Soil Erosion Risk in Europe

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FRONTISPIECE:

Soil erosion by water in mid-Bedfordshire, UK, autumn 2000.
The movement of soil is considerable despite the gentle slope of this site.

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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. 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.
2. Soil erosion by water is a widespread problem throughout Europe.
3. The most dominant effect is the loss of topsoil, which is often not conspicuous but nevertheless potentially very damaging.
4. Physical factors like climate, topography and soil characteristics are important in the process of soil erosion.
5. The Mediterranean region is particularly prone to erosion because it is subject to long dry periods followed by heavy bursts of erosive rainfall, falling on steep slopes with fragile soils.
6. This contrasts with NW Europe where soil erosion is slight 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.
7. 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.
8. With a very slow rate of soil formation, any soil loss of more than 1 t/ha/yr can be considered as irreversible within a time span of 50-100 years.
9. Losses of 20 to 40 t/ha in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t/ha in extreme events.
10. The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing and construction activities.
11. 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.
12. In an attempt to quantify erosion at the European level, a series of projects, using modern digital techniques, are being coordinated by the European Soil Bureau.
13. These projects are essentially process-based and use harmonised digital data on soil, topography, climate and land cover.
14. 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.
15. Combinations of these detachment and transport processes give rise to the three main processes of Rainsplash, Rainwash and Rillwash.
16. Runoff is the most important direct driver of severe soil erosion 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.
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 a GIS.
19. A second expert-based approach is the RIVM soil erosion model. It is a factor model, like CORINE, but it is in many ways a more simplified approximation to the imperfect USLE model.
20. A third 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.

21. The Hot Spots map commissioned by the EEA is a fourth 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.
22. The availability of digital data sets in recent years has facilitated application of the model-based approach.
23. 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.
24. A map of erosion risk in Europe, produced using the USLE model, is a first attempt to quantify soil erosion by rill and interrill erosion for the whole continent. The estimated sediment lost has not been validated but relative differences are thought to be real.
25. The PESERA project is developing and calibrating a process-based, spatially distributed model to quantify soil erosion by water and assess its risk across Europe. The model addresses runoff more directly than other process oriented models.
26. The DPSIR framework is proposed for converting the vulnerability of land use systems to degradation by erosion into information that is readily usable by policy makers since it identifies possible responses, and the *off-site* and *on-site* impacts.
27. In the absence of measured data, the area at risk of erosion could be used as an ‘indicator of state’.
28. It is clear that soil erosion is irreversibly degrading the soils in many parts of Europe, sometimes in a dramatic way in southern Europe but also in a less obvious but still damaging way in northern areas.
29. Mitigation strategies must be implemented as part of an overall Soil Protection Thematic Strategy.
30. The existing European Soil Database provides a harmonised basis for broadly identifying the areas most at risk and for examining the processes responsible. However, at present, reliable point data on actual soil loss and its tendency in future are very scarce, particularly in southern Europe.
31. Computer-based models such as PESERA offer some hope for obtaining better predictions of soil erosion than estimates made in the past. PESERA is important in a European context because it is a runoff model and runoff makes the greatest contribution to loss of sediment.
32. However, 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.
33. Nothing less than a continent-wide soil monitoring network will be needed to provide such data. Refining models and improving the resolution and accuracy of spatial data cannot substitute for real measurements.
34. Finally, soil protection requires a multi-disciplinary approach.
35. There also needs to be general acceptance by the public and policy makers alike that society as a whole has been abusing the soil environment in Europe to such an extent that to do nothing in response could spell disaster for the future.
36. Rectification and amelioration for past and present abuses will cost money and the richer countries must help the poorer countries in Europe in this endeavour.

1 Introduction

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), provides an overview of the extent of soil degradation in Europe. Some of the findings are shown in the Table 1.1 but these figures shown are only a rough approximation of the area affected by soil degradation.

Table 1.1. Human-induced Soil Degradation in Europe[1] (M ha)

WATER EROSION	*Light*	*Moderate*	*Strong*	*Extreme*	*Total*
Loss of Topsoil	18.9	64.7	9.2	-	92.8
Terrain Deformation	2.5	16.3	0.6	2.4	21.8
Total:	21.4	81.0	9.8	2.4	114.5 (52.3%)

[1] Includes the European part of the former Soviet Union.

However, Table 1.1 indicates the importance of water erosion in Europe in terms of area affected. The most dominant effect is the loss of topsoil, which is often not conspicuous but nevertheless potentially very damaging. 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 but the much less severe erosion in Scandinavia where the climate is less harsh and the soils are less erodible (Fournier, 1972).

The Mediterranean region is particularly prone to erosion. This is because it is subject to long dry periods followed by heavy bursts of erosive rainfall, 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 in some places erosion has practically ceased because there is no more soil left. With a very slow rate of soil formation, any soil loss of more than 1 t/ha/yr can be considered as irreversible within a time span of 50-100 years. Losses of 20 to 40 t/ha in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t/ha in extreme events (Morgan, 1992). It may take some time before the effects of such erosion become noticeable, especially in areas with the deepest and most fertile soils or on heavily fertilised land. However, this is all the more dangerous because, once the effects have become obvious, it is usually too late to do anything about it.

The main causes of soil erosion are still inappropriate agricultural practices (Figure 1.1 shows the effect of intensive olive cultivation in Andalucia), deforestation, overgrazing and construction activities (Yassoglou *et al.*, 1998). Increasing the awareness amongst scientists and policy makers about the soil degradation problem in Europe is now an urgent requirement.

The identification of areas that are vulnerable to soil erosion can be helpful for improving our knowledge about the extent of the areas affected and, ultimately, for developing measures to keep the problem under control whenever possible.

Figure 1.1. Intensive Olive (5–80 years old) cultivation near Sevilla, Spain.

In an attempt to quantify erosion in Europe using modern digital techniques, a series of projects are being coordinated by the European Soil Bureau with the aim of assessing erosion risk at continental scale. The end product will be the identification of regions in Europe that are prone to soil erosion, with the emphasis on rill- and inter-rill erosion by water. This information is needed for input to a new Soil Protection Strategy for the EU countries, aimed at combating soil degradation. Other forms of soil erosion are also important, for example gully erosion, landslides and, to a lesser extent, wind erosion but these types of erosion will be addressed in future studies, to develop a more comprehensive picture of soil erosion in Europe today.

2 Processes of Soil Erosion

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. High winds can blow away loose soils from flat or hilly terrain. Erosion by water occurs due to the energy of water as or when it falls toward the earth and flows over the surface. Figure 2.1 shows the destruction of the main highway from Milan to the Simplon pass (Switzerland) by floodwaters, 13-16 October 2000. The damage occurred in the vicinity of Domodóssola, Piemonte, Italy, and demonstrates that erosion is far from being just an agricultural problem.

This chapter deals primarily with the processes of soil erosion by water as this is considered to be the most important form of soil erosion in Europe. The summary below of these various erosion processes, and Section 2.1, were prepared by Gobin *et al.* (2001).

Figure 2.1. Destruction of the main highway from Milan to the Simplon pass (Switzerland) by floodwaters, Piemonte, Italy 13-16 October 2000

Over 90% of non-glacial landscapes consist of soil-covered hillslopes, with the remainder being river channels and flood plains. Although soil covered surfaces are not generally the most active part of the landscape, they provide almost all of the material which eventually leaves a river catchment through the channels. The processes by which material is weathered and transported to the streams are therefore vital to an understanding of how the landscape transports weathered debris on hillslopes (the regolith) and delivers sediment to stream channels.

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

Slope sediment transport processes are of two very broad types, first the weathering and second the transport of the regolith. Within each of these types, there are a number of separate processes, which may be classified by their particular mechanisms into groups (Table 2.1), although many of these processes occur in combination. Most slope processes are greatly assisted by the presence of water, which helps chemical reactions, makes masses slide more easily, carries debris as it flows and supports the growth of plants and animals. For both weathering and transport, the processes can conveniently be distinguished as chemical, physical and biological (Gobin *et al*., 2001).

Table 2.1. Classification of the most important Hillslope Processes.

	WEATHERING PROCESSES	*TRANSPORT PROCESSES*	*Type (S/T)*
CHEMICAL	Mineral Weathering	Leaching	S
		Ionic Diffusion	T
PHYSICAL	Freeze-Thaw	Mass Movements	
	Salt Weathering	Landslides	S
	Thermal Shattering	Debris Avalanches	S
		Debris Flows	S
		Soil Creep	T
		Gelifluction	T
		Tillage Erosion	T
		Particle Movements	S
		Rockfall	T
		Through-Wash	T
		Rainsplash	T
		Rainflow	T
		Rillwash	
BIOLOGICAL	Faunal Digestion Root Growth	Biological Mixing (often included within Soil Creep)	T

Types: T = Transport Limited: **S** = Supply Limited removal

An additional 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 down-hill ploughing produces a direct downhill component of movement as the turned soil settles back. Contour ploughing can move material either up and down, according to the direction in which the plough turns the soil. Contour ploughing in which the soil is turned downhill moves approximately 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.

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

2.1 Soil erosion by water

Although a small amount of material is washed through the soil, the more important erosion processes take place at the surface. Material may be detached by two processes, **raindrop impact** and **flow traction**; and transported either by saltation through the air or by overland water flow. Combinations of these detachment and transport processes give rise to the three main processes, **Rainsplash**, **Rainwash** and **Rillwash**, as indicated in Table 2.2

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

Table 2.2. Types of soil erosion by water.

	Transportation	*Mode*
Detachment by	Through the air	In Overland Flow
Raindrop Impact	RAINSPLASH	N/A
Overland Flow Traction	RAINFLOW	RILLWASH GULLY EROSION

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

If water is flowing with sufficient force, it exerts a force on the soil 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 particle size. 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, 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 for rainsplash within a thin layer of flowing water. Both rainsplash and rainflow are most significant in areas between small channels, or rills, which form on rapidly eroding surface, and are commonly grouped together as inter-rill erosion processes.

Where flow is sufficiently intense to entrain soil particles directly, small channels or rills are formed on the surface, and material is eroded by **rillflow**, which is concentrated along these drainage lines. In cultivated land, resistance to erosion is commonly low within the cultivated layer, but increases considerably at the plough pan, which may be a layer of increased resistance, and also forms a transition to the undisturbed and more consolidated 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.

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

Runoff is the most important direct driver of severe soil erosion. Processes, 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. Both fine scale micro-topography and crusting evolve over the year, in relation to tillage and the growth of crops or uncultivated vegetation, their harvesting or grazing, and the disposal of surface residues.

