Common Criteria for Risk Area Identification according to Soil Threats

Wolf Eckelmann, Rainer Baritz
Stanislav Bialousz, Pavel Bielek
Florence Carré, Beata Houšková
Robert J.A. Jones, Mark Kibblewhite
Josef Kozak, Christine Le Bas
Gergely Tóth, Tibor Tóth
György Várallyay, Markku Yli Halla,
Marko Zupan

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

Institute for Environment and Sustainability

2006

EUR 22185 EN

Frontispiece:

The map for Europe shows the Reference Soil Groups of the World Reference Base for Soil Resources (WRB, 1998). This version of the Soil Map for Europe was produced by Jean Dusart (IES, DG JRC).

The inset photographs illustrate the five soil threats addressed in this report. The authors are grateful to the experts who provided them.

Top right: Rill erosion in the Severn Valley, UK (P.N. Owens)
Lower right: Organic matter decline in the topsoil (NSRI)
Centre: Soil compaction at the base of the plough layer
Lower right: Salinisation in Hungary (Erika Micheli)
Bottom Right: Landslide near Locano, Switzerland

This document may be cited as follows:

Eckelmann, W., Baritz, R., Bialousz, S., Bielek, P., Carre, F., Houšková, B., Jones, R.J.A., Kibblewhite, M.G., Kozak, J., Le Bas, C., Tóth, G., Tóth, T., Várallyay, G., Yli Halla, M. & Zupan, M. (2006). Common Criteria for Risk Area Identification according to Soil Threats. European Soil Bureau Research Report No.20, EUR 22185 EN, 94pp. Office for Official Publications of the European Communities, Luxembourg.

Soil Information Working Group (SIWG)

European Soil Bureau Network (ESBN)

Common Criteria for Risk Area Identification according to Soil Threats

Wolf Eckelmann [(1)], Rainer Baritz [(1)] Stanislav Bialousz [(2)],
Pavel Bielek [(3)], Florence Carre [(4)], Beata Houšková [(4)],
Robert J.A. Jones [(5)], Mark Kibblewhite [(5)]
Josef Kozak [(6)], Christine Le Bas [(7)], Gergely Tóth [(4)], Tibor Tóth [(8)]
György Várallyay [(8)], Markku Yli Halla [(9)], Marko Zupan [(10)]

(1) Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)
Stilleweg 2, 30655 Hannover Germany

(2) Warsaw University of Technology,
Plac Politechniki 1, 00661 Warszawa, Poland

(3) Soil Science and Conservation Research Institute
Garinova 10, 82713 Bratislava, Slovak Republic

(4) Institute for Environment & Sustainability
Joint Research Centre (JRC), Ispra (VA), 21020 Italy

(5) National Soil Resources Institute (NSRI)
Cranfield University, Silsoe MK45 4DT UK

(6) University of Agriculture Prague,
Suchdol, 16521 Praha 6. Czech Republic

(7) Institut National de la Recherche Agronomique (INRA),
Av. Pomme de Pin BP 20619, Ardon, 45160 Olivet France

(8) Research Institute for Soil Science and Agricultural Chemistry (RISSAC)
Hermann Otto ut 15, 1022 Budapest II Hungary

(9) MTT, Environmental Research Centre
31600 Jokioinen Finland

(10) Ljubljana University Centre for Soil and Environmental Science
Jamnikarjeva 101, 1111 Ljubljana Slovenia

MISSION OF THE INSTITUTE FOR ENVIRONMENT & SUSTAINABILITY

The mission of the Institute of Environment and Sustainability is to provide scientific and technical support to EU strategies for the protection of the environment and sustainable development. Employing an integrated approach to the investigation of air, water and soil contaminants, its goals are sustainable management of water resources, protection and maintenance of drinking waters, good functioning of aquatic ecosystems and good ecological quality of surface waters.

