution of Mediterranean landscape (ARCHAEOMEDES Project) revealed that resilience of the landscape increased by means of the compensation mechanisms: the erosive episodes denuded the higher slopes at the same time created colluvial and large alluvial deposits, which had much greater biomass productivity than the original sloping lands.

In South Mediterranean Europe, land degradation is immediate when physical degradation is in phase with agro-pastoral activities. On the other hand, long time human impacts destabilise the ecosystem, so that minor oscillations in the physical parameters might bring about severe land degradation. Under these assumptions, periods of potential desertification and resilience may be traced along with the history of physical and human activities. What becomes worrying is the scale at which degradation currently occurs. Data from the Vera basin in southeastern Spain showed that the deposition of about half of the total volume of degraded material in colluvial fan took some 9,500 years, but the other half was deposited in the last five centuries, since c.a. 1500 AD. The increase of the human impact on the environment appears to be exponential. Part of that increase seems to be due to cumulative increases in degradation sensitivity.

The physical context of land degradation and desertification in Mediterranean Europe

While it is clear that land degradation and desertification is in many ways a product of human activity, nevertheless, it is amplified by physical factors such as climate, topography, soil erodibility and the local vegetation status.

Climate and its variability

Mediterranean environments are characterized by highly variable climatic condition in time and space. Theses areas have been characterized by strong medium term, inter-annual and seasonal variations in rainfall (and to a lesser degree in temperature). From year to year the rainfall may vary by twice the annual average and persistent trends lasting 40-60 years may result in a halving or doubling of the decadal average. These fluctuations increase with decreasing mean annual rainfall. As a consequence drought, though unpredictable in its temporal occurrence, is nevertheless a part of the naturally occurring climatic system. (Thornes, 1996).

Drought is a normal climatic feature of the Mediterranean countries that also strikes non-arid areas when precipitation is sensibly lower than normally recorded levels. Drought has no predictable patterns of occurrence and has serious ecological, economical and sociological effects. Drought may influence the degree of territorial degradation mainly by causing damage to agricultural and livestock production activities. In fact, natural ecosystems generally have the necessary resilience for withstanding periods of drought, while the productive sectors that depend on a constant water supply may be damaged. Drought in arid zones may break the fragile balance that exists between environmental resources and production activities, causing food crises, the abandonment of entire territories, and even migration and conflicts.

Northern Mediterranean basin areas are also exposed to the risk of short but intense rains that, instead of mitigating the effects of the scarcity of rainfall, cause erosive phenomena, thus opening the way for desertification. When short but intense rain falls on soils unprotected by vegetation coverage, the impact of raindrops and the subsequent sheet and rill erosion removes the soil's surface layer that is rich in organic material.

The scenarios regarding the future climatic changes, elaborated using general atmospheric circulation models, agree in indicating an increase in global temperature over the Mediterranean basin area, but do not yet provide a consistent picture of the precipitation and ground moisture trends. The most recent climatic simulations, with reference to the temporal horizon of 2025-2050, produced Mediterranean scenarios with temperature increases in the winter between 1.5° and 3.5° C, and in the summer from 0.6° to 1° C.

Topography, soils and vegetation cover

In the Mediterranean area the topography determines to a great extent the settlement patterns and land-uses practices, as well as being a contributory factor in soil erosion. The physiography of the Mediterranean areas includes diverse arrays of land-forms, a large proportion of which are dominated by sparsely vegetated upland zones (Perez-Trejo, 1994). Steep slopes are common particularly in mountain regions influencing infiltration rates and accelerating runoff and sediment loss. The steepest slopes generate mass movements such as landslides and mudflow. In addition slope aspect affects the solar radiation and temperature which, in turn, affect evaporation, soil water content and subsequently vegetation growth and resilience.

Many soils in the Mediterranean are very susceptible to physical degradation and erosion (one of the most important processes leading to desertification) because of their loamy to loamy-sand texture. Often soils have developed on lithologies which have low resistance to water erosion such as the Tertiary marls of the intermountain basin. The high temperatures in summer together with the sparse vegetation cover cause a relatively low organic matter contents in Mediterranean soils whose structure can be easily damaged by the raindrop impact.

The pattern of natural vegetation in the Mediterranean basin closely mirrors soil moisture availability. Vegetation has evolved to deal with high temperatures and periods of water deficit by selective physiological adaptation. The vegetation cover affects the soil in all its dynamic, including water redistribution over and within the soil, and microbiological activity. Biotic interactions occur which generate and maintain soil in the upper soil through the process of aggregation. This aggregation structure is a strong determinant of the soil's hydrological and biological characteristics, which affects their erosional response. Many authors have demonstrated that both runoff and sediment loss decrease exponentially with an increasing percentage of vegetation cover for a wide range of environment. Thus the degree of soil degradation is in many ways a reflection of the state of vegetation that covers and conditions it, indeed, degradation processes generally begin with the degradation of plant communities.

The socio-economic context

Mediterranean Basin is one of the areas of the world most affected by human induced landscape degradation. In fact the area was already somewhat settled by 4000 BP. All Mediterranean countries had their environments transformed by the human communities. From the Bronze Age onwards the original forest and woodlands were continuously felled and removed for agricultural and grazing purposes. From Roman times onward the water was managed by irrigation systems of considerable complexity, dry agriculture was transformed through a fallowing systems and the development of tillage methods that became more efficient in transforming the soil, and its environment over time.

Two conclusions can be drawn. The first conclusion warns against the idea of a pristine or primeval Mediterranean landscape, free from human intervention, as an unrealistic assumption. We should not try to understand the landscape without the presence of humans but to understand it as it is. This conclusion has strong implications for conservation policies because if we want to conserve our landscape, we are obliged to live in it. The second conclusion is that the land degradation, as understood by UNCCD, had already occurred over the dry lands of Mediterranean Europe since ancient times. Though there is a dramatic evidence for intensification during the last decades, nevertheless it must be seen within an evolutionary perspective, gathering momentum over the past few millennia

In middle of 19th century the land mismanagement stimulated by demographic dynamics resulted in shifting of the agricultural population to marginal lands unsuitable for agriculture. The extension of cultivated areas at the expense of forest implies high ecological alterations due to deforestation and the break-up of the original equilibrium between cultivation, grazing and forestry.

The current drivers of desertification in northern Mediterranean are the technological, social, cultural and economic changes that pervaded the rural life in the second half of the 20th century. The main driving forces of contemporary desertification in Mediterranean Europe are the following. (Thornes 1996;Yassoglou, 2000; Briassoulis 2003):

- The extensive rural out-migrations (especially during the 1905's and 1960's) and the abandonment of non-profitable and marginal agricultural lands
- The intensification of agriculture and the introduction of new farm machinery, new strains of cereals and tree crops, and extensive application of fertilisers.
- The shift from a local and national agricultural economy to a global one, which is related to a European Community economic framework
- The concentration of economic activity in coastal areas and the overexploitation of water resources as a consequence of greater demand for irrigated agriculture, urban development and the spread of tourist influx.
- The low level of perception on the part of the authorities and the public about the processes and the impacts of desertification.

Direct causes of desertification and land degradation: the pressures

Land management practices and land use changes leading to overgrazing, deforestation forest fires, overexploitation of water resources, and secondary salinization are among the most recognized causes of land degradation and desertification.

Changing land management practices as agricultural intensification, abandonment of traditional cultivation practices and expansion of new irrigated areas on previous dry farming land, and land abandoned during the 1950's have had the most damaging effects on land resources. The industrialization and mechanization of agriculture has enabled the farmer to bring into cultivation sensitive sloping lands and enjoy a temporary profit from them. The positive effect of this new agriculture production system, which is driven by sets of couplings between market-driven forces, agro-technological innovation, government subsidies and physical and biological constraints of the natural system, leads, nevertheless, to soil exhaustion, over-pumping of ground water resources and dependency of agrochemicals.

The dramatic technological changes and capital inputs that affected Mediterranean agriculture since the middle of 20th century facilitated the access to water resources that were not previously available. Big irrigation developments were then launched, and new irrigated areas replaced traditional irrigation systems. The mild climate of Mediterranean coastal areas allows off-season production of vegetables. This opportunity, combined with an increasing demand from Central Europe, drives a very intensive and high tech agriculture that competes with tourism for water. In Southern Europe, such external forcing creates positive feedbacks, in such a way that affected areas become sinks for population, investments and water demand, which is usually supplied form groundwater storage. Thus, negative water balance arises from over-exploitation of aquifers and the quality of water resources is down degraded by marine intrusion and pollution with agrochemicals. For example, in Southeastern Spanish coast, deficits of some 400 km3 y-1 are recorded (MIMAM 1998), and around 80% of aquifers are already affected by salinisation (MOPTMA/MINER 1995). External water inputs, such as transfer from other basins and desalinisation, are being developed as a way to restore water balances. There are drawbacks for both options; the first triggers inter-regional confrontations in long drought spells and may promote expansion of new irrigated areas, while the latter leads to a dangerous dependency on energy prices

The increasing water demand by the societies for agriculture, specifically for irrigation brings about the worsening of the quality of irrigation water. Besides, the salt concentration of the residual waters from urban treatment plants and industry is becoming greater and greater, but prevailing practices require their application on the land. An increasing amount of fields are irrigated by secondary waters with considerable salt concentration.

The main manifestations of desertification in irrigated lands are the salinization and sodication of soils, due to inadequate leaching of salts contained in the soil or added in irrigation water. Salinization and water-logging commonly occur together. Where the soil is waterlogged, the upward movement of saline groundwater leaves salts on the surface where water evaporates. In soils that are not waterlogged, salinization can still occur when water containing soluble salts moves from irrigation furrows into the ridges where crops are planted or to high spots in poorly levelled land. Under-irrigation of weakly permeable soils can also lead to salinization if the irrigation water is salty. Poor soil and water management, including insufficient water application, irrigation with saline/sodic waters water without proper agronomic practices, have been identified as being the main drivers of salinization/sodication in several salinity projects.

In Mediterranean landscapes the marginal agricultural areas (*saltus*) was used as grazing and as a buffer for supporting the increase or release of agricultural activity, according to the occasional requirements of concerned populations. This buffer role has been one of the factor that put marginal lands under heavy risk of desertification. At present the dynamic of these areas are subject to three kinds of changes: (i) encroachment of agriculture into marginal areas, (ii) release of agricultural activity and (iii) overgrazing of rangelands

The area and production of traditional tree crops, particularly olive and almond, has greatly increased during recent decades in South Europe driven by regional and national policies (Tables 1.1 and 1.2). This expansion occurs at the expense of marginal grain crops and rangelands. Olive agriculture has experienced deep transformation over the past few years. Traditional rain-fed orchards with widely spaced old and big trees are being substituted by new ones, with young and small trees, planted at higher densities and fed by drip irrigation. Almond tree crops have also experienced a dramatic expansion, especially in Spain and Greece, as a result of policies aimed at fixing the rural population. Almond tree plantations expand over hilly marginal areas, often with high slope gradients.

Table 1.1 Land Use and Sheep Stock Changes in Mediterranean Countries

	Arable land ($x\ 10^3\ km^2$)			**Irrigated area ($x\ 10^3\ km^2$)**			**Sheep stock ($x\ 10^3$ heads)**		
	Mean 1961-65	Mean 1994-98	% var	Mean 1961-65	Mean 1994-98	% var	Mean 1961-65	Mean 1994-98	% var
France	193	183	-5	4.00	17.57	339	8876	10632	20
Greece	29	29	-3	5.30	13.65	158	8764	8845	1
Italy	127	83	-35	24.00	26.98	12	7956	10730	35
Portugal	25	20	-19	6.20	6.32	2	5161	5968	15
Spain	161	144	-11	20.89	36.12	73	20855	23418	12
S. Europe	**535**	**459**	**-14**	**60.39**	**100.65**	**67**	**51612**	**59583**	**15**

Source FAO(2001) In Mendizabal& Puigdefábregas (2003)

Table 1.2 Land Use and Sheep Stock Changes in Mediterranean Countries

	Almond production (10^3 t)			**Olive production (10^3 t)**		
	Mean 1961-65	Mean 1994-98	% var	Mean 1961-65	Mean 1994-98	% var
France	3	4	62	7	15	120
Greece	30	49	62	282	2056	109
Italy	225	91	-59	2192	2843	30
Portugal	14	9	-38	581	280	-52
Spain	158	250	58	1771	3834	116
S. Europe	**430**	**403**	**-6**	**5533**	**9028**	**63**

Source FAO(2001) In Mendizabal& Puigdefábregas (2003)

As previously stated, desertion of marginal agriculture is a general trend observed in European countries since the middle of 20^{th} century. During this period vast areas of terraced agriculture have been abandoned because of the low mechanization potential of terraces. Due to low maintenance, and abandonment, terraces have collapsed causing rapid removal of soil by water run-off, except where stonewalls are protected by the roots of fast growing vegetation. The consequences of the land abandonment in a desertification context will be analysed in section 6.4

Both in Northern and Mediterranean Europe the intensity of grazing has increased, induced by EU cattle subsidies and improving productivity policies (Table 1.1). Land degradation can be greatly accelerated by high densities of livestock which lead to vegetation degradation in, in turn, to soil compaction. The gradual denudation of land caused by overgrazing expose the soil to water and wind erosion (Schnabel, 2003). Under such conditions the soil of climatically and topographically marginal areas cannot economically support enough plant cover to avoid irreversible degradation.