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

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

3 Assessing soil erosion risk

For assessing soil erosion risk, various approaches can be adopted. A distinction can be made between *expert*-based and *model*-based methods. In this chapter the main properties of these two different approaches are described. In addition, a number of recently implemented erosion risk assessments are presented.

3.1 Expert-based methods

An example of an expert-based approach is the soil erosion risk map of Western Europe by De Ploey (1989), showing areas where erosion processes are considered to be important by local experts. A limitation of this approach is that the author does not define clearly the criteria used to delineate the areas deemed to be at risk (Yassoglou *et al.*, 1998).

Factorial scoring is another approach that can be used to assess erosion risk (Morgan, 1995). An example is the CORINE soil erosion risk assessment of the Mediterranean region (CORINE, 1992). The analysis is based on factorial scores for soil erodibility (4 classes), erosivity (3 classes) and slope angle (4 classes). The scores are multiplied, giving a combined score that represents potential erosion risk. To assess actual soil erosion risk, the potential erosion risk map is combined with a land cover factor (2 classes).

Montier *et al.* (1998) developed an expert-based method for the whole of France. As with CORINE, the method is based on scores that are assigned to factors related to land cover (9 classes), the soil's susceptibility to surface crusting (4 classes), slope angle (8 classes) and erodibility (3 classes). An interesting feature of their method is that it takes into account the different types of erosion that occur on cultivated areas, vineyards, mountainous areas and the Mediterranean. This way, the interaction between soil, vegetation, slope and climate is accounted for to some extent.

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

3.2 Model-based methods

A wide variety of models are available for assessing soil erosion risk. Erosion models can be classified in a number of ways. One may make a subdivision based on the time scale for which a model can be used: some models are designed to predict long-term annual soil losses, while others predict single storm losses (event-based). Alternatively, a distinction can be made between lumped models that predict erosion at a single point, and spatially distributed models.

Another useful division is the one between empirical and physically-based models. The choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money.

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

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

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

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

The relative soil loss values produced by models at this scale are generally more reliable than the absolute values. This is not necessarily a problem, as long as one is aware that the model results give a broad overview of the general pattern of the relative differences, rather than providing accurate absolute erosion rates at individual points. Because of this, the availability of input data is probably the most important consideration when selecting an erosion model at the regional/national scale. It would not make sense to use a sophisticated model if sufficient input data are not available. In the latter case, the only way to run the model would be to assume certain variables and model parameters to be constant.

However, the results would probably be less reliable than the results that would have been obtained with a simpler model that requires less input data (De Roo, 1993). Also, uncertainties in the model's input propagate throughout the model, so one should be careful not to use an 'over-parameterised' model when the quality of the input data is poor.

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

3.3 Recent approaches to erosion risk assessment

In the past few years a number of projects have attempted to assess the risk of soil erosion at national, European and International level. The following sections describe some projects that fall neatly into the two categories, expert-based and model- based approaches. Sections 3.3.1 to 3.3.4 contain material prepared by Gobin *et al*. (2001).

3.3.1 The CORINE approach

The CORINE programme, an example of an expert-based approach, was established in 1985 to:

1. Help guide and implement Community environment policy, and to help incorporate an environmental dimension into other policies, by providing information on priority topics.
2. Help ensure optimum use of financial and human resources by organising, influencing and encouraging initiatives by international organisations, national governments or regions to obtain environmental information
3. Develop the methodological base needed to obtain environmental data that are comparable at a Community level.

The CORINE soil erosion risk maps (Figure 3.1) are the result of an overlay analysis by a geographical information system, enabling the evaluation of the soil erosion risk category. The main source of information used was the soil map of the European Communities (CEC, 1985). Potential soil erosion risk was defined as the inherent risk of erosion, irrespective of current land use or vegetation cover (CORINE, 1992).

The map of potential erosion risk (Figure 3.1) therefore represents the worst possible situation. The area of land in this region that has a high risk of erosion totals 229,000 km^2 (or about 10 per cent of the rural land surface). The largest area is found in Spain, mainly in southern and western parts. In Portugal, areas of high erosion risk cover almost one third of the country. About 20 per cent of the land surface in Greece, 10 per cent in Italy and 1 per cent in France is subject to high erosion risk. The difference between the areas of potential and actual erosion risk (see Figure 3.1) reflects the protective influence provided by present land-cover, and the dangers inherent in changes in land use practices.

3.3.1.1 Advantages and limitations

The CORINE soil erosion assessment has the great advantage of simplicity, in that it provides a clear forecast, on an objective basis, for the whole of the area studied. The CORINE methodology is based, at least in principle, on the Universal Soil Loss Equation (USLE), a well-established technology that has been very widely used, both in north America and elsewhere in the world. Being based on a factorial method using a 1km x 1km grid, the method can be applied, using a GIS, at a resolution that allows discrimination within regional areas. Conventional wisdom suggests that the method correctly identifies areas of the Mediterranean that have the highest risk of erosion. As a product of its time, it has considerable merit, and could be improved with the more detailed land cover classification now available.

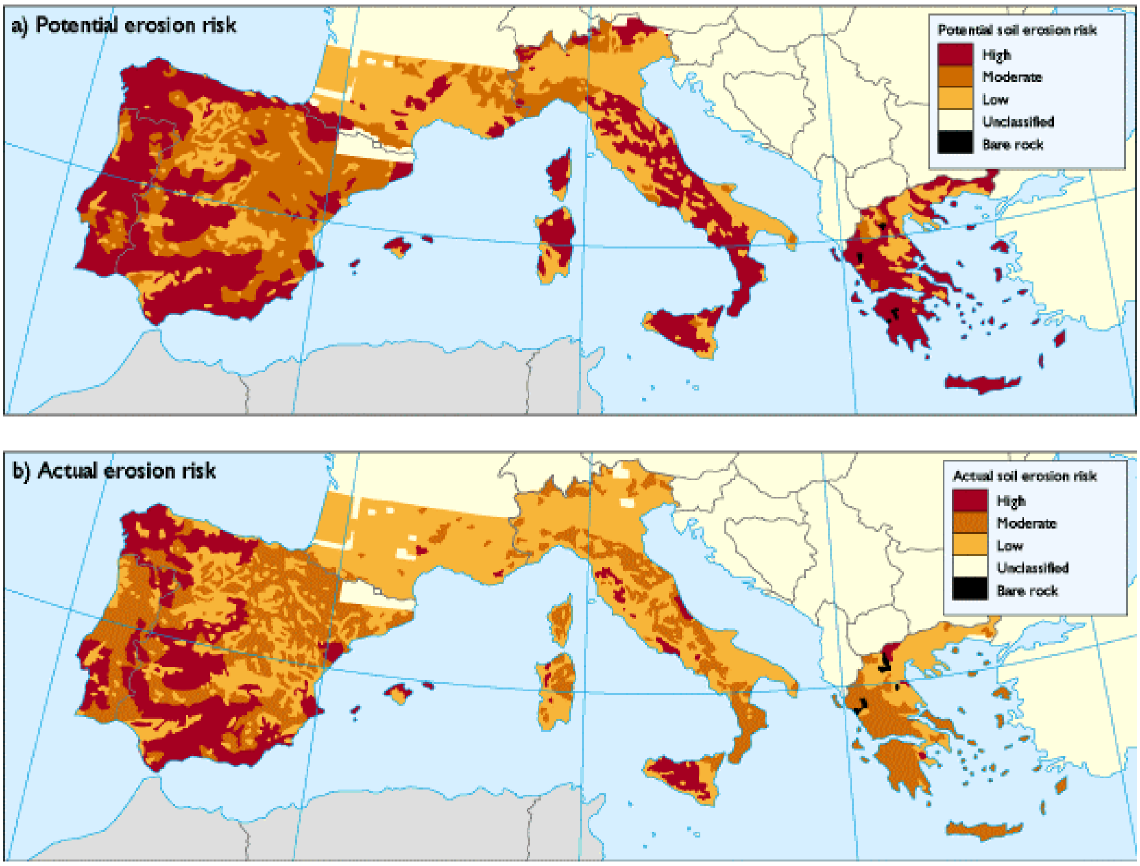

Figure 3.1. Potential versus actual erosion risk as estimated by the CORINE methodology (CORINE, 1992).

The CORINE report concedes that 'future development of this work would allow more sophisticated models of soil erosion to be used … Particularly on improving the factors used in the procedure, notably in the calculation of erosivity and soil erodibility, and in the classification of land cover.' On a qualitative basis, comparison of the Erosion maps of southern Europe appear to show too great a dependence on the climatic factors in determining erosion risk, with relatively less weight given to important factors of erodibility and land cover. Furthermore, 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.

However, the results produced only cover Mediterranean Europe, are not validated and show significant differences from risks by other approaches.

3.3.2 The RIVM approach

As part of a major report on strategies for the European Environment (RIVM, 1992), a baseline assessment of water erosion was prepared for 1990. This assessment of current risk (Figure 3.2) 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, but is currently only available at 50km resolution, so that it cannot readily be interpreted at sub-national scales.