LEGAL NOTICE

EUR 22185 EN

Printed in Italy

FOREWORD

This report presents an overview of common criteria and approaches to identify risk areas for the threats Soil Organic Matter (SOM) Decline, Soil Erosion, Soil Compaction, Salinization and Landslides. Soil inventory experts within the European Soil Bureau Network, joined the Soil Information Working Group (SIWG) to provide scientific and technical support to the European Commission's Joint Research Centre (JRC Ispra) for the identification of areas at risk from these threats. For each threat, definitions, methods of inventory and data requirements are provided. Most of the criteria and approaches presented are put forward for open debate to aid national decision making and to establish what is regionally valid depending on data availability. This report should provide a basis for cross-border comparisons and be a catalyst for the development of more detailed definitions and procedures for elaboration and testing of risk area delineation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page No

EXECUTIVE SUMMARY

I. Background

1. This report was prepared by the Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN). It was requested by the Joint Research Centre (JRC) to augment the technical advice JRC was already providing to DG Environment for the identification of areas at risk of five specific threats to soil – erosion, organic matter decline, salinisation, compaction and landslides.

2. The objective of this study was to identify common criteria for the harmonised definition of risk areas within the EU-25 where Member States should take action to assess and manage these risks.

3. An approach to risk area identification is described corresponding to conventional definitions and methodology for risk assessment and management. Firstly, a conceptual model is proposed in which factors (e.g. climate or land use) acting on a receptor (soil) may cause harm, for example erosion, compaction etc. Secondly, the spatial variation in the risk of this harm or threat is assessed either qualitatively or quantitatively (directly or by modelling). Thirdly, risk area categories are proposed, representing different levels of acceptable threat.

4. The intended output is a technical basis for adopting a tiered approach to the assessment and management of soil threats. The first tier should define broad areas within which further measures, such as more detailed risk assessment and possibly management measures, are required. Outside these areas, no further measures have to be taken.

5. Each of the threats is considered separately within a common framework of practical questions.
   (i) What is the required resolution of spatial and other information?
   (ii) What are the data requirements to establish baseline conditions and identify trends?
   (iii) Where models are used, what calibration data is required?
   (iv) What potential is there to use existing data, particularly that available at the European level?

II. Soil Organic Matter Decline

1. Factors leading to Soil Organic Matter (SOM) Decline are identified as climate, soil characteristics as influenced by parent material (e.g. clay content, presence of carbonates and pH), natural vegetation type, topography, land use (e.g. forest, arable, grassland, built environment, etc), land management (method of tillage, irrigation, grazing intensity, etc).

2. A qualitative assessment of threats is explored, in which factors are considered in relation to soil type and the potential for possible SOM loss is identified. For first tier assessment (Tier 1), this requires soil type information at a minimum scale 1:1,000,000 or preferably 1:250,000, as well as land cover and climate information.

3. Quantitative assessment relies on the availability of data on SOM levels or other soil data from which SOM levels can be predicted quantitatively (e.g. by using pedotransfer functions). There is variable coverage of measured SOM levels in the EU-25 member states, but information held in the European Soil Information System (EUSIS) has been combined with pedotransfer functions to provide harmonised and validated estimates of soil organic carbon (SOC) levels in 1km^2 squares covering all of the EU-25 Member States. Conversion of these estimated SOC contents to levels of SOM combined with the application of threshold values (e.g. <2% or >8%), offers a straightforward method to define areas at risk of SOM decline.

However, the application of common thresholds to the whole European area is expected to lead to an uneven application of risk categories. Therefore, Tier 2 assessments using appropriate regional thresholds would be required.

4. Several bio-physical models are available that predict SOM changes, but at this time there is insufficient spatial information to allow their meaningful use to define Tier 1 risk areas. They may have utility when making higher Tier assessments that consider the risks associated with particular combinations of soil type, land-use, etc, where there is a presumption of unacceptable decline in SOM.

5. It is concluded that a combined qualitative and quantitative approach can be used to define Tier 1 risk areas, based on input data with a minimum resolution of 1:1,000,000 or preferably 1:250,000. This is mainly available at the European level for soil (EUSIS 1:1,000,000 scale, sampled at 1km), topography (90m SRTM) and land cover (250m CORINE), although climate data (MARS 50km) is not available at comparable resolutions.