Deforestation has been one of the important direct cause of land degradation in erosion-prone arid and semi-arid Mediterranean Europe. In the Mediterranean Basin the progressive use of land for pasture and crop cultivation, as well as wood for fuel and construction has lead to the fact that forest covers only around 5 % of its original coverage. In a sense, deforestation can be regarded as an initial trigger to the onset of desertification. The ecological consequences of deforestation are considerable since it results in a shift of balance in the water cycle as well as in promoting soil erosion. The effects of such disturbances are manifest in increased flooding, landslides and the silting up of rivers and dams.

During the last decades the deforestation rate and forest decline have been conditioned by two opposing process. On one hand, forests have been expanded in parts of the European Mediterranean countries. During the period 1965-1984, the total forested area of the region has grown by 6,462,000 hectares, which represents a 14% increase (le Houérou, 1990). Similar trend on forest recovery was reported in one of the most threatened region of Mediterranean Europe: the Guadalentin basin in southeastern Spain (Lopez Bermudez et al., 1996). The advancing forests have occupied abandoned marginal agricultural lands and pastures through a natural secondary succession process. However, the natural recovery is restricted to climatically favourable areas and to moderately damaged lands. Besides this natural reforestation, the observed increase of the forest land is due to afforestation works promoted in the framework of restoration projects to combat soil erosion and desertification.

On the other hand, the Mediterranean forests have been seriously damaged by frequent and extensive wildfires. The areas affected by forest fires have increased dramatically throughout the Mediterranean Basin during the last fifty years. Between 1960 and 1975, the average rate of burning was 200,000 ha/yr., from 1975 to 1980 470,000 ha/yr, and from 1981 to 1985 660,000 ha/yr. The majority of fires occur in both pine-dominated areas with high xerothermic indices and in areas characterized by moisture deficits and marginal abandoned areas. Here, the increase of vegetation density enhances fuel accumulation. In addition to vegetation loss, fires induces changes in physico-chemical properties of the soils. The nature and extension of these impacts are strongly related to the temperature reached, the wildlife habitat destruction, the homogenisation of the landscape, the loss of human life and the damage to infrastructure. Vegetation loss after fires exposes bare soil to torrential rainfalls, increasing erosion risk and making difficult for regeneration of an adequate vegetative cover in areas of high recurrent wild fires.

In Mediterranean environments fire should be seen as an endogenous element in ecosystem evolution. The little plant compositional changes between fires as well as the fire-adaptive traits showed by many plants have led o the notion that fire has played a very important role in the selection of Mediterranean ecosystems. On the other hand, man has used fires as a management tool to modify plant distribution and service food demands. These facts do not mean that fire cannot be an agent of desertification. To understand the role of fire in the current Mediterranean ecosystems it is necessary to consider the relationship between the degradation potential of fire in relation to fire regime: size, intensity and recurrence interval. It is likely that the current fire regime has little in common with whatever regime existed before, either in the prehistoric times or during our more recent history of pastoral and extensive agricultural use of land. The cessation of traditional management practices, the creation of large homogeneous patches of vegetation through land abandonment and afforestation and the accumulation of fuel due to fire exclusion policies are cited among the major causes of the change of forest fire regime in Mediterranean Europe (Moreno, 1996). Fires may now be occurring at times, and with intensities, sizes and fire return intervals different from those of recent or more distant time changing the traditional role of fire in Mediterranean environment dynamic. Under this new circumstance, fire may be the trigger for land degradation and desertification.

Tourism has often been claimed as an indirect cause of desertification (Perez-Trejo, 1994). Mediterranean basin has today become the world's leading tourism areas. An increasing flux of tourists, and now retired people, from the northern European countries to sunny and warmed Mediterranean land have been observed since the last decades of last century agriculture. The tourism exerts a significant impact on environment particularly with respect to land-use pattern and water resources availability. The more impacting is the change of water allocation, which can impair access to water for other economic activities, or drive water prices up forcing cost of production up to levels that only capital-intensive activities such as tourism can absorb. The direct impact of tourism on land-use results from the need of land for ever-growing tourist facilities such as hotels, amenities for sport, cultural and recreational activities and corresponding infrastructures. The land they occupied is realized at the expenses of potential agricultural areas. Finally, an indirect impact of tourism development is that they attract labour due to the relative high wages that people can earn. The desertion of agricultural labour in zones surrounding tourist centres causes land abandonment and the degradation of soil and water conservation systems established on hilly Mediterranean lands

6.3 Assessment of desertification

Part of the text is largely based on a report written by M. Sciortino to be presented in the framework of the MEDRAP project. (Concerted EU Action EVK2-CT-2000-20008)

Assessing desertification is a complex task and there is a lack of a holistic methodology that enables this to be done at the global and regional level. It is quite simple to identify areas that have been degraded in the past and these occur throughout Europe. It is not so easy to separate past desertification from that occurring now. Assessment methods currently being used by the National Action Programmes (NAPs) have looked at a hypothesised sensitivity to desertification but this is different from detecting and assessing actual current trends in desertification. In the future using new GMS techniques and new monitoring technologies it should be possible to actually assess desertification in real time.

At present, most evaluations rely on soil erosion estimates, which are a relevant desertification symptom, but not the only one. The use of soil erosion maps to assess current desertification would involve great risk and uncertainty. At best they might indicate a theoretical risk of some of the drivers and pressures but in reality the link with desertification has never been demonstrated. In practise, most soil erosion in Europe is a consequence of agriculture or other land use practises and policies.

Therefore, the assessment of sensitivity to desertification and actual desertification itself is an issue addressed by European scientific research projects whose importance increased after the United Nation Convention to Combat Drought and Desertification (UNCCD) committed affected countries to elaborate and approve a National Action Programmes (NAP). The issue of sensitive areas has then became part of the policy work and a tool of scientific collaboration among affected countries of the Northern Mediterranean Region.

Sensitivity to desertification is not included among the definitions of UNCCD and therefore is still subject of debate within the scientific community. Sensitive areas don't coincide necessarily with affected areas because this last concept implies the identification of active processes that are reducing the economic and/or biological productivity of the land. The definition of affected areas requires the availability of data that can quantify the impact of the desertification processes and trends of physical, biological or economic indicators. Historical records of indicators are not always available or have not been systematically analyses to reconstruct the evolution of land. Sensitivity represents a snapshot of present land conditions and is actually the only assessment support to decision makers available with existing data and information.

The United Nation Environmental Programme (UNEP) gave in 1992 an alarming picture of the desertification extension and severity at global and regional scale. UNEP assessment of soil degradation in susceptible dry lands areas is still the most updated global consistent work that identifies the extension and severity of desertification in various regions of the word. According to UNEP the extension of drylands in Europe is 299,7 million ha that represent 31% of the continent and the degraded drylands extension is 99.4 million ha (32% of the european drylands). This alarming figure increased the awareness of European Northern Mediterranean countries and motivated more detailed assessments in Portugal, Spain, Italy and Greece.

These countries of the Northern Mediterranean are in different stages of preparation and implementation of their NAP. The formulation of the NAP has been conceived in different ways but nevertheless all the countries shared the need to assess sensitive areas. The national assessments of areas sensitive to desertification have been made using the information layers available at national scale shown in Table 2.

Table 2. Data layers used for national assessments

	Portugal	Spain	Italy	Greece
Area (km2)	91.858	505.988	301.401	131.992
Scale	1:1.000.000	1:1.000.000	1:1.250.000	1:1.000.000
Climate	X	X	X	X
Drought	X			X
Soil	X	X	X	X
Erosion Control				X
Vegetation	X		X	X
Demography			X	
Aquifers over-exploitation		X		
Forest fires		X		

The data layers utilized vary from country to country and only the climate and the soil layers have been used by all four countries. The climate, drought, aquifers, forest fires and erosion control layers are limited to the national territories. The National Assessments herein produced have been obtained by the combination of environmental indicators with a very limited use of socio-economic indicators. Although it is widely recognized the importance of socio-economic indicators their use in the current assessment has been very limited at the national scale. The results shown in Table 3 give on overview

According to the results shown in Table 3 Greece is the most sensitive country of the region followed by Spain and Portugal but because the methodologies applied differ from country to country the main purpose of national assessments is the elaboration of national maps that identify most sensitive areas within the national territory.

Table 3. Sensitive areas at national scale (% of the area).

	Portugal 1997 - 2003	Spain	Italy	Greece
Area (km^2)	91.858	505.988	301.401	131.992
High	11 - 28	31,49		33,25 erosion 1,53 salinity
Medium	60 - 8	21,68		46,76
Low	39 - 40	13,98		15,17
Total Sensitive	100 - 76	67,14	5,5	99,71
Non Sensitive	0 - 24	32,86	94,5	0,29

UNCCD and the European Environmental Agency (EEA) through the project Desertification Information System for the Mediterranean (DISMED) worked to the elaboration of a common methodology among countries of Northern and Southern Mediterranean region. The map published in the web site of EEA shows the results of the assessment of sensitivity for Portugal, Spain, Italy, Greece and Tunisia. The DISMED methodologies worked at the scale of 1:1.000.000 and assessed the environmental sensitivity to desertification not addressing the socio-economic indicators. The sensitivity at this scale is therefore the result of the combination of soil, climate and vegetation indicators.

According to the DISMED results (Table 4), Spain is the country with the highest environmental sensitivity in both the "High" and "Medium" classes followed by Greece, Italy and Portugal. On the other side, the difference among the different countries is in a quite small range of variability. The main goal of DISMED is to provide a reliable assessment of desertification sensitivity by the application of a common methodology to different environmental context. The interest of DISMED is also due to the adoption of a legend and of thresholds values among classes common to all countries.

Table 4. Sensitive areas (%) result of the DISMED project at Northern Mediterranean scale

	Portugal	Spain	Italy	Greece
Area (km^2)	91.858	505.988	301.401	131.992
Very high	0	0	0	0
High	2,51	8,53	3,07	5,83
Medium	28,88	48,29	32,15	36,88
Low	64,70	39,93	64,11	56,27
Total Sensitive	96,10	96,75	99,93	98,98
Very low	3,90	3,25	0,67	1,02

Source: Fondazione Meteorologia Applicata, Florence

Legend:

Very Low - Areas in which critical factors are not present, with a good balance between environmental and socio-economical factors

Low- Areas threatened by desertification under significant climate change, if a particular combination of land use is implemented or where offsite impacts will produce severe problems. This would also include abandoned land which is not properly managed.

Medium - Areas in which any change in the delicate balance between natural and human activity is likely to bring about desertification.

High - Areas already highly degraded through past misuse, presenting a threat to the environment of the surrounding areas

Very high - Areas with severe limitation to the use, with evident desertification processes

Source: EU Desertlink project

Assessment of sensitivity to desertification at regional and watershed scale.

The first scientific effort for the identification of sensitive areas in the Northern Mediterranean region is due to the EU project Mediterranean Desertification and Land Use (MEDALUS) (Kosmas et al. 1999). MEDALUS methodology has been applied to four pilot areas with the support of “ad hoc” field measurements and surveys that improved the understanding of desertification processes and made possible the creation of specific data bases. The MEDALUS methodology has been improved and refined within the Desertlink project and is now available on the web page of the project (www.kcl.ac.uK/deserlinks).

In 1999, the initiative of the Italian National Committee to combat drought and desertification introduced in the Italian legislation (law 152/99) the concept of sensitive areas to desertification and the following year (2000) the Italian NAP was also approved. As a result of these legislative actions administrative regions have been requested to identify their sensitive areas and many of them applied the MEDALUS methodology.

The application of the methodology by different groups produced a first regional assessment of desertification. Having applied different legend and of the threshold values among the classes, the sensitivity to desertification produced in the framework of the activities for the implementation of the Italian NAP, are still not comparable each other and therefore can be considered as a preliminary results and a coordination effort is now under way within the inter regional project Desertnet. Although the results are poorly comparable, they increased the awareness of desertification also outside the scientific community

Table 5. Italian assessments of sensitivity at regional and watershed scale

Regions and watersheds	YEAR	SCALE	Institution
Sardinia	2003	1:100.000	ERSAT Sardinia Region
Sicily	2001	1:250.000	Sicily Region-Territory and Environment Department
Sicily	2002	1:250.000	ENEA-INEA
Apulia	2001	1:350.000	Puglia Region-CNR (Research National Commette)
Apulia	2001	1:250.000	European Soil Bureau; Space Application Institure and Puglia Region
Basilicata	2001	1:250.000	Basilicata Region- CNR (Research National Committee)
Magra River	2001	1:25.000	Magra River Basin Authority
Sarno	2001	1:1.200.000	Sarno River Basin Authority
Left Sele	2001	1:1.200.000	Left Side of Sele River Basin Authority
Right Sele	2001	1:1.100.000	Right Side of Sele River Basin Authority

The results for the Lesvos, Val D’Agri and Mertola are three of the four the pilot areas assessments of the MEDALUS project. They are the only small scale sensitivity assessments available. The assessment of climatic condition is the first step for the identification of sensitive areas. The assessment of aridity may use several index developed and validated by different authors. For reasons of comparability of results the aridity index adopted by UNCCD and its the thresholds values should be used in the context of desertification assessments. Unfortunately this has not been always the case.

The results shown in table 6 produced by different assessments are hardly comparable due to the adoption of different legend of the maps and of the thresholds among the different categories. The choice of the appropriate legend is a critical issue in the production of sensitive maps because maps are tools for communication with media and different stakeholders. Nevertheless the results summarized show that in the climatic conditions of dry sub-humid regions there is a remarkable sensitiveness to desertification that would require an increase of attention to the risk of desertification by decision makers at all levels.