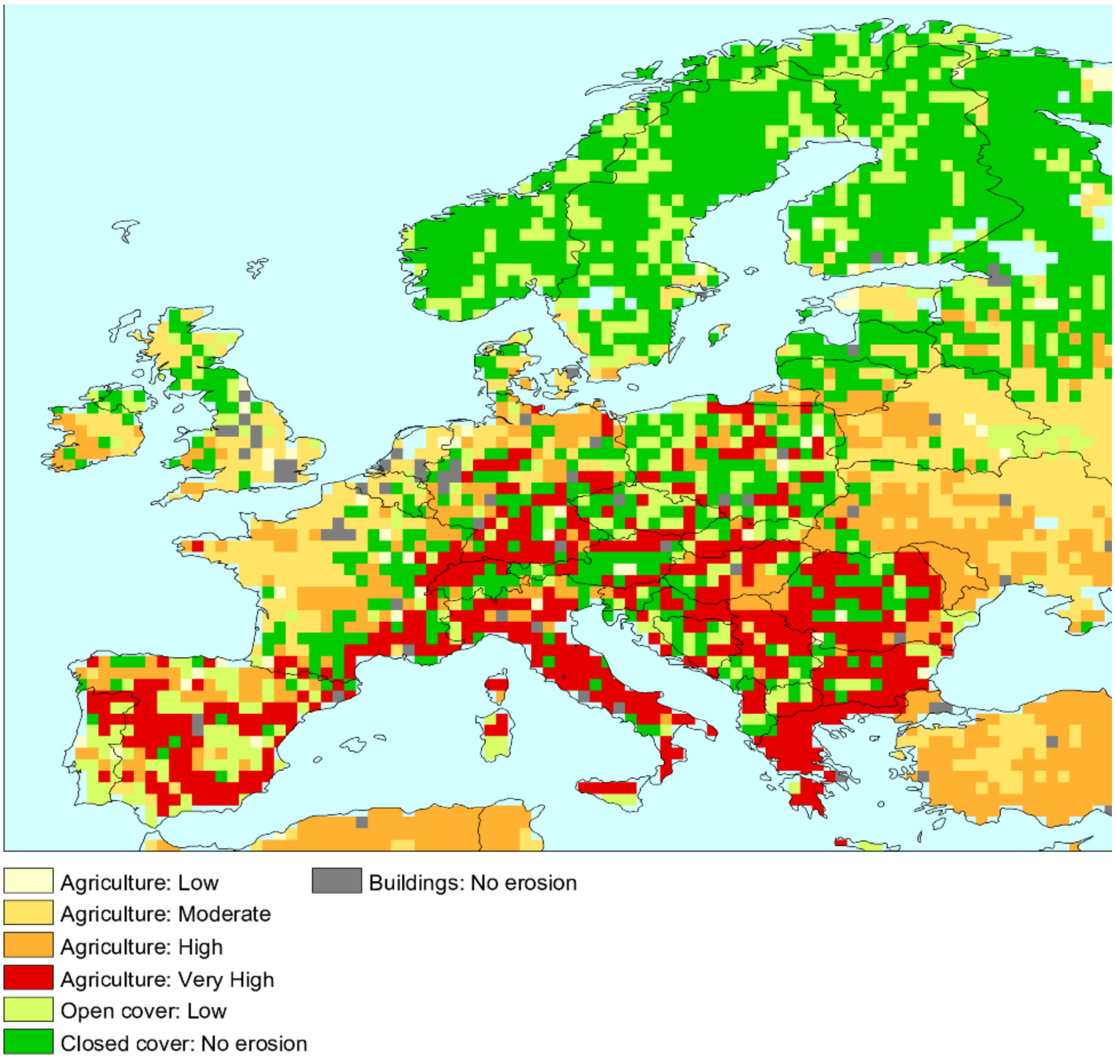

Figure 3.2. Water erosion vulnerability for 2050, according to the baseline scenario by RIVM (RIVM, 1992).

This approach also has the advantage of combining physical and economic elements within a single framework. However the value of this integration must be judged on the reliability of all components, of which only the soil erosion assessment is addressed here.

3.3.2.1 Advantages and limitations

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

The RIVM soil erosion model is a factor model, like CORINE, but, although initiated 6-8 years later, it is in many ways a more simplified approximation to the imperfect USLE model. It may be seen that the soil erodibility takes a similar form to CORINE or USLE, with components for soil type, and a simplified gradient and index. The rainfall erosivity component is seen as an inadequate representation, which contains neither the theoretical basis underlying USLE nor the fair empirical alternatives provided in CORINE. Only land use provides an improvement on CORINE, due to the availability of better land cover data than was available early in the CORINE project. The RIVM method exploits the potential, inherent in any physically based or factor based assessment, of providing scenario analysis, through the inclusion of two dynamic components, the monthly rainfall totals (affecting erosivity) and land cover (affecting the assessed actual erosion).

The RIVM approach is therefore seen to share some of the advantages of all methods which use distributed data sources, by providing an objective assessment across the European area. However, neither the 50km resolution nor the implementation of the factors contributing to erosion is seen as providing a state-of-the-art assessment. In simple terms, it is too crude for supporting the current policy making process.

3.3.3 The 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. The International Soil Reference and Information Centre (ISRIC), in 1988, was commissioned by the United Nations Environment Programme (UNEP) to coordinate a worldwide study. In collaboration with a large number of soil scientists, ISRIC produced a scientifically credible global assessment of the status of human-induced soil degradation within a very short timescale. It was appreciated that this global assessment would have to be made on the basis of incomplete knowledge but nevertheless the attempt was considered worthwhile. The task was subcontracted to correlators in 21 regions to prepare, in close cooperation with national soil scientists, regional soil degradation-status maps, that could subsequently be combined and correlated to produce the GLASOD world map of soil degradation.

It is important to recognise the limited aims of the project, and to observe that GLASOD is the only approach that has, to date been applied on a world-wide scale. It is based on responses to a questionnaire, sent to recognised experts in all countries (Oldeman *et* al, 1991). It thus shares with the Hot Spots approach dependence on a set of expert judgements, but 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 (van Lynden, 1994), questionnaires were sent to scientific teams in each European country for comments and additions on 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.

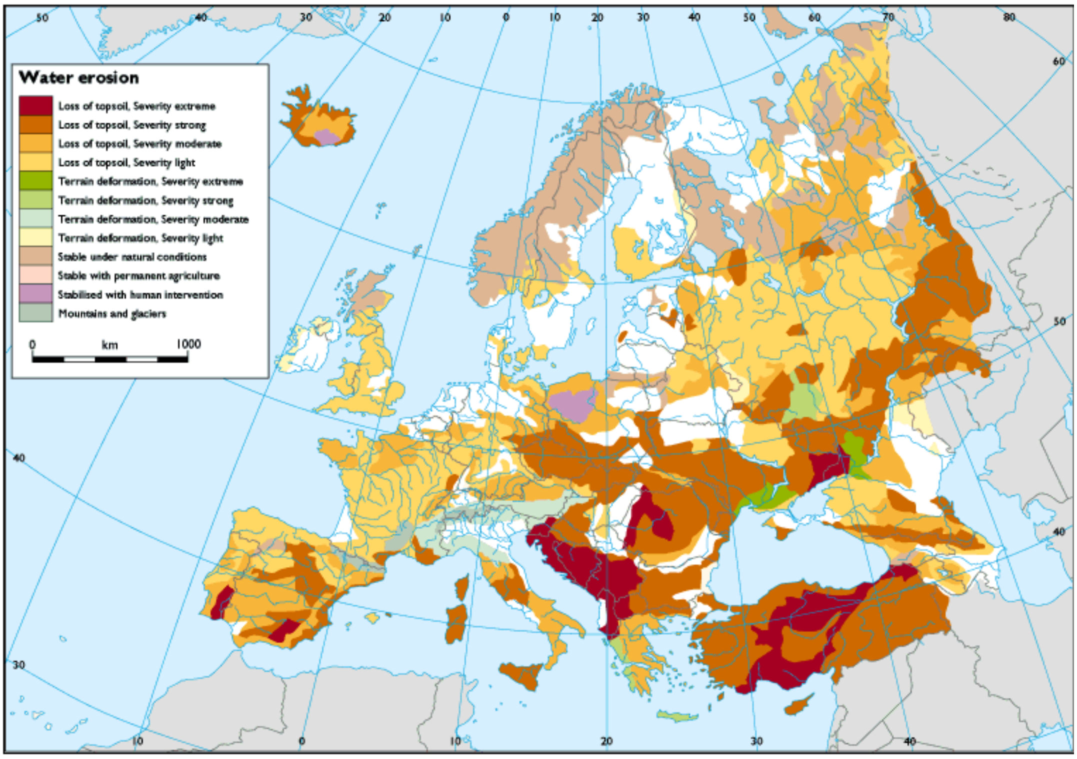

Figure 3.3. ***Water erosion of soils in Europe according to the GLASOD approach (Van Lynden, 1994).***

The GLASOD map (Figure 3.3) 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 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 can be much larger.

3.3.3.1 Advantages and limitations

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

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

3.3.4 The 'Hot Spot' approach

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

The map produced has been developed from earlier maps (Favis-Mortlock and Boardman, 1999; de Ploey, 1989), based on local empirical data, as opposed to CORINE or other estimates based on erosion models, that are considered unsuitable for application at coarse scales (Turner *et al*, 2001). In the Hot Spots approach, expert knowledge is used 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, for rates of erosion in these hotspot areas. The intention is to identify areas of current erosion risk, under present land use and climate, as opposed to either evidence of past erosion, or of the potential for erosion under some hypothetical conditions.

The data provides general or particular information about water erosion for approximately 60 sites or small regions across Europe, with measured erosion rates, which could be placed on the map at 35 sites. Measurements are taken from erosion plots, fields and small catchments.

The data are then grouped into three broad groups, for Eastern Europe, the loess belt and southern Europe, which primarily represent different land use history, parent materials and climate respectively (Figure 3.4).

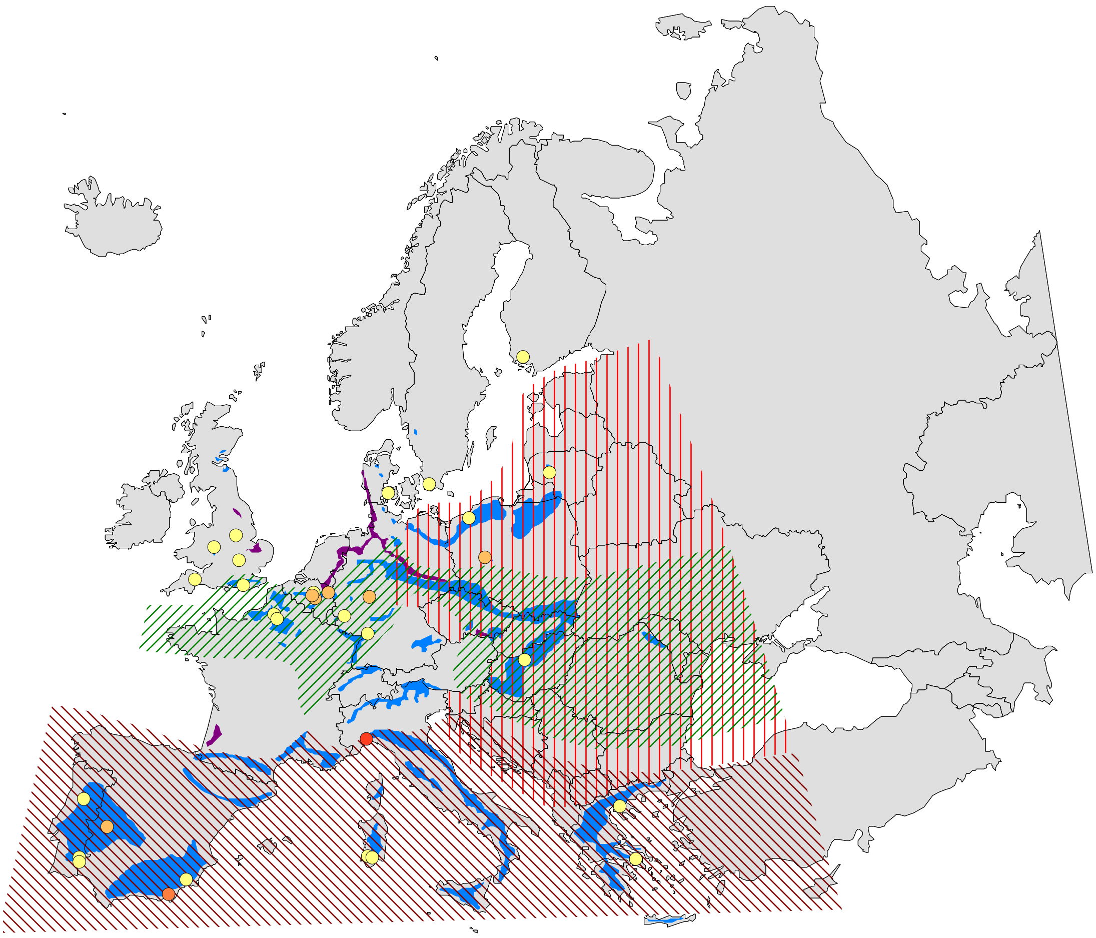

Figure 3.4 Hot Spots map for water and wind erosion (EEA, 2000; EEA, 2001).