III. Erosion

1. Different types of soil erosion arise from different combinations of factors and soil type. At least water, tillage, wind and geological (e.g. coastal) erosion have to be considered and may require separate assessments, although the extent of these can be assessed against a common measure, namely the loss of soil (sediment) per unit area.

2. Relevant factors which affect erosion are climate, vegetative cover, topography, land use (e.g. forest, arable, grassland, built environment, etc), land management (method of tillage, irrigation, grazing intensity, etc). The response of soil to these factors (erodability) depends mainly on soil characteristics which are influenced by parent material (e.g. particle size distribution, etc), with others such as SOM levels being also important.

3. A wholly quantitative approach to the definition of erosion risk areas is complicated by the number of factors that must be considered and their complex interactions with different soil types. For tillage and wind erosion, however, this is the only practicable approach because sufficient data are not available to support modelling over wide areas. For these types of erosion, Tier 1 risk areas should be defined by reference to recognised combinations of soil type and factors that lead to soil loss e.g. topography and land management for tillage erosion or soil type and land use (cover) for wind erosion.

4. Measurements of water erosion have been made over a number of years but the experimental sites are not numerous, nor are the results harmonised, for example the data are from different years with different weather conditions. Furthermore, the coverage of the EU-25 Member States is sporadic and biased to locations where erosion has already been identified as a problem and/or within reach of research scientists supported to collect erosion data. In conclusion, a truly quantitative basis for the definition of risk areas using site measurements is not possible at this time.

5. A number of competing models for predicting water erosion are available. The Pan-European Soil Erosion Risk Assessment (PESERA) model is considered to be more appropriate for estimating soil loss by rill and inter-rill erosion, under European conditions, than the Universal Soil Loss Equation (USLE), which was developed in North America. Most data requirements of the PESERA model can be met for a Tier 1 risk area delineation, either directly or by derivation from available data - soil (EUSIS), topography (SRTM), land cover (CORINE), land use (NUTS3) and precipitation (MARS). However, the PESERA model requires further validation and testing at sites providing representative combinations of soil type and erosion factors, if it is to be relied on for a European-wide Tier 1 risk area definition.

IV. Compaction

1. Soil compaction is defined as a reduction in soil porosity and a corresponding increase in bulk density, caused by mechanical stress resulting from human activities, leading to a deterioration of one or more soil functions.

2. The main focus should be on compaction arising in agriculture and forestry because of their predominant extent in Europe, although other activities (e.g. construction, outdoor leisure and sports, etc.) may be significant causes of compaction at local level.

3. A major cause of compaction is the use of agricultural and forestry machinery, but the degree of compaction depends on the type of machine and the applied loadings, which relate to the production type and system. Additionally, the impact of machinery on soil is dependent on both soil type and its wetness, so the timing of machinery use is an important factor. Animal movement and density is also an important cause of soil compaction and similarly is variable depending on soil type and wetness.

4. The variety and variability of farming practices, together with a lack of necessary detailed information on their spatial extent and their impacts on different soil types, makes assessment of Tier 1 compaction risk areas uncertain, even on a qualitative basis.

5. Nonetheless, it is proposed that the main stress factors leading to compaction and their spatial extent could be identified, in principle, from information on land cover (CORINE), land use (NUTS 3) and topography (SRTM). Further, the detailed analysis of management practices is needed (e.g. crop systems, stocking densities, etc). The listed information could then be related to spatial soil information (EUSIS) and also to climate data (to assess periods when soil wetness is above a critical threshold).

V. Salinisation

1. Factors leading to excessive accumulation of salts in soil may be natural (e.g. rising groundwater, saline surface and ground waters and marine influence) or anthropogenic (e.g. irrigation, hydrological modification, chemical additions and disposal of saline wastes).

2. Within Europe there are significant areas of saline and sodic soils which have arisen naturally or due to past land management. In addition, some areas are at risk of salt and / or sodium damage. The direction of future management of these soil systems is divergent, with some being required for agricultural production, in which case protection and remediation from salt damage are anticipated, while others are being conserved or modified to provide valuable support for saline habitats.