Table 6. Sensitive areas at watershed and regional scale (% of the area)

	Lesvos Greece	Val D'Agri Italy	Mertola Portugal	Sicily Italy	Sardinia Italy	Valencia Spain
Very High			7,2			15
High	37	1,4	23,3	6,9	51	9
Medium high			5,6	46,5		
Medium	52,4	34,5	31		38	28
Low	7	64	7,1	32,5	5	30
Total Sensitive	96,4	99.9	83,1	85,9	94	82
Non Sensitive	3,6	0.1	14,3	7,2	1	7
Excluded Areas				6,9	5	11

6.4 Impacts of desertification. Land abandonment and water resources

Desertification is a complex process of simultaneous degradation of soil, water resources and vegetation, which can affect natural, semi-natural and agricultural systems, as well as other human activities. Figure 1 provides a summary of the ecological processes of desertification, as well as their consequences in terms of damages to the natural and human environment . Collectively, this degradation leads to a loss in resilience, soil quality and in ecosystem integrity and health. This results in a loss of both ecological and social capital.

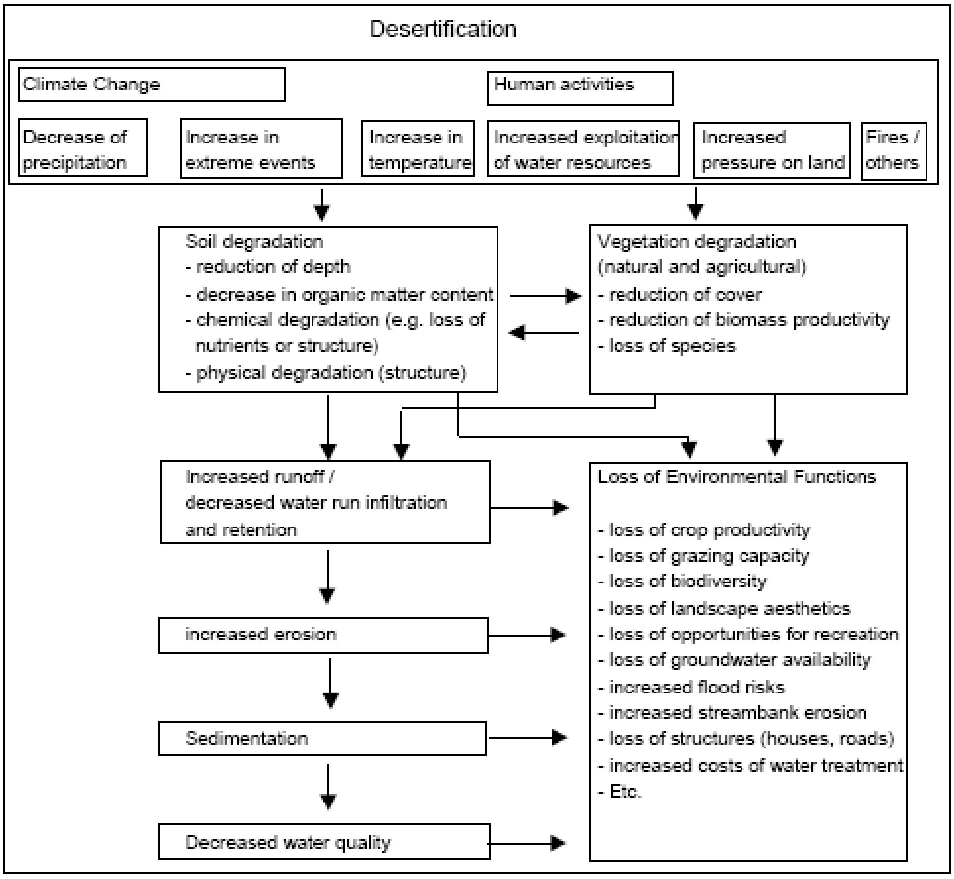

Figure 1. Schematic overview of the driving forces and consequences of desertification (From Hein, 2002).

Impacts of desertification on land resources functions

The complex of desertification process diminishes the productive capacity of the environmental system. This productive capacity can be described in terms of 'functions of the environment' (De Groot, 1992). Functions of an environmental system can be subdivided in four main groups (namely production, regulation, carrier and information functions). Land degradation and desertification result in a decline of the performance of a particular function. Therefore, an integrated assessment of the impacts of desertification should be consider all environmental functions performed, which may include agriculture, forestry but also functions as sedimentation control and provision of habitat to wildlife. A tentative list of potential impact of desertification is shown in Table 7.

Most of the potential impacts are closely related to soil erosion impacts (see taskgroup 3 report). So that in this report we are going to focus on those critical functions which has been single out as more sensitive to desertification (Imeson, 2000; Imenson and Cammeraat, 2002):

- Water and nutrient regulation function
- Soil and water conservation function

Table 7. Checklist of the potential costs of desertification and land degradation

Function	Description	Potential impacts
Regulation functions		
1. Water supply	Better groundwater availability and moisture retention, through good infiltration of rainfall	Loss of ground water resources
2. Water regulation	Lower runoff and flood risks, due to good infiltration of rainfall, or to retention of water in ecosystems.	Loss of surface water resources, and/or increased flood risks
3. Soil retention	Vegetation cover important against erosion	Increased erosion leading to loss of productive capacities of the oil and/or to sedimentation
4. Soil formation and maintenance of fertility	By litter formation and organic matter addition, or by accumulation of sediments.	Loss of resilience of ecosystems because of negative impacts on the soil formation processes
5. Carbon sequestration	Sequestration of carbon in biomass	Loss of the amount of carbon sequestered
Production functions		
6. Food supply	Production of dryland crops.	Loss of productive capacity of the land
7. Grazing	Sheep and goat grazing.	Loss of pasture quality
8. Raw material	Fibre for fabrics	Loss of possibilities to extract raw materials
9. Genetic resources	Old cultivated varieties, or wild plant species diversity.	Loss of genetic diversity
Habitat functions		
10. Refugium	As habitat for natural species	Loss of biodiversity and nature
Information functions		
11. Recreation	Drylands may provide opportunity for tourism and recreation, including outdoor activities.	Loss of opportunities for recreation
12. Historic information.	Heritage value of traditional agricultural practices	Loss of historic information
13. Aesthetics	Valuable scenery.	Loss of scenery
14. Existence /bequest value	Desert landscapes or water resources may have special value in regions of water scarcity.	Impacts on landscapes

Source: Hein, 2002

The Water and Nutrient Regulation Functions of the Soil

The loss of water and nutrient regulating functions can be caused by the deregulation of several processes. Water regulation functions require a soil medium which is able to store and retain water, what is closely related to the maintain of soil porosity and permeability. This is, in turn, favoured by the aggregation of primary particle in larger water-stable aggregates. The aggregation processes are a consequences of biological activity of the soil and reflect the dynamics associated with the input and mineralization of organic matter (*vid* taskgroup 5 report).

Water-stable soil aggregation can be considered as an indicative of the success and failure of biological activity in creating and maintaining the water and nutrient regulation function which, in turn favours retention of available soil moisture and water and nutrient transport. This biological activity depends on there being both a sufficient input of suitable organic matter and periods of time during which soil moisture and temperature do not limit the activity.

In a large extent of desertified areas, the loss of vegetal cover brings about a diminution of soil organic matter. This reduction has a direct effect on soil structure by weakening of the soil aggregates. The weakened soil aggregates brake into smaller ones upon the impact of the raindrops, the slacking caused by wetting and the cultivation. Small aggregates and primary particles fill the soil pores on its surface and lead to the formation of crust reducing infiltration. The degradation of the structure on the surface has a negative effect on the biomass productivity of the soil by reducing water availability for plants and hampering the revegetation. Thus, the loss of water and nutrient regulation function bring about a feedback self-accelerated mechanism that, if not arrested, accelerates land degradation

In more arid soils the water regulating function is mainly regulated by dispersion of clay minerals. Dispersion conditions are frequently found in soils that contain low amounts of slat but where a large proportion on this consists of sodium. The clay dispersion is a climate-sensitive process. A climatological threshold above or below of which the soil being either flocculated or disperse has been proposed for southern Europe (Lavee et al.,1996). Where the annual precipitation is below about 400 mm yr^{-1} dispersion is the key process regulate infiltration. The areas of soil affected by dispersion vary both temporally according to the amount of rainfall and spatially, anywhere salt accumulates in soil.

Soil and Water Conservation Function

Landscape can be seen as a mosaic of hydrological or ecological response units whose spatial arrangement is the result of the processes of water, nutrients and sediment transport at hillslope and catchment scales. These processes are regulated by positive feedbacks between the vegetation, soil and water that reinforces the redistribution of rainfall and runoff within each unit.

The degradation of water and nutrient regulation functions of soil caused by land degradation and desertification can result in an increase of runoff and erosion at coarser scales (hillslope and catchment scales) and the reduction of landscape performance for soil and water conservation. This is reflected in three responses emergent at hillslope scale (Imenson and Cammeraat, 2002):

- Changes in the distribution of sediment and runoff source and sink areas. There are changes in the size, behaviour and location of sink and sources of water and sediments on slopes
- A general loss of soil depth at sources sites and a potential increase at accumulation sites
- An increase of hydraulic connectivity between bare patches, increasing runoff volumes during extreme rainfall events

At catchment scale, the impact of desertification because of the loss of soil and water regulation function is a change of hydrological and erosive response, which manifest itself as:

- Higher discharge peaks and sediment loads after extreme events
- Increasing fluvial erosion on river banks
- Channel incisions and ephemeral gullies development resulting from heavy winter rainfalls
- Silting up of reservoirs and other water storage structures
- Spreading pollutants on valleys and downslope areas

Impact of desertification on natural and economic capital

Both organisms and people transform their environment by investing in the capital that will generate and sustain future life. The functions mentioned above arise initially as a result of the transformation of energy by plants into substances that can be accessed and utilized by animals and man. Nearly all of the work done in a landscape is performed by plants and animals who invest in a capital that man can access through domesticated animals and plants. The functions mentioned above are in fact in theory dependent on the replenishment of this capital (See Huxley 1880). If people are dependent on this “capital” the soil has to be managed correctly. If they are not dependent on the capital created by organisms in the soil e.g. “capital” is provided in substances or by alternative livelihoods, and production is achieved through the use of fertilizers, there is no need to be so mindful of the work being done and the functions being performed by organisms. Using this reasoning Imeson (2004) proposed a universal desertification indicator. It considers desertification pressure as the ratio between a) the amount of capital generated locally and b) the capital being supplied from elsewhere. This applies throughout the system, both in the soil and in agriculture. Non sustainable practices occur when the supply of external capital causes the amount of natural capital to decrease,

Land abandonment

It is recognition that desertion and desertification are related problems in rural areas because, as the sustainability of agriculture falls through the direct impacts of desertification and climate change, people move from areas of lesser to areas of greater opportunity to provide a livelihood for themselves and their families. This in turn leads to an accelerated population decline to levels below the threshold necessary to support basic facilities and services.

In the southern European Union land abandonment is the major large-scale change occurring. However, land abandonment is a continuously operating process and in some cases an integral part of the agricultural system (Thornes and Burke, 1999). It comes and goes recurrently according to the economical and social context.

Land abandonment does not necessarily mean that land is no longer used, either by agriculture or any other rural economy; it means a change in land use from the traditional or recent pattern to another, less intensive, pattern. Whether causes of land abandonment are natural or socio-economic is still subject to debate. Land abandonment occurs because of external driving forces, such as market changes, or as a consequence of land degradation which lead the system to cross some irreversible threshold, such as the critical depth for plant growth.

It is often claimed that land abandonment invariably leads to land degradation and desertification. Nevertheless, Mediterranean landscapes have being shaped by a socio-natural system that is highly “disturbance-dependent” in which many aspects of nature in it depend on regular human intervention for their survival. Such environments do therefore degrade both where there is too much pressure and when the pressure is insufficient, as is widely shown by the consequences of land abandonment. Some authors have pointed out that from the dominance of human action of the Mediterranean ecosystem the resilience of social dynamic is just as important for its survival that the resilience of non-human communities for the survival of this type of system

Whether an abandoned land will move towards recovery or desertification depends on the state of the land at the time of its abandonment and what follows afterwards. The abandonment of highly human-shaped landscapes often moves the system towards to a threshold that, when crossed, may led to irreversible degradation. In Mediterranean Europe the most vulnerable lands are those on sloping terrain and shallow soils, which have been stabilized by erosion control terraces. These landscapes are in a metastable equilibrium, which exists only as long as the terraces are maintained and the damages repaired. Once abandoned, the terraces collapse and accelerated erosion start to remove the soil from them. The post-abandoned use is also a key factor of the future evolution. For example, the intensive grazing of abandoned agricultural field hamper the recolonization of pioneering vegetal cover and leave the bare soil exposed to the impact of raindrops.

The abandoned fields show quite different evolutions depending on environment and land-use features. The influence of some of these, especially soil type, water availability, and the type of previous and post-abandonment land use, on the system dynamic after abandonment is highly local dependent. The evolution of vegetation types depending on age of abandonment shows clear tendencies: the predominance of annuals in the fallow land and the field abandoned for five years, and a progressive decrease of annuals until they barely appear by the time scrub lands have developed. Shrub and perennials show the opposite behaviour, though in a less pronounced way and with different time scales. It can take more than 20 years for shrub lands with a high percentage of ground cover to develop. Studying the effects of the land abandonment for a 1-30 years period in southeastern Spain, Martínez-Fernández et al, (1996) showed that total organic carbon content was the soil property more closely related to both the vegetation dynamic and age of abandonment. The results show that, after the abandonment of agricultural practices, an evident recovery of organic matter content may be detected even in the early stages.