3.3.4.1 Advantages and limitations

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 it ill-suited to this approach. There is, however, scope for combining data from the literature with ongoing measurements and estimates from some factorial or modelling approach as a means of rational interpolation. In its present form the most important information contained in these maps lies in the considerable experience of its compilers, which it is hard to document or 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 identified on this map are definitely areas of high impact, but that there is no reliable way to extrapolate these local results, even to their surrounding area. The main limitation is that the spatial representation is much too coarse to be of practical use to policy makers.

3.3.5 The USLE approach

The well-known Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) has been used for many research studies of 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 & Govers, 1996). It also represents a standardised approach.

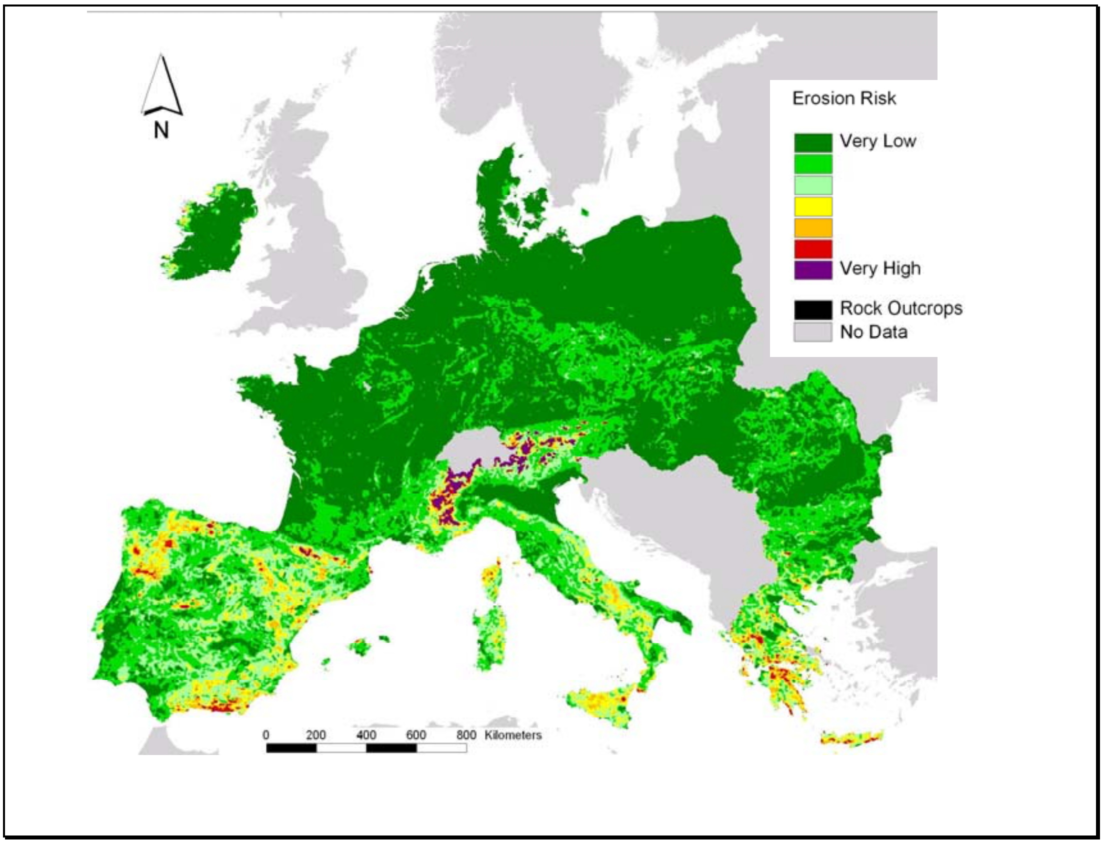

Figure 3.5. Actual Soil erosion risk in Europe.

The application of the USLE in Europe (Van der Knijff *et al.*, 2000) is a first attempt to produce a map of quantitative soil erosion by rill and interrill erosion for the whole continent. The estimates of sediment loss are not validated in most cases but relative differences are thought to be real. It is an example of the model-based approach.

The map of estimated annual soil erosion risk shown in Figure 3.5 is based on a 1km x 1km data set for all 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 3.6.

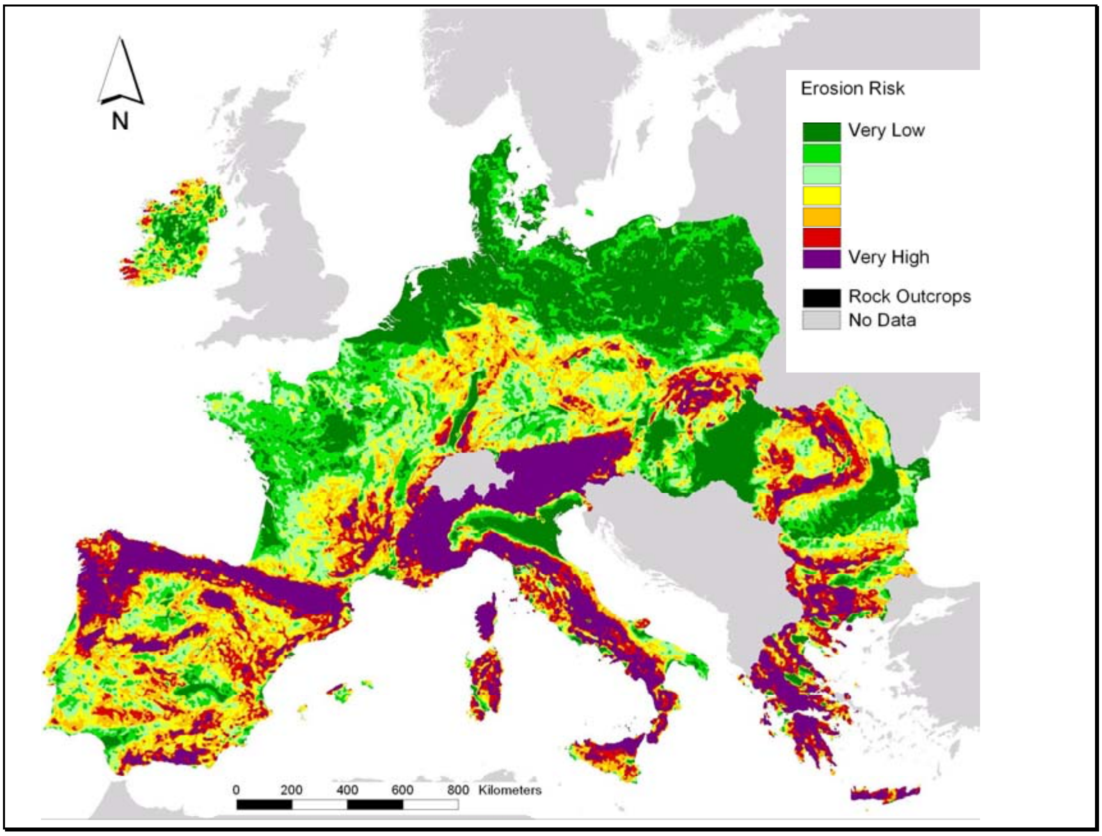

Figure 3.6. Potential Soil erosion risk in Europe.

The approach used to produce the map of actual soil erosion risk in Europe (Figure 3.5) has been updated by Grimm *et al.* (2002). This has resulted from a modification of the erodibility factor K using a new soil parameter, the tendency for the soil to form a surface crust. The conventional wisdom here is that there will be more runoff on sloping land that has a crusted surface. The incorporation of crusting in the assessment of erosion risk is a component of the INRA approach (Le Bissonnais and Daroussin, 2001) described in the following section (3.3.6). The resulting map (Figure 3.7) of actual soil erosion risk in Europe is essentially a refinement of the methodology developed by Van der Knijff *et al*. (2000), that used soil texture alone to estimate the erodibility (K) factor.

Running the Van der Knijff *et al.* (2000) model for Italy, 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 3.7. The modified model developed by Grimm *et al.* (2002) has also been run on the Italian data.

3.3.5.1 Advantages and limitations

One of the main advantages of the Universal Soil Loss Equation (USLE) is that it is well-known and it has been applied widely at different scales. Compared with the methods described above, it probably gives the most detailed information about the Europe-wide distribution of soil erosion risk. Its value lies in the fact that the estimates of erosion are based on standardised, harmonised data sets for the whole of Europe and the model produces quantitative output as actual loss, for example t/ha/year.