Another impact associated with land is the increase of fire risk due to the accumulation of biomass on abandoned fields after recolonization processes. In grasslands the decrease of grazing pressure induces a replacement of nutritious herbs by rough pasture (woody species) with a greater fire risk. The impacts of land abandonment and subsequent recolonization on water regime have been noted by experts (Thornes and Burke, 1999). Although the water balance and erosional response to abandonment are not unequivocal, the effects of land use changes on water resources are fully realised. There is, therefore, an urgent need for their appraisal for the actions being considered in the policies and programmes to combat land degradation and desertification

Water resources. Salinization

Aridity, drought and desertification are distinct, but closely related, concepts. In fact, the United Nation Convention to Combat Desertification (UNCCD, 1996) also includes drought in the formal convention. Aridity is a permanent situation, related to climatic characteristic of a region, and often associated to a mismatch between availability of and need for water. Drought is an extreme meteorological events, temporary and reversible in nature. Desertification is, as it has already been defined, a complex phenomena involving soil, water, and land cover, evolving slowly in time, and irreversible in many cases (Table 8).

Table 8: Main characteristics of aridity, drought and desertification

Xeric regimes	Nature produced	Man induced
Permanent	Aridity	Desertification
Temporary	Drought	Water shortage

Source: Correia, 1996

The relationship between drought and desertification is rather complex. Arid and semi-arid regions are more fragile and more frequently subjected to water shortages. For this reason they are very vulnerable to desertification if social and economical factors lead to a persistent and excessive use of soil and water resources. The question rises when the opposite relation is considered: is desertification a triggering factor of drought?.

The biogeophysical feedback between desertification and drought is not yet clearly defined and quantitatively established. Nevertheless, it is clear that there is a positive cycle with aridity leading to drought, drought leading to desertification, desertification leading to a more persistent drought condition and ultimately accentuating the arid characteristics.

A good example of this feedback is described in Mediterranean region due to the impact of desertification of soil and water conservation functions of the landscape. As land degradation occurs, soil storage capacity is reduced, runoff increases and erosion thresholds are passed. The high inter-annual variability of rainfall moves Mediterranean soils inexorably towards the threshold of land degradation as the pressure on vegetative cover increase through the lack of soil moisture. This degradation trajectory may be accelerated within a global warming scenario as it is indicated by the ICCP. MEDALUS research suggests significant reductions in the biomass of grass and bushlands in areas having more than seven rain-free months per year in the Iberian Peninsula as temperature and atmospheric CO_2 rise and estimated made by Spanish Ministry of Public Works indicate a 17-20% reduction of flow of major Spanish rivers (Thornes, 2002). Even accepting the errors associated to a current simulation models, the results show a decrease in the water supply for river flow replenishment and aquifer recharge.

In addition to natural irregularities on water supply associated to climatic conditions, the public perception of desertification in Mediterranean areas has been heightened by water resources shortage arising from the human induced water problems, including:

- The increasing water demand to meet the need of tourism in desertification sensitive coastal zones.
- A number of major floods, whose magnitude and time to rise have been affected by vegetation removal and soil erosion, but whose impacts have resulted from failure of flood plain zoning.
- The heavy reliance in Mediterranean countries on irrigation for agricultural production: in Greece 80% of water is used for irrigation, in Italy 50%, in Spain 68% and in Portugal 52%.
- The continued rise in the demand for irrigation water.
- The over-pumping of groundwater which also reduces channel flow, causes sea intrusion in coastal aquifers, and provokes salinization.
- The deterioration of water quality due to small dilution and transport capacity of rivers and the transport of nutrients and pesticides from intensive agricultural areas by eroded sediments.

The environmental relationships between the impact of salinization/sodification and the extension of desertification have been highlighted in several studies and reports. Figure 2 summarizes the relationships reported .

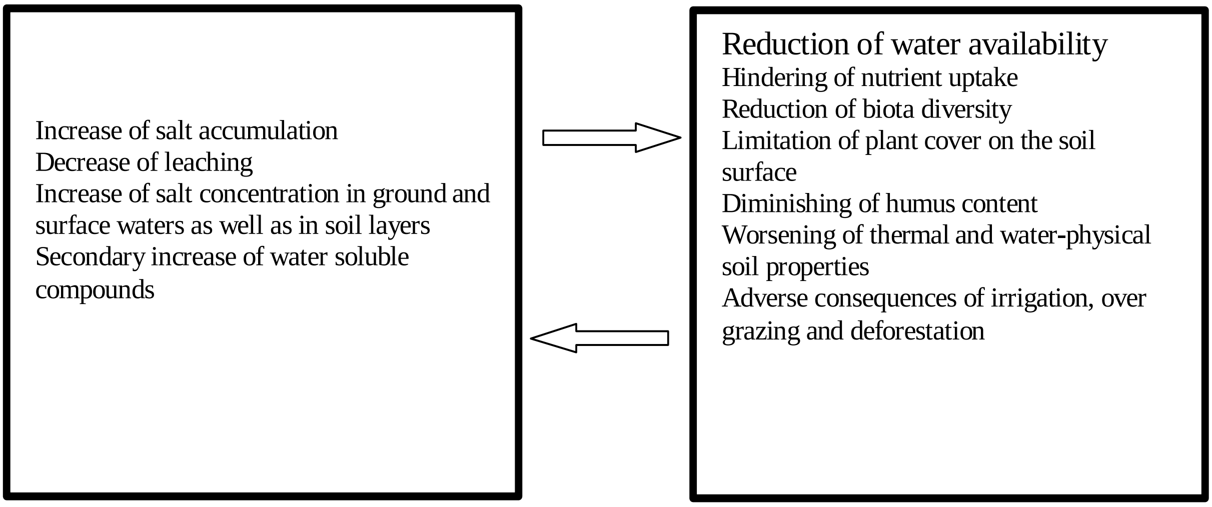

Figure 2. Environmental relationships between the impacts of salinization/sodification and desertification (Szabolcs, I. 1992. Salinization and desertification. Acta Agronomica Hungarica, 41:137-148; Crescimanno, G. 2001. An integrated approach for sustainable management of irrigated lands susceptible to degradation/desertification. Final Report ENV7-CT97-0681)

Sodium (Na) dissolved in irrigation water affects the structural and hydraulic characteristics of soil , affecting water flow in the soil. The deleterious effect of Na on soil structure can be attributed to swelling and/or dispersion of clay particles, migration of clay into the soil pores with subsequent occlusion, slaking of aggregates and loss of aggregate stability. Reduction of infiltration capacity due to soil surface crusting, and reduction in hydraulic conductivity affect the growth of plants by decreasing the amount of water available in the root zone. Salinity may have negative direct effects on crop yield by reducing the ability of plant roots to absorb water; the reduced availability of water to a plant is due to soluble ions and molecules causing an osmotic pressure effect. Evaporation and transpiration by plants remove almost pure water, leaving soluble salts in the soil; as a consequence, not only matric but also osmotic potential decreases, as soil moisture decreases.

6.5. Measures to combat desertification

Measures to combat desertification include policy and technical actions to by applied on areas affected by current or past desertification processes. Recommendations aimed at combating desertification need to integrate socio-economic and environmental factors. Actions for making compatible environmental conservation and economical progress should be developed and properly implemented.

Prevention, mitigation and restoration measures

Prevention and mitigation actions to combat desertification can be summarized as:

- Integrated land use planning and application of sustainable- systems of exploitation of land resources.
- Management practices leading to a rational use and protection of soil, water resources, vegetation, landscape and ecosystems.

Integrated land use planning

A deep transformation of the present social and economical scheme is necessarily required to modify people's pressure upon resources and thus to avoid overexploitation. This applies particularly to the rural world, which is the sector most directly affected by desertification.

It is essential for farmers to realize that maintaining the present resources consumption rates will lead desertification-prone systems to a total collapse in the near future. However, market-driven pressures and the large investments made create systems with high inertia, forcing most farmers to continue their current exploitation rates. It is necessary to revise the present agrarian policy bearing in mind the risk of desertification and to develop linked forecast and integrated land use planning strategies.

Integrated land use planning to combat desertification should contribute:

- To reduce the inertia of the exploitation system by diversifying economy and fostering the development of secondary and tertiary sectors in rural areas.
- To reduce agricultural and other water demands.
- To control the expansion of new irrigated lands on sensitive sloping lands.
- To control urbanization and soil sealing on areas of high agricultural quality.
- To preserve extensive farming systems; to transform the least viable irrigated lands into extensive systems.
- To protect current springs, wetlands, and natural flows in rivers and ephemeral channels.
- To promote woodland conservation and preserve functioning of woodland ecosystems.

The implications for management of land use planning actions should be refined at the local scale.

Land management practices

Suitable measures to mitigate desertification problems related to the exploitation of water resources may be penalizing water wasting, improving irrigation schemes, preserving the soil and water conservation strategies of extensive farming systems, and fostering alternative water resources such as seawater desalinization.

In the context of desertification, rangeland management faces three major problems: marginal agricultural systems, overgrazing, and wildfires.

Grazing must be adapted to specific conditions and grazing capacity of each rangeland. For Mediterranean rangelands, some rules to test if proper grazing is being applied in a particular rangeland are the following (Papanastasis, 2003):

- Utilisation percentage: animals should not consume more than 50-60% of the annual growth on the particular species involved
- Stubble height: for herbaceous species, animals should graze down to no less than 6 cm of the palatable species by the end of the grazing period
- Range trend: range condition should be improved with grazing; degradation is exemplified by dominance of weeds, reduction of soil organic matter, and soil erosion; in shrublands, degradation may also be detected by significant shrubland encroachment.

Wildfires caused by burning for renewing pasture lands is a prevalent threat in many parts of southern Europe. The impact of this practice is much higher when combined with overgrazing by animals brought to the burnt area just after the fire. To improve the grazing capacity without damaging ecosystem, fire should be prescribed or controlled, i.e. it should be applied on the right place, at the right time, with the right method, and by the right people, namely trained technicians. Forest fire prevention programs should include a specific program for uncontrolled burnings to modify the human behaviour of the rural population in the use of fire.

An important part of the budget of the forest services in Mediterranean countries is devoted to fire suppression resources. A more equal balance of the public means invested between fire extinction and forest management for prevention and restoration is desirable. Forest fire management has to find more effective approaches by improving strategies and technologies for prevention. Forest insurance implementation would assure restoration in the most frequent present forest degradation process.

Prevention and mitigation measures in marginal agricultural lands should be focused on soil and water conservation (see Task group 4.1 report on measures to combat soil erosion).

Restoration measures

Once some thresholds are exceeded, even if the degradation-driving forces are reduced, degradation can only be reversed by restoration actions. Restoring degraded/desertified lands is a complex task that faces a complex process. The introduction of desirable species or the increase in plant cover are surrogates of the main goal: restoring ecosystem functioning, allowing self-sustainable system organization (Vallejo et al. 2003).

Degraded areas and arid/semiarid lands are not always correlated, as low/sparse plant cover is not synonymous of desertification. Spatial variability, where vegetation is interspersed by bare soil patches, has a prominent role in dry land ecosystem processes. The question is to what extent this heterogeneity is fully functional or, by the contrary, is producing net losses of resources that might be repaired by restoration actions. Off-site damage occurrence, recently developed indicators of land degradation, and the expertise of stakeholders and managers should be taken into account to answer this question.

Abandoned uplands in semi-arid areas are preferential spots for land restoration, since abandonment is usually followed by further degradation and collapsing of soil conservation structures.

Once target areas are identified, the next step is to define threshold conditions of degradation that allow successful restoration, both in social, economical and technical terms. It is wasteful to conduct costly and extensive reforestation programs in extremely degraded lands without a consistent prevision of the chances of success. Burned lands in desertification-prone areas are also potential target areas for restoration actions, since plant recovery rates use to be very slow.

Since degraded ecosystems are characterized by net losses of resources, productivity and resilience, ecological restoration in desertification-prone areas is conceived to (i) create fully functional vegetation patches that contribute to a process of re-allocation of water, materials and nutrients and to the general productivity; (ii) to increase ecosystem diversity, stability, and resilience; and (iii) to prevent further surface and landscape degradation, soil erosion, and off-site damage.

Current approaches to improve restoration of desertification-prone areas focus on the amelioration of water stress using efficient water management practices, in the creation of favorable microsites for natural plant colonization, and in the utilization of soil surface heterogeneity and facilitation by existing vegetation. The restoration of vegetation in semi-arid degraded lands should be based on a wide set of species choices to match the potential diversity of habitats and degradation stages, and should be carried out according to natural vegetation patterns, with the aim of recover previous landscape processes.

Limiting conditions prevailing in very degraded land increase the cost of restoration actions, which apply the best technology to cope with the scarcity of resources and the stressing environment. Low-cost land restoration techniques often fail in so hard conditions. Therefore the cost-benefit analysis for best-technology actions is expected to yield a very positive balance.

Restoration projects should include evaluation and monitoring schemes, both incorporated in the project budget. Furthermore, establishing a monitoring system has a positive feedback effect on the quality of the restoration project design.