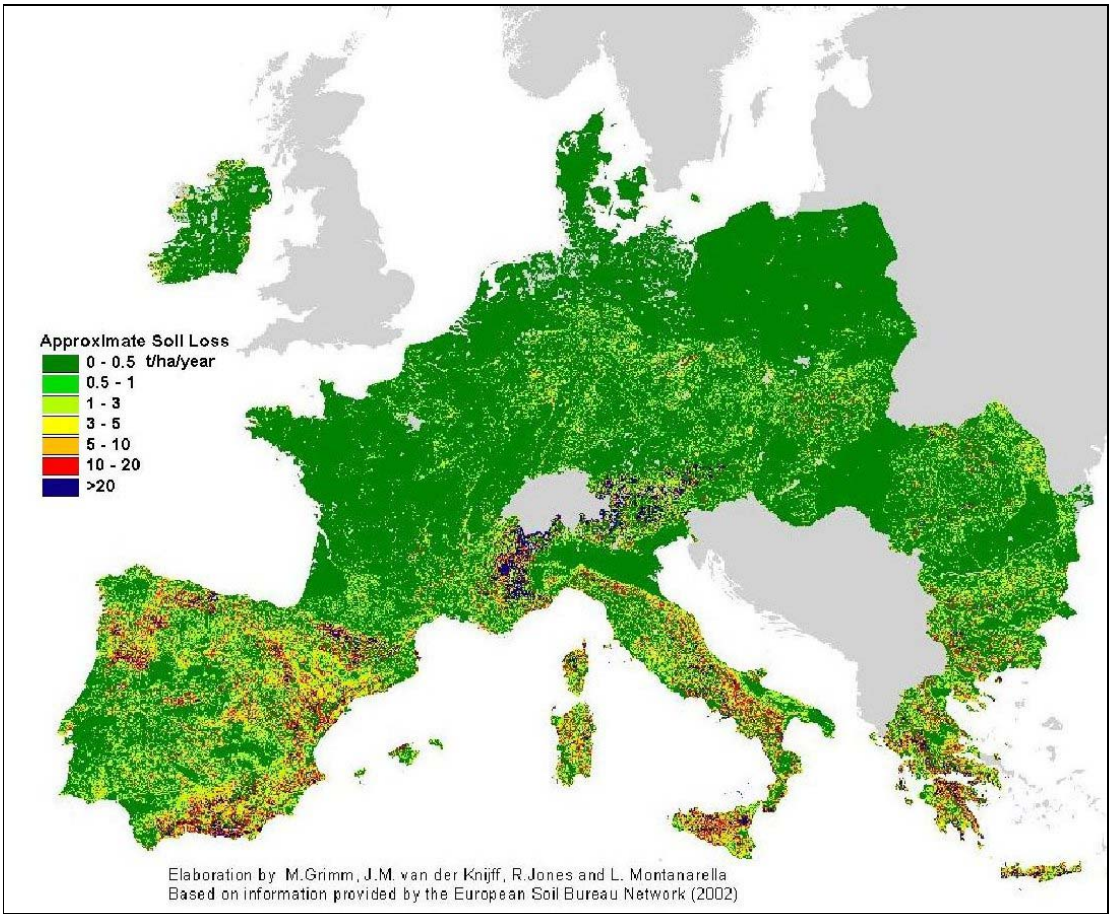

Figure 3.7. Actual Soil Erosion Risk in Europe incorporating soil crusting.

However, in this study for Europe, a quantitative assessment may not be considered appropriate in view of the quality 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 sources such as the estimation of vegetation cover, rainfall erosivity, soil erodibility and the effect of management practice (including contouring, strip cropping, terracing and subsurface drainage (Renard *et al.,* 1997). It should be appreciated that management practice may be one of the most important factors affecting erosion in many cases.

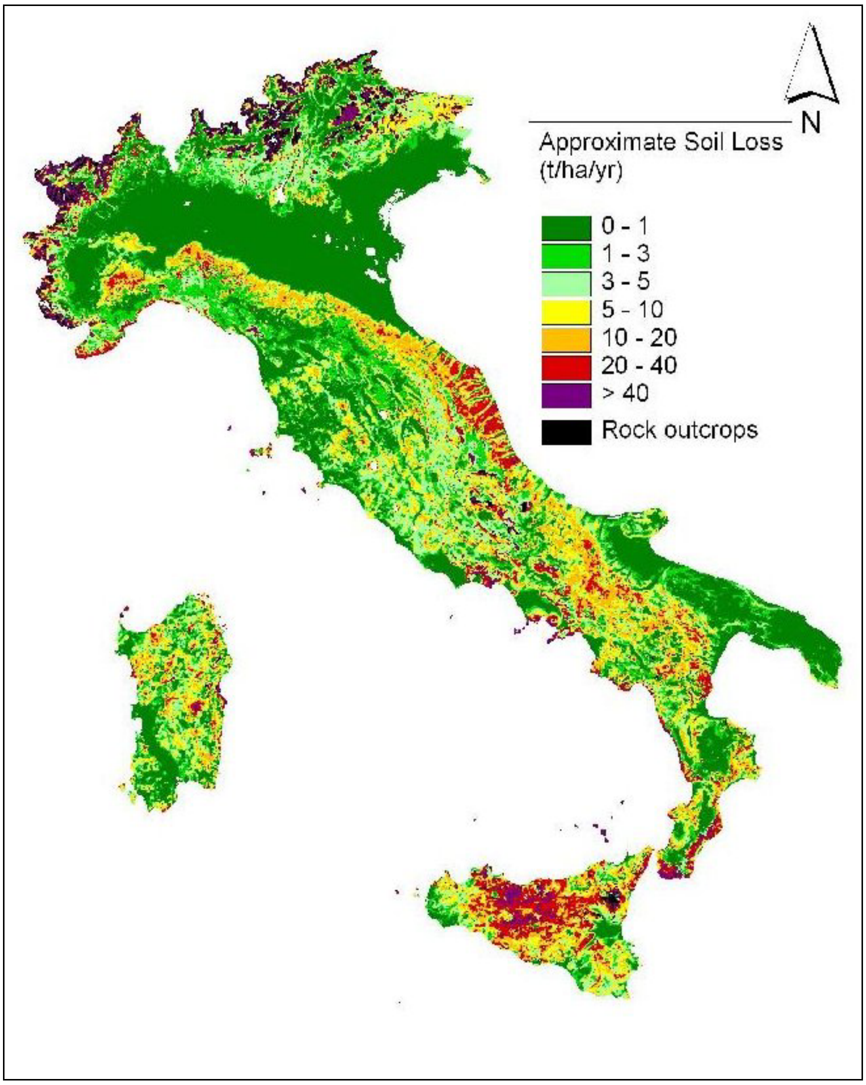

Figure 3.8 Actual Soil erosion risk in Italy, based on the USLE.

In conclusion, the results of this study may be considered as a further step towards a harmonised soil erosion risk map of Europe. Some major improvements could be achieved by using a more detailed digital elevation model, a better representation of rainfall erosivity, and satellite data that have better spectral and geometric characteristics than the NOAA AVHRR data that are currently used to estimate the vegetation cover. Finally, more detailed soil data is needed (especially soil depth, stone volume and surface texture).

3.3.6 The INRA approach

This approach elaborated by INRA (Institut National de la Recherche Agronomique, France) should be considered as an intermediate step towards a "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.

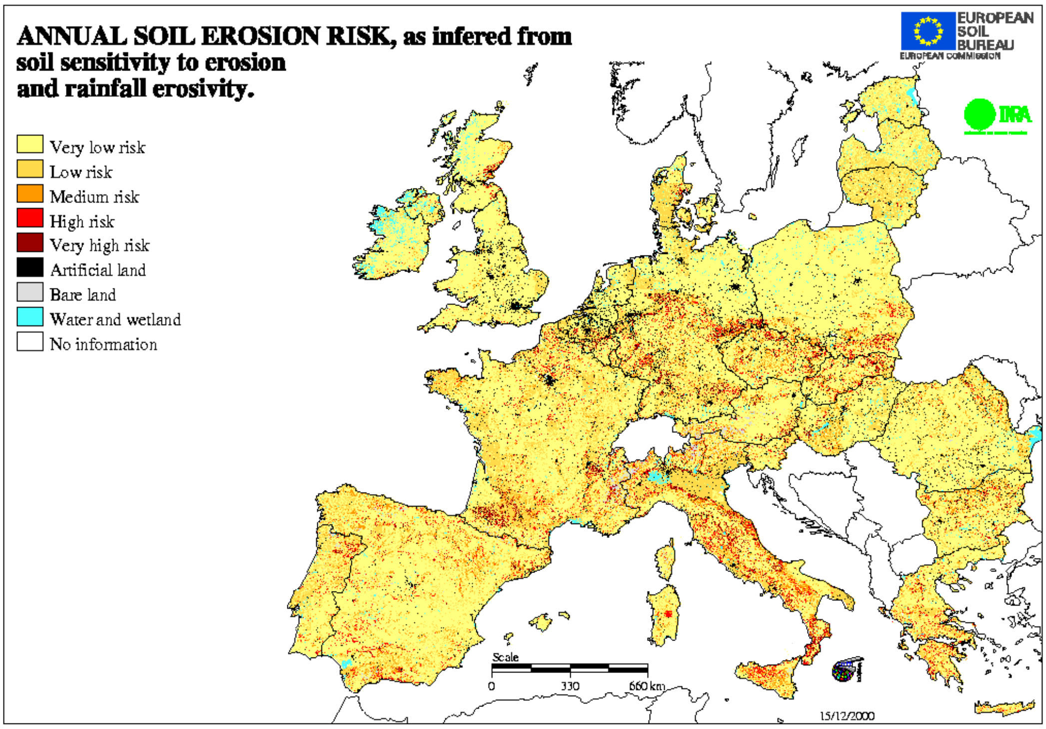

Figure 3.9. Annual Soil Erosion risk in Europe

The model uses empirical rules to combine data on land use (250 m resolution raster version of the CORINE Land Cover database at scale 1:100,000), soil crusting susceptibility, soil erodibility (determined by pedotransfer rules from the Soil Geographical Data Base of Europe at scale 1:1 Million), relief (1 x 1 km resolution raster digital elevation model) and meteorological data (25 years of daily meteorological data at 50 km resolution). Figure 3.9 shows the annual soil erosion risk for Europe using this approach. Spatial units for the presentation of results can be defined using either administrative units (Figure 3.10) or watershed catchment units (Figure 3.11).

The goal was to develop and apply a methodology based on present knowledge and available data for the assessment of soil erosion risk at the European scale. Factors influencing erosion have been graded for the diverse geographical situations existing in Europe and erosion mechanisms have been expressed with the help of experimental and expert-defined empirical rules. Land cover and crust formation on cultivated soils were considered as key factors influencing runoff and erosion risk.

This approach is clearly different from expert assessment as performed for the GLASOD approach project. It bases on a modelling approach using a hierarchical multifactorial classification. It is designed to assess average seasonal erosion risk at a regional scale. The model is based on the premise that soil erosion occurs when water that cannot infiltrate into the soil becomes surface runoff and moves soil downslope. A soil becomes unable to absorb 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).

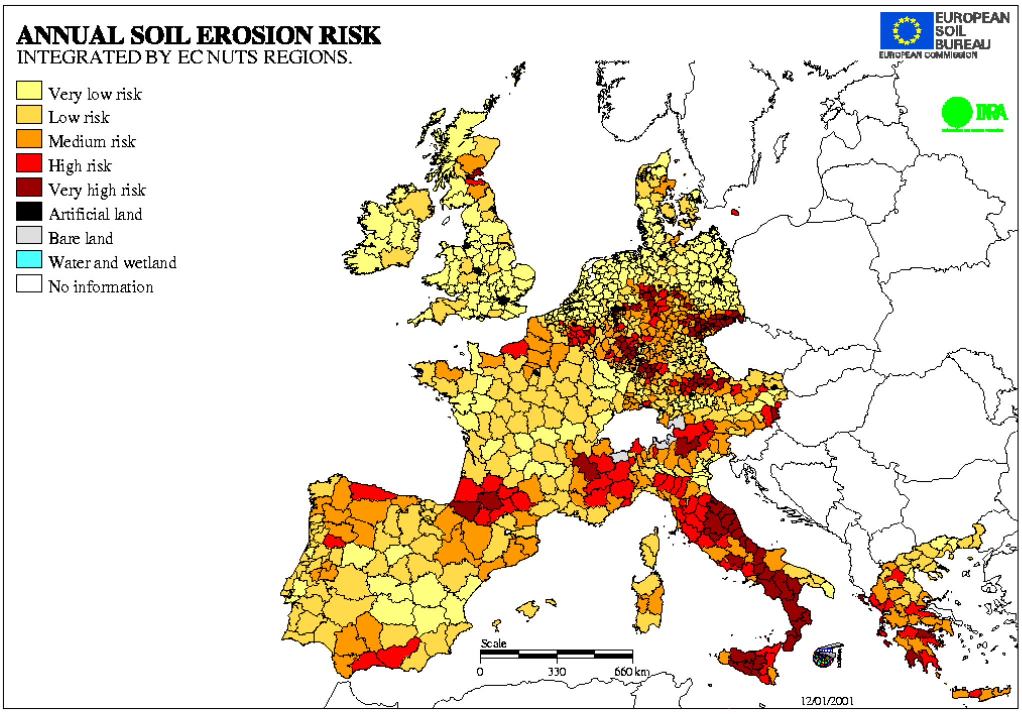

***Figure 3.10**. Annual Soil Erosion risk in Europe based on administrative units*

These two types of runoff generally occur in different environments: Bare crusting soils for the first one and humid areas for the second one, though they also may be combined in some cases. Once runoff is initiated on a cultivated field, various forms of erosion are likely to occur, showing various combinations in space and time: Sheet hillslope erosion, parallel linear erosion, and gully erosion.

The model developed here attempts to provide a global assessment of these various upstream erosion forms.

3.3.6.1 Advantages and limitation

The methodology presented here allowed to generate a single homogeneous map of erosion risk at the European scale that makes it possible to compare between regions. The decision tree type model considers different types of erosion depending on land use. The production of seasonal maps shows the importance of the seasonal effect on erosion.

The aggregation according to different spatial units makes it possible to adapt the results to different users needs. Finally, the model is easy to modify in terms of the rules and to update with new data.

The modelling approach presented here is very simple and versatile: it can accommodate heterogeneous data resolution and quality; it does not require the use of parameters that are not available at national scale, as does the USLE model. This new approach is much more precise and accurate than the CORINE erosion model. Both approaches are based on a decision tree, but the latter uses a single decision tree and takes into account only 2 land use classes, 3 climate classes and 4 slope classes. In addition, the CORINE erosion model does not take crusting into account.

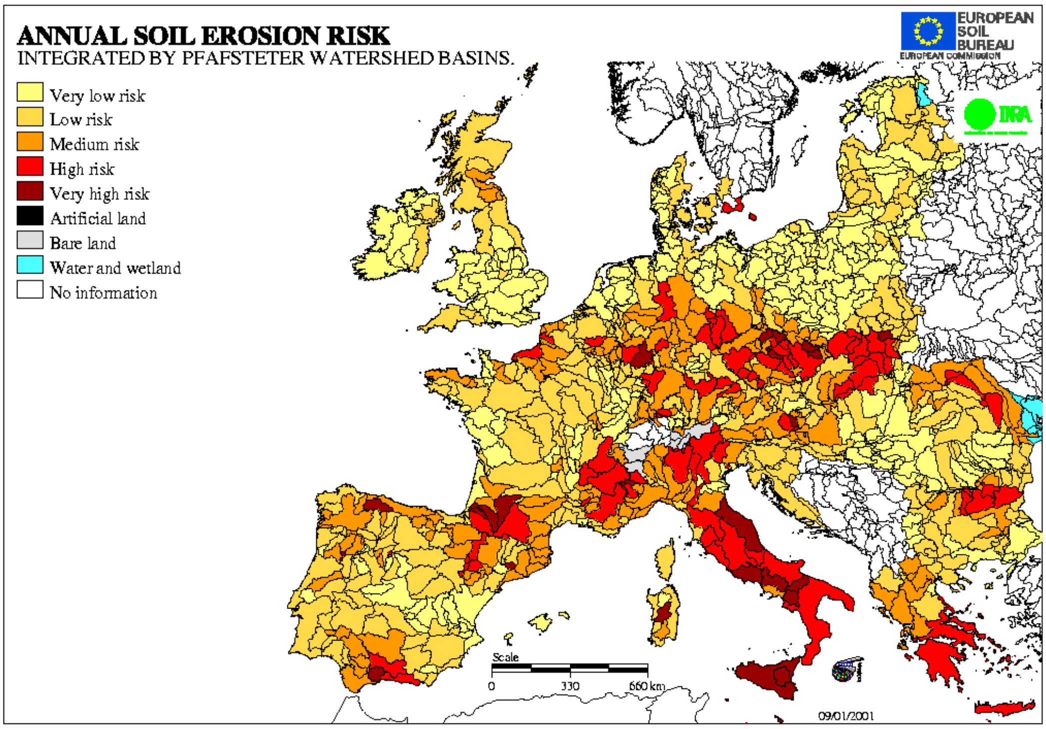

Figure 3.11.. Annual Soil Erosion risk in Europe using watershed catchment units

However, the disadvantages of qualitative methods remain in this model. In particular, the final information is provided on a 5 class scale of risk and it is not possible to link these classes to quantitative values of erosion, nor is it possible to assess the errors associated with the results.

However, errors and uncertainty associated to the results are much more dependent on the resolution and quality of the input data than on the model itself, because the model is based on very simple and global assumptions accepted by all experts. The main source of uncertainty in this model is certainly related to the parameters obtained from the soil database, i.e. susceptibility to crusting and erodibility, because both the spatial resolution and accuracy of these data are very low. Another limitation is the 1km x 1km grid resolution for the DEM, which does not result in accurate assessment of slope values in areas of gentle relief or short hillslopes. In addition, CORINE Land Cover and agricultural statistics data should be updated.

3.3.7 The PESERA approach

The PESERA approach was initially proposed by a consortium of soil erosion experts in Europe. The main components are shown in Figure 3.12 and the associated objectives are described below. A fuller description of the project, and the expected deliverables, can be found in the Technical Annex to the PESERA Project, Contract No. QLKS-CT-1999-01323, (see Gobin *et al.* (1999)

The first major objective of the PESERA project is to develop and calibrate 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 will also be extended to include estimates of tillage and wind erosion, although there has been less preliminary work done and these components may not be completed within the lifetime of the present proposal.

The specific objectives of PESERA are:

1. To develop a process-based and spatially distributed water erosion model that can be applied at a regional scale.
2. To develop an assessment strategy to validate the model and attach a predicted accuracy to the erosion forecast. This will involve establishing spatial and temporal resolution linkages within the physically based model structure.
3. Statistical methods will be developed to link rainfall intensities to interpolated precipitation grids.
4. To calibrate the PESERA model through the use of measured soil erosion data. A database will be compiled on soil erosion rates measured at European test sites.

The second major objective of the Project will be to validate the developed PESERA model at low and high resolution and across different agro-ecological zones, and to compare the PESERA model output with other models or methods used for erosion risk assessment. The robustness and flexibility of the PESERA model will be tested through demonstrating its performance at different resolutions and with different data input.

The specific objectives are:

1. To link data input on climate, soil and topography to appropriate model variables at the different resolutions. Pedo-transfer rules and equations will be developed to link soil parameters to available soil information. Interpolation techniques will be improved to optimise the use of existing climate and soil databases for erosion studies.
2. To develop meaningful soil cover grids derived from vegetation cover information obtained from SPOT VEGETATION images, to compare the VEGETATION images with NDVI images, and where possible, to calibrate this information with SPOT HRVIR images.
3. To compare the PESERA model output for catchment studies with other high-resolution models operating at catchment scale. This will involve selecting pilot

catchments across different agro-ecological zones, and examining the effect of input data quality and detail on the prediction accuracy of the model.
4. To explore the model's performance at low-resolution pilot regions covering different agro-ecological zones. In addition, the PESERA model output will be compared to other models and expert systems designed to assess soil erosion risk at the regional scale.
5. To compile comprehensive databases on factors affecting erosion in Europe (climate, soils, topography, vegetation and land use) from existing information and from newly acquired information such as vegetation cover derived from SPOT VEGETATION.

At the European scale, the initial need is seen to develop 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 loss of soil.

The specific objectives of this part of the project are:

1. To identify erosion risk areas and quantify present soil erosion rates at the European scale and at selected region or country pilot zones.
2. To predict possible effects of future changes in climate and land use on the soil erosion risk in Europe through scenario analysis.
3. To provide policy makers with a scientifically based soil erosion indicator capable of quantifying and monitoring changes due to policy.
4. To develop a www-based software system that will enable a range of users to run the erosion model.
5. To establish model user groups at two different levels: expert-users actively involved in scientific research within Europe and end-users responsible for executing agricultural and land use policy directives. The interaction with user-groups is seen primarily as a consultative process.
6. To provide soil erosion data for Europe to third parties undertaking related projects such as global change studies.

The third major objective will be to ensure the relevance of the PESERA model for policy-makers. It will be demonstrated that the approach adopts a nested strategy of focussing on environmentally sensitive areas where remedial action may be required.

The major achievements of the Project will be development of a model that identifies areas at risk to erosion, quantifies the erosion and prediction error, and enables scenario analysis. Establishing a strong expert and end-user network across Europe will enable further developments in PESERA to be sustained after Project funding.

A basis for the model to be developed already exists and it will adhere closely to hydrological models, taking into account spatial distribution patterns of sediment loss. Erosion rates in individual storms are estimated using a sediment transport equation that has explicit terms for topography, overland flow runoff and soil erodibility.