Social awareness and technology transfer

Intrinsic complexity of desertification processes and a sociocultural difficulty in assuming problems that have long-term consequences are major factors hindering the establishment of prevention and mitigation measures. On the other hand, there are some features related to desertification processes -drought, floods and forest fires- that have contributed to increase social awareness about the problem.

The scientific community should be encouraged to continue to generate and disseminate information, and to create awareness of the environmental problems associated with land degradation and desertification. Information and environmental friendly methodologies should be provided to people affected by desertification but especially to those at the local level, who are the most direct1y affected. Collaboration at local level among scientists and stakeholders, and society involvement are key milestones towards successful application of mitigation programs, and therefore should be always fostered.

The huge amount of mitigation experiences all over the Mediterranean countries should be compiled, elaborated, evaluated, and made available to the various sectors involved at the various management levels. The establishment of a network of pilot projects would be a powerful tool to facilitate the dissemination of the best available measures. These exchanges should be channeled through the national structures within the respective National Action Plans to Combat Desertification.

Policy options to combat desertification

(Part of this section is largely based on the outcomes of the project MEDACTION EVK2-CT2000-00085)

The international awareness of desertification as a global problem stems from the World Conference of the United Nations at Nairobi in 1977. However, until the Rio de Janeiro Conference on Environment and Development, in 1992, a formal commitment to combat this threat was not acquired by the United Nations.

The UN Convention to Combat Desertification in the countries affected by severe droughts and desertification, particularly in Africa (UNCCD), was adopted in 1994. In order to ensure its adaptation to the socio-economic, geographic and climatic factors of affected countries, the Convention was structured in four Regional Annexes: Africa, Asia, Latin American and Caribbean, and Northern Mediterranean. On October 2001 a fifth Annex for Eastern and Central Europe was established.

The UN Convention to Combat Desertification (UNCCD) encourages governments to enact enabling legislation and to develop appropriate institutional frameworks helping their populations to mitigate desertification. The Convention obliges the signatory parties to prepare and implement National Action Programmes (NAPs) and Regional Actions Programmes (RAPs), assessing the present state of desertification in the country and the broader geographic region, outlining a strategy for mitigation and providing guidelines towards this purpose.

From the start, the Annex IV (Northern Mediterranean) countries, Greece, Italy, Portugal, Spain and Turkey work on building and applying their National Action Programmes, in which desertification factors and mitigation measures, political, technical, legal and fiscal are identified. In the same way, Annex IV countries cooperate in the preparation of a Regional Action Programme by defining its terms of reference, harmonising their activities, fostering pilot project and setting up information networks

A large number of existing EU Policies and policy initiatives (see Table 9) impinge on the bio-physical as well as socio-economic conditions of member states already, that may be contributing directly or indirectly, positively or negatively, to land degradation and desertification in these countries. At the same time, the National Action Porgrammes (NAPs) of the four Annex IV member states are linked to, depend variously on, these EU policies (e.g. CAP, regional policy,.) for their implementation.

Therefore, the EU needs, on the one hand, to tune its policies to the purpose of combating desertification in the affected regions within its territory and, on the other, to provide an enabling policy environment to support making strategic, coherent and coordinated (horizontally/sectorally and vertically/spatially) decision with respect to desertification, as well as facilitate their effective implementation. It might be done by the formulation of explicit desertification European policy that synthesizes and coordinate existing policies to contribute to control land degradation and desertification.

Some recommendations to formulate and implement a successful desertification policy are the following (Thornes and Burke, 1999; Briassoulis, 2003; Rubio 2003):

Integration across sectors and spatial levels

One of the crucial problems facing the EU is that it has to formulate policies concerning land degradation, in such a way that their effect is compatible with, and can safely and efficiently be applied to, a wide range of national, regional and local circumstances. These circumstances in turn reflect a conjunction of phenomena operating at very different spatio-temporal scales, scales which are inherent in the wide range of dynamics involved. Many instances of land degradation are the result of the fact that decision-making structures, and/or the policies which they formulate and implement do not map very well onto the territories of the natural and socio-economic phenomena they concern. Decisions made globally can have a deep disruptive impact locally. To avoid, reduce, limit and mitigate land.

Table 9: European Union policies related to desertification

Economic policies
- Monetary policy
- Fiscal policy
- Other macro-economic policies (trade policy, competition policy, technology and standardization policy)

Regional development policies
- Community Structural Funds (ERDF)
- Cohesion Fund (CF)

Transport policy
CTP – Common Transport Policy and the TENs (Trans-European Networks)

Spatial policy
No Common spatial policy – only the European Spatial Development Perspective (ESDP)

Tourism policy
No Common Tourism Policy
Policy initiatives in other areas affecting tourism (transport, competitiveness, culture, etc.)

Social policies
- General welfare policy
- Employment/labour policies
- Poverty and social exclusion policies
- Social security/Pensions policy
- Health policies
- Education policy
- Migration policy (not formulated yet)

Horizontal environmental policy
- EAPs, EEA, Research programmes
- Environmental Impact Assessment Directive (CD 85/337/EEC, CD 97/11/EC)
- Freedom of access to information on the environment (CD 90/313/EEC)
- Standardizing and rationalizing reports on the implementation of certain directives relating to the environment (CD 91/692/EEC
- EC legislation on voluntary schemes (eco-auditing, eco-labeling, etc.)
- Integrated Pollution Prevention and Control Directive (IPPC)
- Strategic Environmental Assessment Directive (SEA) (CD2001/42/EC)
- Environmental levies (taxes and charges)

Forest policy
No Common Forest Policy
Regulations in other policy areas relevant to the forest sector (e.g. agriculture/CAP, biodiversity protection, trade, etc.)

Rural development policies
- Common Agricultural Policy (CAP)
- Agri-environmental regulations
- Rural development programmes (LEADER, etc.)

Water resources policies
- European Water Framework Directive
- Protection and management of the NATURA 2000 freshwater sites

Biodiversity protection policies
- Habitat and Birds Directives and NATURA 2000 network
- European Landscape Convention
- Other Directives related to biodiversity
- Directives for other sectors that relate to biodiversity (e.g. agriculture)

Soil protection policies
No Common Soil Policy
Various measures (crop rotation, fallow, terracing, economic incentives, NATURA 2000 habitats, agri-environmental measures, soil erosion monitoring programmes)

Source: Briassoulis, 2003

degradation and desertification we need to adapt both research and policies to the many variable scales at which socio-natural landscape dynamic operate. It is important to consider desertification as an issue involving the whole of society. More recognition should be given to the importance and responsibilities of all social sectors involved in the study and control of the desertification processes. Efforts should be made to ensure transfer of ideas and information between these sectors. It is also important to develop regulations at the owner level that lead to the restoration of inadequate agro-forestry, urban and recreation uses of the land.

Coordination of efforts and activities as well as cooperation among competent organizations, communities and other stakeholders

Collaboration and co-operation between European organisations and institutions should be established in order to promote initiatives concerning joint programmes, financial aspects and technology transfer for developing pilot research projects of soil degradation processes. It should be proposed to the Commission of European

Communities the support of research programmes and projects and the establishment of a network for exchange information, technology and scientific knowledge on land degradation processes.

Participation of local population, the scientific community and non-governmental organizations in decision making

In applying the research results to policy formulation and the implementation of the policies, much more attention must be paid to the people at which policies are aimed. While there has been extensive investigation of the physical properties of land degradation, there is still considerable gap with respect to specific ways of measuring the socio-economic aspects of desertification. This has profound consequences with respect to policy formulation and implementation. The need for integrating socio-economic and environmental factors must be emphasised in developing recommendations aimed at combating desertification processes. The use of a mixture of participant observation, unstructured interviewing and more structured elicitation techniques is essential to developed the policies. It is essential that the end-users of the policies be fully informed of the alternatives and their consequences.

Long-term orientation, congruent with the promotion of sustainable development in affected areas.

Successful programmes to check desertification should encompass all the complexity of this problem, including its physical, ecological, sociological and economical components. Moreover, they require reliable instruments of diagnosis and forecast, allowing for the application of the right treatments at the right places.

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SOIL EROSION

Task Group 7 on
MONITORING SOIL EROSION IN EUROPE

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Executive Summary and Recommendations

- Monitoring soil erosion should be based on an **indicator based approach**.

- The **area at risk of soil erosion** is proposed as an indicator of **state** of soil erosion. The indicator should be derived from:

1. An assessment of soil erosion risk derived from an appropriate tool (e.g. an erosion model);

2. Measurements of actual soil erosion rates (t/ha/y) at a limited number of sites.

- A risk assessment tool/model is needed for the following reasons:

1. Selection of measurement sites (plots and catchments): selected sites should have a moderate to high erosion risk and be representative for an agro-ecological zone;

2. Interpolation of results from local measurements to larger areas: to assess the state of soil erosion in areas where no measurements have been done while accounting for local conditions of the factors affecting soil erosion;

3. Scenario analysis: to predict soil erosion under different land uses and/or climate change.

- At a European level, the use of a unique methodology is recommended in order to get comparable results. The use of national or regional assessments may be useful to verify the result of a European model (and vice versa).

- In order to produce reasonable results, modelling requires:

1. Input data;
2. Calibration and validation.

- The **input data** for a soil erosion model consists of static and dynamic data.
    - Static data are to be determined at the start of the monitoring process (no further monitoring is required), and consist of:

        - Soil data;
        - Topographical data.

The accuracy requirements of these data depend on the type of model and the scale of the modelling (European or national/regional). More details are given in the report.

- Dynamic data requiring specific monitoring:

- Land use and land management data;
- Climatic data.

The accuracy of these input data will largely determine the quality of the resulting indicator, e.g. its ability to show the effects of local management interventions resulting from policy measures (action driven monitoring). Different data collection methods are discussed in the report. The recommended time interval for the measurement of land use data is once in ten years. For climatic data, long term averages are necessary.

- Calibration and validation requires **measurements of actual soil erosion rates (monitoring sensu stricto).** We recommend that first use should be made of existing sites and only in cases where existing data are not sufficient should additional sites be selected.

- Measurement should be carried out at the plot scale and at the catchment scale (nested approach). At the catchment scale a combination of methods can be used, as discussed in the report:

    - Mapping visible erosion features;
    - Continuous measurements of sediment transport at the outlet of small catchments;
    - Measurements of sediment deposition in ponds and lakes.

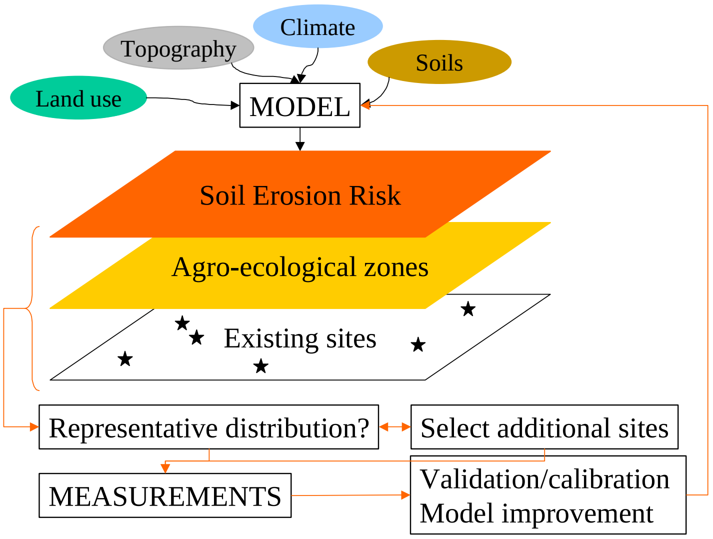
As soil erosion is highly variable in time and space, soil loss measurements should be continuous. From these long term measurements, averages can be determined, e.g. over a period of 10 years.

- **Actions to be taken** to set up a European soil monitoring system are:

1. Use existing measurement data on soil erosion and apply existing risk assessments tools (models) using the best available input data to identify areas at high or moderate risk of soil erosion. These data should provide the **baseline (t_0);**
2. Make an inventory of existing measurement sites;
3. Check whether existing sites are representative with respect to soil erosion risk and within agro-ecological zones;
4. Select additional sites if necessary;
5. Start collecting new data at all sites (e.g. over a period of 10 years);
6. Validate and calibrate the model using the collected data;
7. Improve model concepts;
8. Produce new model output: these data should provide the first trend in soil erosion (**t_1-t_0**) with respect to the baseline (e.g. t_1-t_0 = 10 y);
9. Select additional sites if necessary.
10. …

The process should be seen as an iterative one, which can be visualised as follows:

Practical methodology using modelling and measuring: an iterative process



- In areas susceptible to salinisation and sodication, monitoring of the following parameters is recommended:
  - Electrical conductivity as an indicator of salinisation; and
  - Sodium Adsorption Ratio (SAR) as an indicator of sodication.
- Monitoring on site impacts of soil erosion and salinisation/sodication requires the monitoring of soil quality indicators. A list of potential parameters is given in Table 1. However, these parameters and data are less relevant at a small, e.g. European, scale but are more relevant at large, e.g. regional or local, scales.

Introduction

In this report, emphasis is put on monitoring the state and trends of soil erosion in Europe. However, the proposed methods also allow for monitoring pressures (through land use) and impacts. Provided that measurements are carried out at a sufficiently large scale, the effects of specific land use and management practices, i.e. the responses, can also be monitored (i.e. action driven monitoring).

1. Overall approach

Monitoring trends of soil erosion by measuring actual soil loss requires a relatively high input of financial and human resources compared to soil physical, chemical or biological properties, because soil erosion events are highly variable in space and time. Peaks of soil erosion events differ from place to place and from year to year. Therefore, the monitoring of soil erosion in the field requires:

a) installations which are managed year round and sampled continuously;

AND/OR

b) a strict and frequent sampling scheme of measuring different sites at the same time.

Both methods have advantages and drawbacks, especially in terms of accuracy. In both cases, it is clear that the monitoring of soil erosion is very expensive and technically complex.

Consequently, the number of sites for monitoring *sensu stricto* has to be limited, and an **indicator based approach** is suggested. The actual area affected by soil erosion is the best indicator of state (Gobin et al., 2003). The area at risk is an important surrogate indicator, and can be estimated using an appropriate tool (model), together with the necessary spatial data sets to define the boundaries of these areas. Trends in soil erosion can be estimated from periodic estimates. This implies:

- the choice of a good model;
- high quality input data; and
- testing and validating the model at carefully selected erosion monitoring sites.

The recommended scale for the modelling is 1:250,000. The model should be able to simulate scenario's of soil erosion under changing climatic conditions and, most importantly, under different land uses and land management practices leading to changes in vegetation cover.

In summary, the Working Group on Soil Erosion proposes an **indicator based approach**, combining an **assessment of soil erosion risk** at a European and national scale with **measuring actual soil erosion rates** at a limited number of representative sites (= monitoring *sensu stricto*).

2. Choice of a model

The proposed indicator of state to support a European soil protection policy, i.e. the area at risk of soil erosion in Europe, should ideally be determined by means of a unique methodology. The main advantage is that model results will be at least comparable and of relative value. The accuracy of the result will mainly depend on the accuracy of the input data (see point 3). A second constraint is the ability of the model to account for soil loss by processes such as gullying, landslides, snowmelt erosion, wind erosion, tillage translocation, sub-surface erosion, etc., which are often of high local relevance.

In order to cope with the assessment of soil loss by different processes in different regions, several options exist:

i. Combining different soil erosion processes in one model and developing a single soil loss map at a European scale.

This is the most ambitious, but also the most complex option. The option is not realistic at the short term, given the current knowledge gaps on the potential interactions of the many different soil loss processes. Even at the long term, the feasibility of such approach can be questioned.

ii. Developing individual models and maps at a European scale for the most relevant soil erosion processes.

This option is more realistic, however not currently available. It could be considered as a research priority on a short to medium term time scale.

iii. Carrying out a **'qualitative expert assessment'** of a currently available European soil erosion map, such as produced by the PESERA model, allowing the identification of areas where predictions of the model at a European scale over- or underestimate soil losses due to the fact that specific erosion processes are not taken into account or for any other reasons. This type of 'practical validation' can be based on a comparison with national and sub-national maps (using models/methods that deal with locally relevant soil erosion processes) and on local expert knowledge of the terrain.

This option is strongly suggested by the WG on Soil Erosion, as it makes the best use of currently available technologies at the European scale, and is the most feasible at the short term. Acknowledging national modelling efforts and local expert knowledge will also increase the positive involvement of Member States in the Soil Strategy.

The WG on Soil Erosion forbears from promoting a specific model, and refers to the report on WP2 'Nature and Extent of Soil Erosion in Europe', where several approaches are discussed. However, we recommend the three most recent approaches for further consideration, i.e.:

- the USLE approach;
- the INRA approach;
- the PESERA approach.

Of these models, PESERA is the most conceptually appropriate because it takes into account:

1. Runoff and eroded sediments separately, which are the two main components of the global erosion process;

2. Daily frequency distribution of rainfall, month by month, which allows the model to account for both regular and exceptional events;

3. Dynamics of crusting and vegetation cover month by month;

4. Other climatic information such as freezing days etc., that in part determine for snow effects.

Other models, such as USLE and INRA do not take these aspects into account. Hence, the PESERA model seems a promising tool for decision-making in Europe. The WG on Soil Erosion acknowledges that modelling needs to be improved, both conceptually to account for different soil loss processes and by increasing the accuracy of input data. It is expected, however, that this will continue to progress very fast.

3. Data needs

3.1 Land use data and land management data (vegetation cover)

Vegetation cover is considered as the most important parameter for policy making purposes, as this is the only parameter that will be directly affected by a policy. It is acknowledged that modelling changes in soil erosion rates due to changing land use and land management requires information at a national or even regional scale, and down to the field parcel level. However, a Pan-European dataset meeting these requirements of spatial resolution and accuracy only exists for agricultural land under Community aid schemes. At present, a combination of several existing data sources, as proposed by the members of the WG on Soil Erosion, may lead to the compilation of such a dataset covering the entire land surface of Europe. The main data sources or data collection methods are:

3.1.1 Data collection methods

- **Remote sensing at a European scale**

The best available data source is the CORINE land cover project, but both the temporal and spatial resolution are problematic. Updating the data is time consuming and very costly, and therefore limited to a frequency of about 10 years. The first CORINE project dates from 1990, from which the European land cover database is derived, with up to 44 land use classes. The European land cover database is currently being updated by the joint ‘Image 2000 and CORINE land cover 2000’ project. The result is a general picture of broad land use classes as observed in a particular year. Within arable land, for instance, no distinction can be made between different crops, nor can land management practices be identified. Hence, this dataset can be used to derive a soil erosion indicator for European policy makers, revealing general trends in soil erosion due to land use change over a longer period, but not dealing with local management interventions (Gobin et al., 2004). This could partly be overcome by correcting the CORINE land cover database with other data sources, e.g. agricultural statistics (census data) or agricultural parcel data collected for area payments under the CAP (see below).

Using remote sensing technologies for monitoring vegetation cover resulting from a specific land use and land management requires a very high spatial and temporal resolution, as well as considerable field-verification/ground-truthing. As an example, at least three coverages per year would be needed in order to distinguish between different crops. Such an intensive monitoring scheme is not realistic for the whole of Europe, but could be carried out for selected representative areas. The results could then be extrapolated both in time and in space, requiring crop growth models for temporal extrapolation and the subdivision of Europe into agro-ecological zones for spatial extrapolation. Agro-ecological zones are soil erosion zones characterised by specific climatic and environmental conditions, and by typical forestry and agricultural production systems, including pasture. In such agro-ecological zones, which may cross national borders, soil loss is caused by a given set of processes and can be attributed to certain climatic and environmental conditions and human influences. The development of such a map has been recommended by the WG on Soil Erosion as a priority research topic.

- **Agricultural statistics and census data at national and European level**

In all Member States, information on land use is obtained each year from the annual agricultural and horticultural census, where farmers are asked to fill in a questionnaire asking for a range of information. The data are not geo-referenced, but collected at the farm level so can be located in a particular municipality, catchment, etc. Whilst giving an idea of the extent to which certain crops are grown and a rough idea of regional trends, it will not provide the data to field scale. Moreover, information may be collected at different levels of detail in different countries. Especially, data on land management and specific erosion control measures are often not recorded (e.g. Austria, UK, Belgium…). In Switzerland, farm census data were used to develop a soil cover indicator at national level every 4 years, describing soil cover intensity by crops during the year and the use of soil-protecting tillage practices with reduced intensity (linkage to USLE soil use and management-factors C and P).

At the European level, the nomenclature of territorial units for statistics (NUTS) provides the means to spatially present agricultural statistical survey and census data. These data cover all Member States and include information of crop type and area, farm size, farming income, crop yields, livestock type and number at the NUTS 2 and 3 levels (i.e. regional level). The last available datasets are from 1997 and 1998 (Gobin et al., 2004). The compilation of European land use statistics through this means could be of more use if data were provided at the local, i.e. NUTS 4 and 5 levels.

- **Agri-environmental programmes**

In several Member States, information on land management and specific erosion control measures is collected through agri-environmental programmes, e.g. the Austrian programme for an environmentally sustainable agriculture (ÖPUL). This may be an important complementary data source. In Norway all farmers receiving subsidies provide information about their production systems (crops, tillage, yield etc) and management methods on farm and field level. Subsidies are given for reduced soil tillage, sedimentation ponds, vegetative bufferzones, changing cereal area into permanent pasture, repairing hydro-technical equipment. Therefore data information is collected at the field level and stored in a database, allowing trends in agricultural practices related to erosion to be identified.

Alternatively, much information will be required at the farm level for compliance with the new CAP requirements and with various other regulations and Directives. In England, the Government is developing a new computer-based system, called the Whole Farm Appraisal, which will contain information on actual practices such as reduced tillage, livestock management, etc., and is also likely to include details of practices that farmers are carrying out to meet cross-compliance requirements under the CAP. However, this will not be introduced fully until after 2007.

- **Geographical databases on land use (and land management) on an individual field basis collected for area payments under CAP regulations**

In all EC member states, detailed information on vegetation (crop) cover is available on an individual field basis as defined by the Council Regulation (EEC) No 3508/92 of 27 November 1992. This regulation established an Integrated Administrative and Control System (IACS) for Community aid schemes. Land Parcel Identification System (LPIS) represents a key component of the IACS, used by authorised institutions for the administration and control of subsidies in agriculture. LPIS is based on the spatial identification and registration of so-called production blocks, which are defined as continuous areas of farming land delimited with relatively stable natural borders. LPIS national databases contain main attribute classes that include a unique parcel number, area, crop type and details of aid applications. Airborne images in the form of digital orthophotos and vector boundaries identify agricultural land parcels.

- **Using a sampling scheme and extrapolating data to larger areas**

In Norway, a grid system (3 x 3 km²) is used to monitor the change in agricultural landscape, producing statistics on national and county level with a 5 year time interval (i.e. the time needed to cover the whole country). At grid points hitting agricultural land, aerial photographs are taken from a 1 x 1 km area, with the grid point as a centre. Land use and landscape elements (stone walls, farmer roads, waterholes etc) are identified on the pictures and the information is stored on a database. Each year, 10 % of the plots are visited in the field to calibrate the interpretations. A similar system is under development for the monitoring of landscape quality, biodiversity and cultural landscape elements. From each grid in an 18 x 18 km net, aerial photographs are taken (1 x 1 km plots). The programme will produce statistics about all Norwegian nature and landscape types.

- **LUCAS**

See under point 5.

3.1.2 Proposal

Several examples were provided by the members of the WG on Soil Erosion, illustrating how the above mentioned data sources on land use are combined to produce a national or sub-national dataset. Some initiatives:

✓ In Germany, a soil cover indicator was derived from the Corine land cover database, corrected with statistical data from the Main Representative Survey to assess the actual erosion risk on a regional scale (Erhard et al., 2003).

✓ In Norway, orthophoto's are used to update RS land use maps at the scale of regional projects.

A homogeneous Pan-European dataset could be obtained by compiling national datasets, but problems with comparability of land use classification systems between countries may arise, and standardisation will be a prerequisite. *This approach would, however, be very resource intensive and it is questionable whether it is necessary to gather detailed information on both land use and land management for the whole of Europe.*

An alternative, perhaps more efficient, approach has been proposed by the German Federal Institute for Geosciences and Natural Resources in its Final report (Task 6) for the 1999 subvention to the European Topic Centre on Soil (Düwel and Utermann, 1999). Figure 1 summarises the proposed approach.

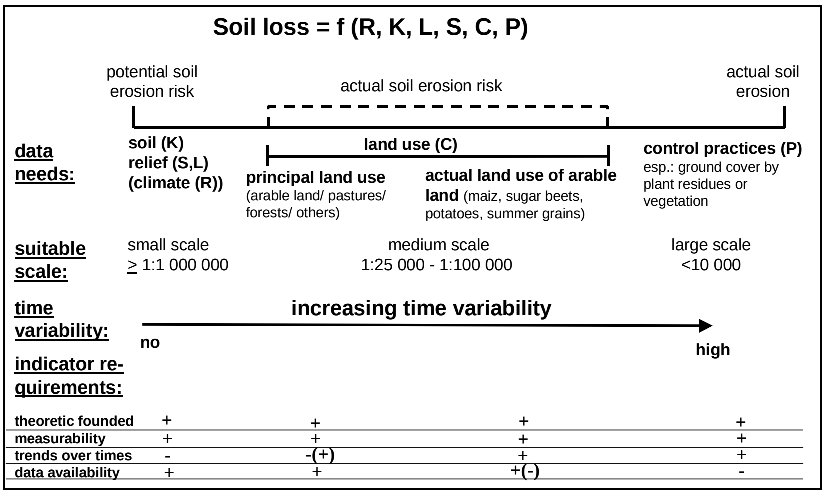


Fig. 1: Indicator based approach for monitoring soil erosion

Following this approach, the **first step** should be to identify areas with a high potential of soil erosion risk with regard to soil erodibility and relief. The **second step** is to identify areas where there is a high risk of actual soil erosion, taking into account the principal form of land use (e.g. arable land). A **third step** is the monitoring of ground cover in these high risk areas, derived from actual land use and control practices (or land management), allowing an assessment of the state of soil erosion by water through modelling.

It should be possible to meet the data needs for the first and second step (soil erodibility, relief and principal form of land use) at a **European level**. Data on ground cover, based on land use and land management is only needed for **high risk areas**, so efforts can be considerably reduced. This implies the suggestion that 'action-driven' monitoring is should be limited to high risk areas.

3.2 Meteorological data

For the PESERA model, data are needed for the following meteorological parameters:

- ✓ Mean daily rainfall;
- ✓ Daily potential evapotranspiration;
  - ✓ Daily minimum and maximum temperature.