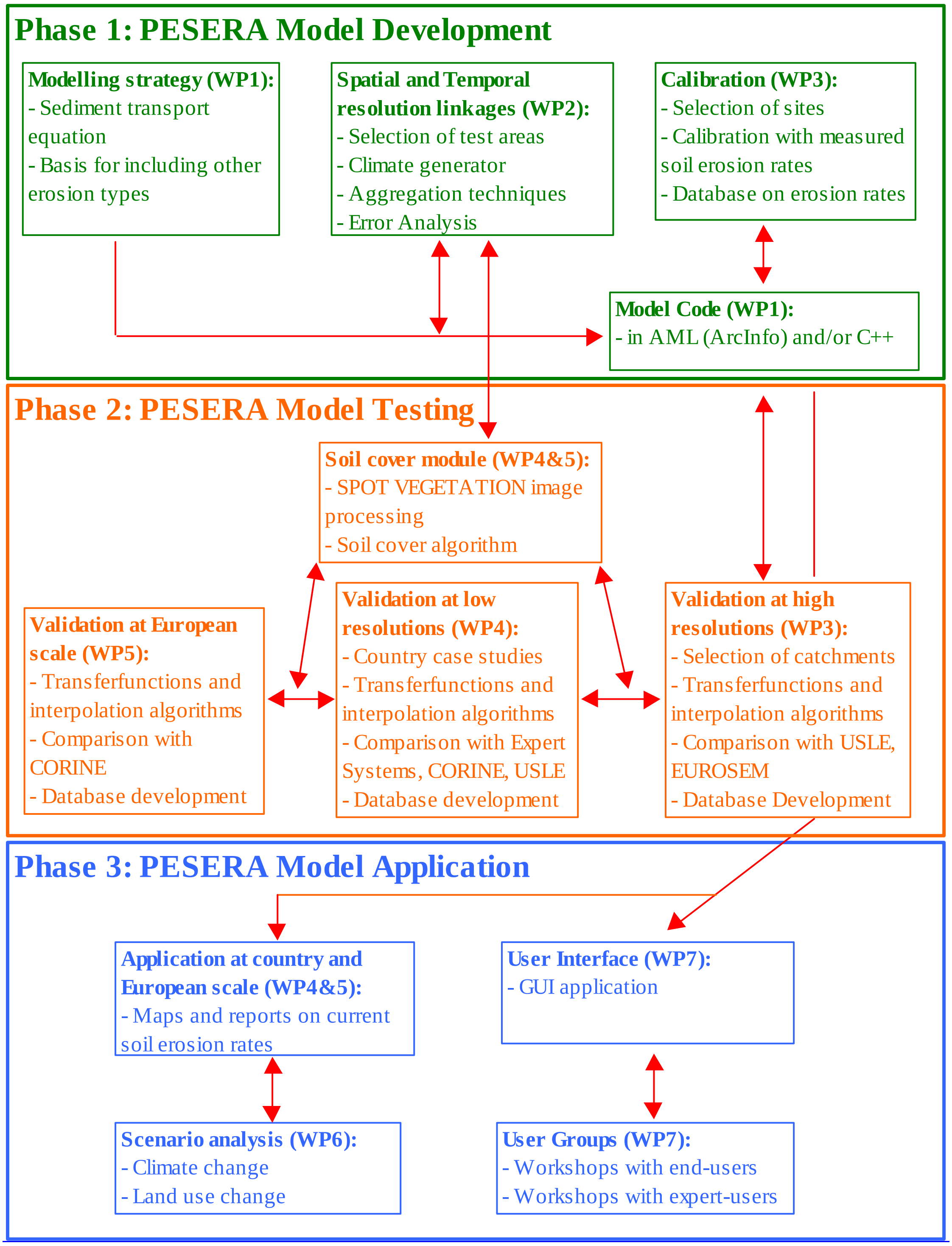

Figure 3.12. PESERA Project *(Gobin et al., 1999)*

Other soil characteristics and land/soil cover are implicitly incorporated as a soil runoff threshold. The sediment loss, expressed as sediment delivered to the base of hillsides, is calculated as the summation over the frequency distribution of storms on a monthly basis. This modelling approach was already applied to data compiled for a pilot zone in Europe. A early version of the PESERA model was applied to appropriate data for France and a map showing the erosion risk demonstrates the feasibility of this new approach (Figure 3.13).

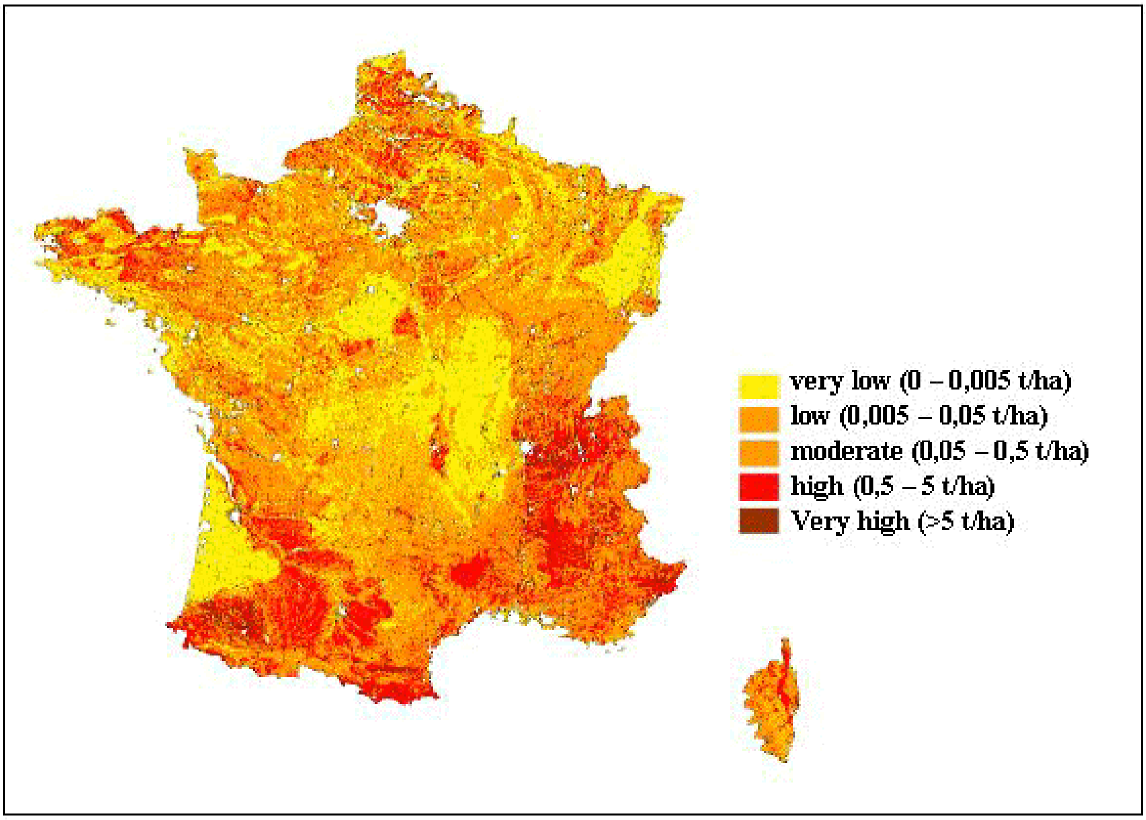

Figure 3.13. Soil Erosion risk in France using the PESERA approach
(Kirkby and King, 1998)

3.3.7.1 Advantages and limitations

The quantitative model has the potential for dealing with Pan-European applications, more easily than an expert based model, and forms a basis for replacing the CORINE estimates, without making excessive data demands. However, further development of the model and a substantial amount of calibration and validation work are essential.

The model will be evaluated to ensure that the results can be considered reliable, particularly for Pan-European applications. The results will also be validated at low and high resolution and across different agro-ecological zones. The PESERA model output will be compared with the output from other models or methods used for erosion risk assessment.

The robustness and flexibility of the PESERA model will be tested through demonstrating its performance at different resolutions and with different data input. But the resolution and the quality of the input data may still cause uncertainties and errors associated to the results.

The model is designed to handle spatial and temporal data of variable quality and detail. It will allow an application at European level and at a regional and country level. 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. The conceptual basis of the PESERA model will also be extended to include estimates of tillage and wind erosion, although there has been less preliminary work done.

Moreover scenario analysis for different land use and climate changes are planned. 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.

4 Indicators of Soil Erosion

Different human activities (driving forces) exert pressures on the environment and change its quality (state). The change of environmental conditions has impacts on other environmental issues. Society responds to the changes and impacts through environmental, general economic and sectoral policies. This chain of causes and effects has been inserted into the DPSIR Framework - Driving forces, Pressures, State, Impact, Response – as shown in Figure 4.1. (after Gentile, 1999). The development of relevant indicators for reporting makes use of this framework.

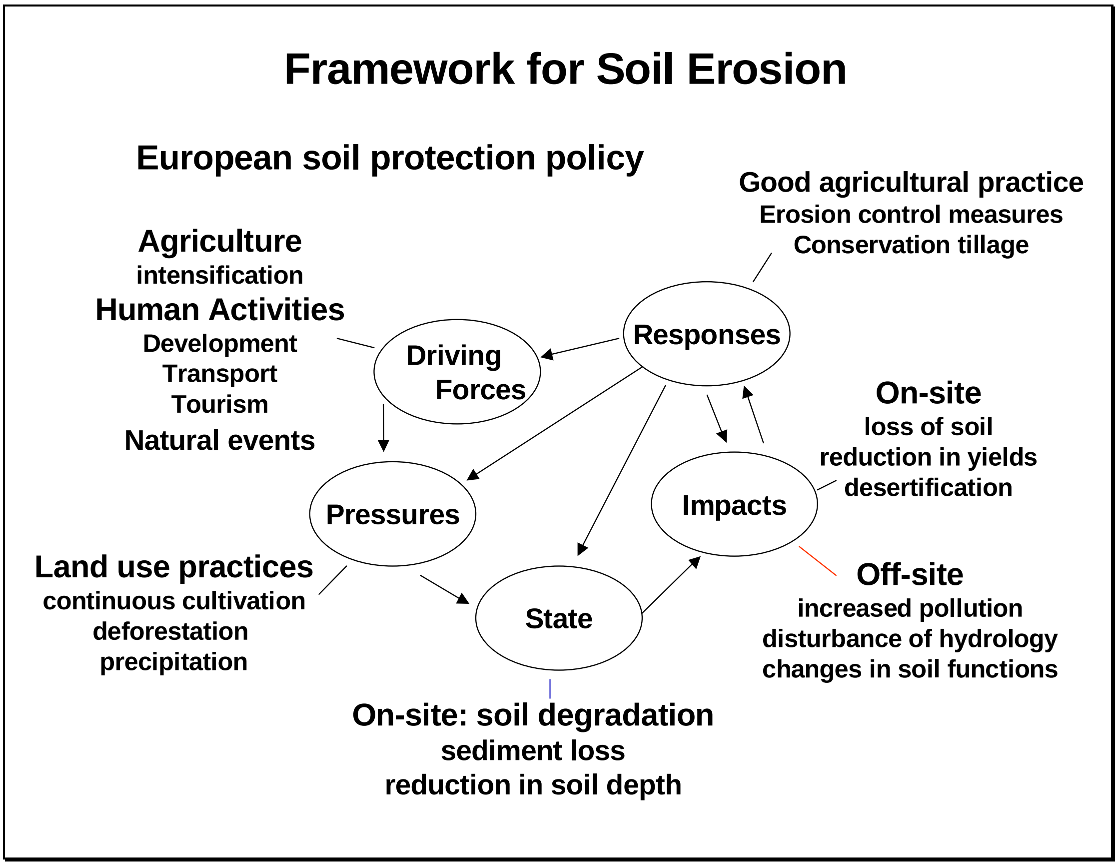

Figure 4.1. DPSIR Framework applied to soil erosion

For the purposes of environmental audits, an indicator has been defined as 'a parameter, or value derived from parameters, which points to/provides information about/describes the state of a phenomenon/environment/area with significance extending beyond that directly associated with a parameter value' (OECD 1993).

4.1 Indicators of driving forces and pressures

An understanding of socio-economic driving forces and soil erosion is still very limited. Agriculture in general is a very important driving force for soil erosion. An example for some of the less-favoured areas in the Mediterranean showed that with increasing subsidies stocking rates went up and resulted in overgrazing and more erosion.

According to the EEA and ETC/S (1999, 2000), the main driving force on soil, that causes erosion in regions with potential and actual soil erosion risks, is the intensification of agriculture. This is a complex indicator and it is related to different pressure indicators. The corresponding pressures are cost-effective but unsustainable land use practices, the use of machinery for the cultivation of enlarged fields, the overgrazing and other instruments of intensive land use practices. Average field sizes (and increase of field sizes), combined with average farm size per region as well as the consumption of fertilisers and the number of grazing animals, give an indication of the intensification of agriculture.

The intensification of agriculture is not necessarily directly related to soil erosion. The higher the degree of intensity of agricultural land use the higher may be the soil loss by water and wind erosion in potentially high erosion risk areas, but agricultural intensification and soil conservation are not mutually exclusive. For example an intensive farming system employing soil conservation measures, such as terracing and cover crops, may result in less soil erosion than a more extensive system that does not involve conservation techniques. Intensive land use can be combined with efficient soil conservation measures. In the Belgian Loess belt for example, land under steep slopes has been taken out of production while the agriculture has been intensified.

One major remark is that the intensity of agriculture should never be evaluated alone in relation to erosion. Soil loss due to erosion is a result of the interaction of climate, topography, soil properties, land cover and land management. Land cover also includes the natural vegetation.

Moreover it is argued that agricultural intensification, in isolation, could be misleading and therefore it is proposed to include human population, land development, tourism, transport, natural events and climate change with agricultural intensification as driving force indicators of soil erosion. Thus land cover change and precipitation can be used for pressure indicators of soil erosion, as they are seen to be directly influencing the degree of soil erosion. Land cover (LC) change can be detected by combining the CORINE LC with vegetation change monitoring techniques (AVHRR/VEGETATION). Precipitation can be derived from the GISCO climatic and/or the MARS meteorological databases.

4.2 Indicators of state

From a scientific and technical standpoint, the most appropriate indicator is the area affected by erosion. However, because there is a serious lack of direct measurements of soil loss, by water and by wind, a surrogate parameter or indicator is needed.

4.2.1 Area affected by soil erosion

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

An important surrogate indicator of actual erosion is its risk. A *risk* is the chance that some undesirable event may occur. *Risk assessment* involves the identification of the *risk*, and the measurement of the exposure to that risk. The response to risk assessment may be to initiate categorisation of the risk and/or to introduce measures to manage the risk. In some cases, the risk may simply be accepted. In other cases, the priority will be to adopt a mitigation strategy. Various approaches that can be adopted for assessing soil erosion risk are presented in chapter 3.

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 appreciated. Accurate data are therefore scarce. Estimates from member states, based on national data sets, could be compared with estimates derived from European data sets (e.g. the European Soil Database).

Although, there are difficulties in making measurements, existing data should be compiled and stored centrally for comparison with model estimates. Erosion models offer 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 and finalise such a model within the next two years.

4.2.2 Actual and potential soil loss

Soil erosion state indicators should be able to provide a picture of both the extent and the severity of the potential soil erosion risk and of the actual soil erosion risk (Düwel and Utermann, 1999). The potential risk calculations should take into account climatic, topographic and edaphic conditions (e.g. Figure 3.6), whereas the actual risk should take into account both vegetation cover and actual land use (e.g Figures 3.5 and Figure 3.7). The indicators of state should also provide information on the rate of the actual soil loss under the existing soil management and erosion control practices and on the rate of soil loss tolerance. The comparison of the potential with actual soil erosion risk could be considered as a risk due to land use changes.

The proposed indicator is the extent of total soil loss by soil erosion due to water, measured in tonnes per ha per year. The PESERA methodology will be able to result in a Pan-European soil erosion risk map. A regional model that allows for estimating the potential soil erosion risk should be combined with periodical monitoring of actual soil erosion in selected test areas.

4.2.3 Transport of sediments

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

Data on sediment transfer are advocated as valid measurements of actual soil loss (EEA-ETC/S, 1999). However, the sediment source remains highly uncertain and can rarely be traced back to surrounding land, riverbanks or channel. A digital database to define catchment boundaries in Europe (scale 1:1,000,000) is under development at the JRC. Data on sediment concentrations and annual suspended sediment yields should be related to the catchment area. However, the data may not be readily available at present. The European FreshWater Monitoring Network (EuroWaterNet) could be a possible source for data on river sediments.

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

4.3 Indicators of impact

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

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

4.4 Indicators of response

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

4.4.1 Conservation practices

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

Conservation practices have been demonstrated to considerably reduce soil loss through erosion in other parts of the world. Many of these practices increase plant cover and therefore directly reduce erosion. Many are also recognised as 'good agricultural practice'. However, data and information on conservation practices are rarely collected systematically and stored centrally in Europe. Conservation practices are important in reducing or eliminating soil erosion but they are usually only adopted after soil erosion has been identified as a significant problem.

4.4.2 Mitigation strategies

Conservation practices are important in reducing or eliminating soil erosion but they are usually only adopted after soil erosion has been identified as a significant problem. Data and information on conservation practices are rarely collected systematically or stored centrally in Europe. The indicator proposed is the 'expenditures for special soil erosion prevention programmes, including forest fire protection'. Measures involve implementation of fire prevention systems and building of holding reservoirs.

5 Conclusions and recommendations

Having identified the various processes associated with soil erosion in Europe, a simple methodology is needed for converting the vulnerability of land use systems to degradation by erosion, as estimated by research scientists, into information that is readily comprehensible to policy makers. The DPSIR framework defined by OECD (1993) is an example of a simple model for presenting the various aspects of erosion in a way the policy makers can identify a suitable mitigation strategy. Figure 4.1 is an attempt to highlight the pressures and driving-forces affecting/causing degradation through erosion. Possible responses are identified and the approach further aids the policy making process by partitioning the *off-site* and *on-site* impacts.

Figure 5.1 ***Olive trees (> 100 years old) on 15 deg slope in Andalucia, Spain, where the soil has been almost completely eroded away***

It is clear that soil erosion is irreversibly degrading the soils in many parts of Europe. This is happening sometimes in an extreme way in southern Europe (Figure 5.1, 5.2) but also in a less obvious but still damaging way in the northern areas. Mitigation strategies must be implemented as part of an overall Soil Protection Thematic Strategy. The existing European Soil Database provides a harmonised basis for broadly identifying the areas most at risk and for examining the processes responsible. At present, reliable point data on actual soil loss and its tendency in future are very scarce, particularly in southern Europe.

For implementation of an effective soil protection strategy in future, accurate spatial data on the distribution of soil types in addition to better climate and land cover data than are currently available, are also needed.

Any management intervention that becomes necessary to ensure compliance with a Soil Protection Directive could have significant economic consequences. Without better data than the European Soil Database at 1:1,000,000 scale, the CORINE Land Cover database at 1:250,000 scale; and the MARS Agroclimatic database at a resolution of 50km x 50km, a soil protection strategy could become unworkable in future.

Figure 5.2. Water erosion exposing roots of vines in Côtes du Ventoux

Computer-based models such as PESERA offer some hope for obtaining better predictions of soil erosion than estimates made in the past. PESERA is important in a European context because it is a runoff model and runoff causes the greatest loss of sediment. However, for precise environmental auditing, model estimates must be validated at sites where actual sediment losses are measured. Furthermore, to quantify trends, erosion measurements should be added to the list of those that are needed for the whole of Europe. Nothing less than a continent-wide soil monitoring network will be needed to provide such data. Refining models and improving the resolution and accuracy of spatial data cannot substitute for real measurements.

Finally, soil scientists must work increasingly with scientists from other disciplines, for example biologists, geologists, chemists, mathematicians, statisticians, ecologists, social scientists and economists to address the problem of soil erosion. It is a complex problem requiring a multidisciplinary approach. There also needs to be general acceptance by the public and policy makers alike that society as a whole has been abusing the soil environment in Europe to such an extent that to do nothing in response could spell disaster for the future. Rectification and amelioration for past and present abuses will cost money and the richer countries must help the poorer countries in Europe in this endeavour.

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7 Glossary

AVHRR	Advanced Very High Resolution Radiometer
CAP	Common Agricultural Policy
CEC	Commission of the European Communities
CORINE	Co-ordination of Information on the Environment
DPSIR	Driving force-State-Impact-Response
EEA	European Environmental Agency
ETC/S	European Topic Centre on Soil
EU	European Union
GIS	Geographical Information System
GISCO	Geographical Information System for the European Commission
GLASOD	Global Assessment of Human-Induced Soil Degradation
GUI	Graphical User Interface
ISRIC	International Soil Reference and Information Centre
JRC	Joint Research Centre
MARS	Monitoring Agriculture with Remote Sensing
NDVI	Normalized Difference Vegetation Index
OECD	Organisation for Economic Co-operation and Development
PESERA	Pan European Soil Erosion Risk Assessment
RIVM	National Institute of Public Health and Environment (Netherlands)
SEMMED	Soil Erosion Model for Mediterranean Areas
SOTER	Soil and Terrain database
UNEP	United Nations Environment Programme
USLE	Universal Soil Loss Equation
WP	Working Package