These data are needed at a resolution of 10 km x 10 km. They are currently best available at national scale (more accurate than MARS data). These national data then have to be compiled at a European scale.

3.3 Topographic data

Modelling soil erosion at a European scale requires a DTM with a recommended resolution of 250 m. The currently available DTM has a spatial resolution of 1 km, from the EROS database in the USA (Gobin et al., 2004).

3.4 Soil data

The European Soil Information System (EUSIS) provides a harmonised and spatial coverage of soil types and descriptions, based on FAO nomenclature, at 1:1m scale (ca. 1 km x 1 km) in all European participating countries. The database enables spatial data queries, data extraction and thematic mapping (Gobin et al., 2004).

A minimum dataset needed for soil erosion modelling at a European scale consists of:

- ✓ Surface texture;
- ✓ Soil depth;
- ✓ Soil type.

This information should be available at a scale of 1:250,000.

For this purpose, the harmonisation of existing soil databases at regional, national and European levels, and the compilation at a 1:250,000 scale, are necessary. For parts of Europe, soil information is available at this scale. In some Member States, however, major soil mapping efforts will be necessary, given the limited amount of available soil data and the coarse scale of available soil maps. New mapping initiatives have to be carried out according to a standardised method and legend. This reveals the urgent need for co-ordination at a European level. At present the European Soil Bureau Network is co-ordinating the efforts to improve EUSIS. The WG on Soil Erosion strongly suggests the whole process of data collection and harmonisation be steered by the European Commission.

The accuracy requirements of the soil data depend on the type of model and the scale of the modelling (European or national/regional). More detailed soil information may be required at larger scales. In Germany, for example, the ad hoc working group “Permanent Soil Monitoring of the Joint Federal States Working Group for Soil Information” recommends a number of parameters for consideration by the Länder when installing and operating permanent soil monitoring sites in Germany, based on a stratified approach (selecting representative sites, unlike using a grid). In its report “Permanent Soil Monitoring, Installation and Operation of Permanent Soil Monitoring Sites" (Barth et al. 2000), the following mandatory and optional parameters are proposed:

- Mandatory physical soil parameters:

- ✓ Grain size distribution (i.e. soil texture)
- ✓ Bulk density
- ✓ Solid substance density
- ✓ Pore size distribution
- ✓ Saturated hydraulic conductivity (Ks) - laboratory measurements

- Optional physical soil parameters:

- ✓ Unsaturated hydraulic conductivity (Ku) - laboratory measurements
- ✓ Hydraulic conductivity (Ks and Ku) - field measurements
- ✓ Penetrometric (or cone) resistance
- ✓ Aggregate stability
- ✓ Soil-water content, volumetric
- ✓ Soil-water tension

- Mandatory chemical parameters of the soil solid phase (selection):

- ✓ C_{tot}, C_{org}

In the WG on Soil Erosion, the measurement of aggregate stability is strongly suggested by some members, while others are rather sceptical and propose to explore the possibility to use pedotransfer functions to derive this parameter from basic soil parameters. The advocates of measuring aggregate stability point to the fact that (i) it is an integrative soil property which combines the effect of texture, mineralogy, OM amount and quality, salinisation and/or sodication, etc., and (ii) it is directly related to soil crusting (and resulting reduction in infiltration) and erodibility, so it is able to reflect both short term and long term changes of soil influence on erosion. According to them, aggregate stability is the easiest way to monitor the effect of land use and management on soil sensitivity to erosion. Some members suggest this parameter is measured on arable lands in “seedbed” condition, which corresponds to the condition of maximum vulnerability of soil to erosion. The main arguments of the opponents are (i) the high spatial and temporal variability of this soil property, (ii) the important differences that are found when determining this parameter with different methods, and the difficulties that will arise in any attempt to find a unique determination method that is widely accepted.

Also, for erosion in areas covered with snow and where the soil is frozen during the year, aggregate stability is an important factor related to soil erodibility. Compared to areas without frost and snow it seems that aggregate stability has an even stronger seasonal variation. Therefore, there is a need for agreement both on methods for aggregate stability-rainfall erosion and on methods for aggregate stability-snowmelt erosion. Methods used for determination of aggregate stability should therefore also include determination of aggregate stability during winter period (this is a research gap).

Furthermore, the WG agreed that hydraulic conductivity and bulk density are also useful parameters to help identify soil compaction problems (which results in an increased erosion risk).

4. Monitoring soil erosion *sensu stricto*

Within the proposed 'indicator based approach', measurements of actual soil erosion rates are essential to calibrate and validate the model used for assessing soil erosion risks in Europe. A model can only produce sensible results when it is properly calibrated and validated in the region where it is applied, and when accurate input data are available. On the other hand, measurements of actual soil loss provide the best indicator of soil erosion in a certain area. Depending on the measurement methods used, one can obtain state indicators and/or impact indicators. State indicators may reflect both the severity and the extent of soil erosion. Provided that the measurements are sufficiently representative, values can be extrapolated to the agro-ecological zone in which the measurements have been carried out, providing an alternative for model assessment. In summary: measuring actual soil loss is not only important for calibrating and validating models, but also has a very important value in itself.

The Working Group on Soil Erosion strongly suggests that maximum use should be made of existing sites which are continuously but independently being set up by different research groups in Europe but without any co-ordination at a European level. **We recommend that first, use is made of existing data and only in cases where existing data are insufficient should additional monitoring be carried out.** Efforts need to be made to see whether the different methodologies used in the different countries allow the comparison of the results at a European level, or whether the data only have a value at a national/regional level.

Measurements of soil erosion rates are suggested at two levels: at the plot scale and at the catchment scale. A **nested approach** is recommended, i.e. plot sites should be preferably located within the geographical boundaries of the monitored catchments.

4.1 Measurements at the plot scale

Measurements at the plot scale provide point data and are not suitable for providing information on the extent of soil erosion at national scales, given their poor spatial representativeness. However, fully instrumented plot sites are useful for studying the processes causing soil erosion. Long term datasets of soil erosion measurements at plots in different agro-ecological environments may be used to test model concepts. For instance, the equations of the PESERA model have been calibrated on such measurements (Gobin et al., 2004).

For erosion processes where European models still have to be developed, e.g. snowmelt erosion, input from plot scale measurements is absolutely vital for development, calibration and validation. Also, for studying the effects of climate change on soil physical parameters related to erosion, the plot scale is necessary.

With regards to soil erosion monitoring at the plot scale, there are two projects currently on-going within Europe. The projects, SOWAP and GECAP, are collaborative between EU-Life Environment, academia, NGOs and industry, and cover Spain, Southern France, Italy, UK, Belgium and Hungary, with further sites to be constructed this year in the Czech Republic and Northern France. The projects not only measure erosion under conventional practice but also investigate options for soil and water conservation. More information can be found at www.sowap.org.

4.2 Measurements at the catchment scale

Measuring soil loss at the catchment scale can be done by one, or ideally a combination, of the following methods (explained below):

- Mapping visible erosion features;
- Continuous measurement of sediment transport at the outlet of small catchments;
- Measurement of sediment deposition in ponds, lakes or reservoirs.

An important issue is the selection of catchments where the measurements will be carried out. As already stressed, use should be made of existing sites. However, a representative sample should be obtained for the whole of Europe. In theory, the selection of catchments or test regions could be based on the best available soil erosion risk map for Europe, and on a map with agro-ecological zones (to be developed for Europe). A representative sample of test areas (catchments) would mean that all agro-ecological zones are represented by at least one test site, depending on the size of the zone, and on the variability of landscapes within an agro-ecological zone. Moreover, the selected areas should be characterised by a moderate to high erosion risk. In Switzerland, for instance, such an approach has been adopted to select a maximum of 10 test regions in which detailed model calculations and mapping of erosion damage will be carried out. As Switzerland has a total area of 41,284 km², this means a density of about 1 test area per 4,000 km², whereas the density with respect to the area at risk of soil erosion will be even higher. In Norway, a programme for monitoring erosion and water quality was established in 1992. Soil erosion and the loss of nutrients are monitored in 10 small watersheds dominated by agriculture. In six areas the amount of pesticides in the water is also monitored. In Spain, the Experimental Erosion Monitoring and Evaluation Station Network (RESEL), set up in 1995, is aimed at monitoring erosion and hydrological processes in a network of stations representative of erosion landscapes of greatest interest in the Spanish territory (a total of 40 experimental catchments and plots). This network intends to establish a database at the national level in relation to erosion processes, hydrological cycle and water quality, which enables real data to be used to design preventive actions and use and management plans in areas liable to desertification.

However, it is likely that the main driver for erosion monitoring will come from the Water Framework Directive (WFD). Such monitoring will be conducted on a catchment basis but only in those catchments where soil erosion is identified as being responsible for the decline in biological and chemical water quality. Catchments where soil erosion is a pressure will be identified on the basis of historical local knowledge from inspections of water bodies, water quality data and risk assessment. The WG on Soil Erosion is convinced that, if our goal is to protect the soil and not just the water, the method for catchment selection described above should be adopted.

- **Mapping visible soil erosion features**

The mapping of visible soil erosion features allows for a relatively reliable assessment of severe (linear) erosion forms and sedimentation, whereas sheet erosion can only be estimated. However, to quantify these features it needs to be performed at a sufficient temporal resolution. One inspection per year is certainly inadequate, but seasonal inspections based on timing of agricultural management practices could provide a detailed picture. At the same time, data about land use and land management practices in the catchment should be monitored.

A very nice example can be found in Switzerland, based on 7 years experience with soil erosion damage mapping. Mapping of the test areas is normally carried out four times a year:

✓ in spring before tillage, for soil erosion occuring over winter time;
✓ in early summer after tillage and drilling, for soil erosion under low vegetation cover;
✓ in late summer, for soil erosion after thunderstorms;
✓ in late autumn after drilling of winter-wheat.

For each erosion rill, its length, mean width and mean depth are surveyed and the volume of soil loss determined. In case of interrill erosion, the percentage of damaged area per field is assessed and quantified by using results for soil losses from field measurements. Additional information concerning off-site damage, water inflow and wheel tracks is also registered and stored in a data base. Furthermore, the monitoring programme also includes interviews with farmers every 5 years.

A comparable methodology exists in Germany (DVWK, 1996). In Lower Saxony (Germany), mapping in selected catchments is carried out at the end of each winter as well as an additional survey after an important soil erosion event. The mapping includes not only the various erosion forms but also vegetation and special protection measures as well as questioning farmers in the region.

In Norway, the Agricultural Environmental Monitoring Programme (JOVA) combines soil erosion mapping with monitoring water quality at the outlets of selected agricultural catchments. Water quality measurements include nutrients, pesticides and suspended solids as a measure of soil erosion. Geo-referenced information on crop type and farming activities is available at the field parcel level on an annual basis, as provided by the farmers. Mapping of visible soil erosion features is performed by visiting each field after the winter season and after heavy rainstorms causing erosion events during the year. For each erosion rill, its length, mean width and mean depth are surveyed and the volume of soil loss determined (similar to the example from Switzerland). Because the same fields are visited each year it is possible to relate erosion features to farming practices and to the location in the catchment. The combination of sediment measurements at the outlets of catchments, detailed farming information at the field scale, and the erosion mapping in the same catchments, provide a monitoring system that allows the identification of erosion sources and forms, the extent of erosion and the effects of management practices. More than 10 years of erosion damage mapping exists.

An advantage of mapping is the possibility to analyse causes directly in the field, to assess special cases (inflow from roads, exfiltrating subsurface flows, furrows, small slope depressions, failure of hydro-technical equipment etc.), to identify the pathways of eroded material from the field to off-site objects (e. g. surface waters) and to assess off-site damage. A drawback of this method is its strong dependence on weather conditions. Therefore long-term investigations over 10 or more years are necessary in order to make reliable assessments of long-term average soil losses, which can be compared to the results of model calculations. Therefore, mapping can be considered as a resource intensive but very valuable tool. In the example of Switzerland, an experienced surveyor maps a 200 ha arable test area in one day.

This method allows the derivation of a state indicator on both the extent and the severity of soil erosion, as well as a pressure indicator, e.g. on land (mis)-use, and an impact indicator, e.g. on off-site damage. In addition, long term data can serve to calibrate and validate models.

- **Continuous measurement of sediment loads at the outlet of small catchments**

The measurement of sediment loads in streams is a useful tool for assessing the state and impact of soil erosion, as well as for model validation, provided that the data are used cautiously and, if necessary, combined with suitable techniques to trace back the sediments to their origin.

The main uncertainties with linking sediment load measurements with actual soil loss in the field arise from the fact that:

✓ an unknown part of the eroded soil may be deposited on its way to the river; and
✓ an unknown fraction of the sediment originates from the river bed and the river banks (within channel sources).

In addition, processes other than rill and interrill erosion may be responsible for the delivery of sediment to rivers, such as mass movements, gullying, tunnel erosion, etc. In Nordic countries and in the Alps, sediments can also originate from glaciers. Obviously, this has to be taken into account when using sediment load data for validating models.

Estimates of both suspended sediment and bed load are needed. Suspended sediment in most instances is derived from the land, as opposed to within-channel sources, and thus is a relatively good measure of soil erosion. Studies throughout Europe (e.g. Owens et al., 2000) have demonstrated that in rural and agricultural landscapes usually > 50 % and often > 80 % of the suspended sediment load being actively transported by rivers is derived from the erosion of the land surface. It is nevertheless important during any monitoring programme to determine from where the sediment has come from, i.e. its sources, as this will provide vital information on the amount that has derived from soil erosion.

Several techniques exist to measure suspended sediment load and bed load. A lot of data may already exist in the archives of water power and river authorities. Sediment concentration and discharge may be measured using turbidity monitors and automatic water samplers (sediment) and pressure-transducers or gauged sites (discharge). The obvious advantage of monitoring suspended sediment is that it would link to the Water Framework Directive (WFD). As such, monitoring sites, sampling procedures and protocols would follow protocols either already existing within the WFD or currently being developed by the WFD Expert Group on AMPS (Analysis and Monitoring of Priority Substances). In addition, the European Sediment Research Network (SedNet, www.sednet.org) is, amongst other things, reviewing available methods to measure sediment loads in rivers and methods to identify sediment sources.

To obtain a picture of the spatial distribution of the sources of soil loss within a watershed, there are only a few appropriate methods:

- The most straightforward and probably the most reliable, but highly resource intensive, method is mapping visible erosion features, as explained above, and as illustrated by the Norwegian approach.

- Alternatively, the use of environmental radionuclides (for instance caesium-137; ^{137}Cs) are costly and in addition, their accuracy may be a problem. The majority of members of the WG on Soil Erosion agree that these methods should not be recommended as standard methods for monitoring purposes. According to those in favour of the radionuclide approach, there exists some potential to use such tracers to assemble information on erosion rates in different environments and soil types in Europe and as a means to monitor changes in soil erosion through the use of repeated surveys at key sites. A multi-radionuclide approach is to be recommended because different radionuclides provide information on erosion rates over different time periods, such a decades (^{137}Cs) and storm-event (^{7}Be). The use of radionuclides as tracers complements the information obtained by plots and catchment studies, and monitoring of river sediment, and could form part of a nested monitoring approach.

- Another method is sediment fingerprinting. This method has been carried out for the Environment Agency for England and Wales to assess the source of sediments in salmonid fisheries, and in particular to verify whether the sediment is derived from river banks or fields. Such data, whilst useful for identifying sources, is not useful for identifying extent.

- A last option to be considered is the use of a sediment delivery ratio, although many uncertainties exist, which may be worth further investigation in research projects. Research questions might be:

✓ What is a reasonable area of a catchment with regard to costs, reliable measurements and representative results?

✓ What is the correct sediment delivery ratio?

  - this could involve a review of the literature, or
  - comparative measurements of sediment loads and soil losses from fields in the catchment.

  ✓ Is the sediment delivery a sensitive indicator of soil erosion due to land use changes?

(cfr. Final report on Task 6 of the Technical Annex for the 1999 subvention to the European Topic Centre on Soil)

- **Measurement of sediment deposition in ponds, lakes or reservoirs.**

For this approach, the same principles that apply for the interpretation of data on sediment loads in rivers are valid. Sedimentation data from ponds and reservoirs are often used to validate soil erosion models. For instance, Van Rompaey et al. (2003) validated the soil erosion risk map of Italy, based on the USLE (Grimm et al., 2003), using sedimentation records from lakes and reservoirs, provided by the experimental Institute for Soil Study and Conservation of Florence (MiPAF). Also, model results from USLE, INRA and PESERA at a European level were validated with sediment data from reservoirs in Belgium, Czech Republic, Italy and Spain (Van Rompaey et al., 2003b). Recently, the OECD (2001) Joint Working Party on Agriculture and Environment adopted the recommendation to use such data for the derivation of off-farm sediment flow state indicators.

5. Comments on LUCAS with respect to monitoring soil erosion

LUCAS is an EU-wide land use/land cover area frame statistical survey, based on a regular grid of 18 km by 18 km (Bettio and Kayadjanian, 2003). Each year between May and July, about 100,000 sampling points across the EU are visited in order to collect data on land cover and land use, as well as on the environment. In autumn, more detailed information on farming practices is gathered through farmer interviews. The field survey in spring includes the observation of existing 'visible' erosion features at sampling points falling in cropland. The presence of rills and gullies is observed within the so called 'extended observation window', i.e. a circle with a radius of 20 m around the sampling point.

The results of the first LUCAS survey conducted in 2001 show the limitations of this qualitative assessment of soil erosion. No soil erosion was detected at a relatively high percentage of sampling points, and the spatial distribution of soil erosion did not correspond to the generally accepted trends within Europe. Bettio and Kayadjanian (2003) attribute this essentially to the timing of the field work, and acknowledge that modifications and adaptations would be necessary to better respond to the needs of harmonised data at the European level. Nevertheless, they state that LUCAS may contribute to this aim:

- as an existing operational European survey platform on which data gathering on soil erosion could be based, respecting the complex character of soil erosion processes throughout Europe;

- as an ancillary data source of issues closely linked to soil erosion, such as land cover and, by means of the farmer's interview, information on agricultural practices, farmers perception, etc.

Another advantage of LUCAS is that it can be easily extended to any other country, especially candidate countries and provide a standardised assessment of soil erosion.

The Working Group on Soil Erosion acknowledges the potential advantages of LUCAS, but identified the following problems related to (i) its conceptual basis, being an area frame statistical survey, and (ii) the way it is currently assessing soil erosion. Obviously, it is difficult to suggest improvements to the conceptual basis (as shown below), apart from suggesting an alternative approach. In contrast, some of the current modalities could be modified in order to improve the assessment of soil erosion in Europe using LUCAS, as indicated below by the symbol '✐'.

i. Conceptual basis

The observation of soil erosion at point locations and the distribution of the monitored sites according to a fixed grid are inconsistent with the <u>recommendations of the WG on Soil Erosion:</u>

✓ To measure soil erosion in selected catchments, according to a <u>nested approach of measurements at the plot scale and at the catchment scale</u> instead of **point observations** as carried out through the LUCAS survey;

✓ To <u>measure</u> soil erosion in these catchments (by means of the methods listed in point 4.1 and 4.2), in order to obtain a <u>quantitative result</u> (average soil erosion rates) and not just to observe the presence or absence of soil erosion features as prescribed by LUCAS, resulting in a **qualitative assessment** of soil erosion. Moreover, the visual assessment by LUCAS is not able to account for sheet erosion;

✓ To determine the <u>distribution</u> of monitoring catchments according to the best available soil erosion risk map and a delineation of agro-ecological zones for Europe in order to obtain <u>a representative set of test areas (catchments), i.e. by means of stratified sampling</u> instead of a **random distribution of observations** as obtained by the fixed grid of LUCAS, which does not take into account the complex landscape and climate patterns influencing soil erosion processes.

✐*One suggestion to improve the conceptual basis of LUCAS could be to enlarge the 'extended observation window' to an area suited for soil erosion observations, e.g. the (smallest possible) catchment around the observation point. However, the size of the catchment would depend largely on the local topography, with larger catchments in flatter areas where it is less worthwhile to measure soil erosion. This modification would, however, imply the monitoring of about 100,000 catchments (i.e. the number of observation points), not all of which would be useful to increase our knowledge of soil erosion in a particular environment. Hence, a lot of unnecessary measurements would be done, significantly affecting the efficiency of the system. In contrast, a smaller number of representative catchments at well selected locations according to the WG's recommendations would provide a more cost efficient alternative.*

ii. Current modalities

a. The main problem identified is the **fixed time schedule of LUCAS**, implying only one observation of soil erosion per year in spring time, the sites being sampled one after the other. Given that the occurrence of soil erosion is strongly dependent on both weather and vegetation conditions, its temporal distribution is highly variable across Europe, which is characterised by significant climatic and vegetation gradients. Hence, **the identification of soil erosion features strongly depends on the time of sampling, and the current time scheduling of the LUCAS survey may lead to unreliable results**. For instance, at the moment of sampling, the farmer may have just restored damage by ploughing, or soil erosion may occur the day after sampling, etc., so no visible signs of soil erosion would be detected. In contrast, the WG on Soil Erosion recommends a <u>high temporal resolution of measurement, i.e. high frequency or continuous measurements</u> (see point 4.2). For instance, when mapping visible erosion features in selected catchments, seasonal inspections based on the timing of agricultural management practices and particular weather conditions would provide sufficient accuracy. The same applies to any monitoring system for soil erosion, also to a grid system.

✐*A potential improvement of LUCAS consists of modifying the time schedule of the field visits, implying a higher frequency adapted to area specific conditions with respect to vegetation cover, farming practices and weather conditions. Consequently, this may involve a different time scheduling for different areas (agro-ecological zones) within Europe.*

b. The LUCAS survey is currently lacking the measurement or description of parameters affecting the soil erosion process, rendering the observation of the presence or absence of soil erosion features meaningless.

✐*A potential improvement of LUCAS would require the measurement or description of relevant (i) soil parameters and (ii) 'landscape' parameters such as slope, slope length, vegetation cover and soil surface conditions (e.g. crusting), and the presence of erosion control measures.*

c. The training of the surveyors in recognising soil erosion features and in understanding soil erosion processes are extremely important. The results of the first survey showed significant operator bias. Surveyors must have the same idea of what 'a soil erosion feature' is.

✐*A potential improvement of LUCAS would require the training of the surveyors in the basics of soil science and in particular in the understanding of soil erosion* *processes and in recognising soil erosion features according to clear definitions.*

d. The information obtained from the farmer interviews concerning land management is often not precise and only covers part of the observation points (about 6 %).

☞ *A potential improvement of LUCAS would require increasing the number and thoroughness of farmer interviews.*

Conclusion

It can be concluded that significant modifications are required to make LUCAS provide a reliable picture and meaningful information on soil erosion in Europe, inevitably leading to increased financial investments. Before deciding to use and therefore to modify LUCAS for soil erosion monitoring in Europe, the cost of the required modifications should be estimated. The advantage of making use of an existing system, already financed by the European Union, may be undermined when accounting for these additional costs.
The question is whether it is useful to allocate more resources to this system, given that, in the opinion of the Working Group on Soil Erosion:

a. its conceptual basis means it is not the best option for monitoring soil erosion; an attempt to improve the concept could render it extremely expensive and inefficient;

b. an alternative concept based on stratified sampling, as proposed by the WG on Soil Erosion, would probably fit better to the needs of a multi-purpose and action-driven monitoring system for soil erosion in Europe in a more cost efficient way.

6. Monitoring salinisation and sodication

In a first step, areas susceptible to salinisation and sodication should be identified. Monitoring should only be carried out in those areas. The following parameters are suggested:

6.1 An Indicator of Salinization

Soil salinity is generally measured on an aqueous extract of a saturated soil-paste by measuring the electrical conductivity, ECs. Because the ECs and the total salts concentration of an aqueous solution are closely related, ECs is commonly used as an expression of the total dissolved salt concentration of an aqueous sample.

In order to determine ECs, a saturated soil-paste is prepared by adding distilled water to a sample of air-dry soil while stirring and then allowing the mixture to stand overnight to permit the soil to fully imbibe the water and the readily soluble salts to fully dissolve. A conductivity meter is then used to measure the electrical conductivity, Ecs.

6.2 An Indicator of Sodication

The *Exchangeable Sodium Percentage* (ESP), represents the amount of exchangeable Sodium expressed as a percentage of the Cation Exchange Capacity (CEC).
The ESP is defined by the relationship:

$$ESP = (exch.Na^{+}/CEC)\times 100$$

The exchangeable sodium is determined by difference from leached Na^{+}, determined using a flame photometer, and the amount of soluble Sodium, determined from the saturation extract.
A useful and easier to measure index for predicting the tendency of an incoming soil solution to bring the soil at a value of ESP in equilibrium with the SAR of the applied solution is the Sodium Adsorption Ratio (SAR), defined by the relationship:

$$SAR = [Na^{+}]/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$$

where all the concentrations are in meq/l. SAR is expressed in terms of ion concentrations rather than of ion activities. The SAR of the saturated extract of the soil can be considered a measurement of the hazard of soil sodication.

7. Monitoring on site impacts

On site impacts of soil erosion and salinisation or sodication may be connected to soil quality and soil functions. Soil quality is an intuitive concept that refers to how well the soil performs its (ecological and human-related) functions, e.g. a soil's filter and buffer capacity, or its production function. Indicators of soil quality are measurable soil attributes that provide a sound basis for assessing the impact of soil erosion on the soil system itself (on site). The WG on Soil Erosion recommends the monitoring of a minimum data set of physical, chemical and biological variables that allows us to quantify soil quality and to derive an on site impact indicator for Europe (Table 1).

For instance, the production function of a soil is certainly damaged by soil erosion. In Mediterranean countries this may even lead to a complete loss of this function and a subsequent abandonment of a site. In temperate regions, however, this is rarely happening. The most important influence of decrease of soil productivity due to erosion that we have determined was not due to decreased availability of nutrients, but a lack of water availability (Strauss and Klaghofer, 2001) due to loss of topsoil. Thus valuable indicators are water holding capacity and rooting depth. According to the slow nature of the soil erosion process, these features could be measured at specified points at intervals of 10 years. However, they can also be used to monitor effects of past erosion on soil.

8. Monitoring air quality

With respect to the impact on air quality, methods are well established to monitor air pollution from particulate matter/dust that could be used to monitor sediments derived from wind erosion. However, due to the largely rural occurrence and unpredictable nature of wind erosion events, it is unclear whether such measurements would be practical or meaningful.

Table 1: Minimum data set of soil attributes for the quantification of soil quality and for the derivation of an on site impact indicator for Europe (García Álvarez et al. 2003; modified from Doran and Parkin, 1994; Larson and Pierce, 1994).

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

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