3. The input data required to identify risk areas includes: soil profile and physical and chemical characteristics, groundwater hydrology and composition, land use, land management, and climate. Although some of this information is available at the European level, this is not necessary given the well-understood regional limitation of salinity problems, which are absent from many EU-25 Member States. The extent of risk areas has been identified in a ‘Map of salt-affected soils in Europe’ (Szabolcs, 1974).

VI. Landslides

1. A landslide may be defined as 'the movement of a mass of rock, debris or earth down a slope'. Landslides belong to one of two types: slow moving or fast moving.

2. It is possible to distinguish driving factors for landslides on the one hand and directly triggering factors for landslide events on the other. Among the driving factors are geology, slope angle, land use, land management and depth of permeability to water. Common triggering factors are intense rainfall or melting snow, less common ones are changed land use, seismic events, etc.

3. The best predictor of areas prone to landslides (Tier 1) is the number of past landslides identified per km^2. Tier 2 risk assessment within areas with an active landslide history can be based on the development of a ground behaviour map which, combined with land use, enables the prediction of landslides and planning of landslide management strategies.

I. Introduction

1. Terms of Reference for the SIWG

The Soil Information Working Group (SIWG) was etsablished at the 2004 plenary meeting of the European Soil Bureau Network (Ispra, November 2004) with the objective of bringing forward the issues of soil data availability and harmonization.

The European Commission is currently preparing a Directive on the protection and sustainable use of soil, building on three elements: the legislative framework (including a Technical Annex), a Communication, and an Impact Assessment. In the context of preparing the Technical Annex, the Commission seeks advice on the common criteria for risk area identification. For this purpose, DG ENV B.1 (Agriculture and Soils) initially contacted JRC Ispra for scientific and technical support, and at the last meeting of the European Soil Bureau Network (ESBN) Steering Committee (SC) (Brussels, 29 April 2005), it was agreed that additional support would be provided through the SIWG.

In order to facilitate the work of the SIWG, DG ENV prepared a written mandate, containing the following key elements:

1) What should be the level of detail of soil information maps/data used as basis for the risk identification?
2) In case models are used, what input data are at least required to assess baseline and trend?
3) How should the models be calibrated?
4) What is the potential contribution of existing Community data or monitoring activities to the risk area identification?

The SIWG has addressed these questions specifically for each of the following threats: *soil organic matter decline, soil erosion, soil compaction, salinisation and landslides.*

The general concept behind the proposed Directive on soil is to be able to target measures on areas where a risk has been identified, e.g. practices to prevent or reduce soil erosion. This requires the identification of the location of the threat. Further implementation of the Directive will need status and trend identification, planning of measures, and validation/success control. In future, the SIWG may be in a position to make recommendations for improved soil inventories and monitoring. Initially, risk categories need to be elaborated for the Directive's Technical Annex, representing a common grading in order to improve the comparability of results/reporting. Furthermore, common criteria need to be identified so that Member States may be requested to identify risk areas according to minimum standards of quality and resolution.

This report presents the results of the first series of brief discussions of soil inventory experts within the mandate of the SIWG. The document contains ideas and knowledge of exemplary experience with risk identification in some countries, mostly limited in quality by the extent of the available soil information. Even though the level of soil information in some EU Member States is high, the availability of digital, well-documented and validated data is generally scarce (Bullock *et al.*, 1999; Jones *et al.,* 2005). This also reduces the comparability of national approaches to soil protection. It should be achievable in the further development of the Soil Thematic Strategy to develop a common framework which attempts to keep the linkage with pan-European data, and thus to provide comparable data which can be interpreted in a meaningful way not only for the Member States, but also for continental-wide Europe.

2. Risk Assessment

Appendix I provides some basic definitions of terms related to risk assessment. Common definitions are difficult to find since the field of application brings important modifications. The main definitions come from the human health risk assessment or chemical risk assessment.

In any risk assessment, a differentiation between the hazard and the likelihood of a hazard occurring (risk) has to be made. The assessment of risk requires a multi-step approach, starting from the identification and description of the hazard, towards a so-called exposure assessment and risk characterization. In environmental protection, the DPSIR concept (OECD, 1993) – Driver, Pressure, State, Impact and Response – was developed in order to address the first two steps in risk assessment.

In the context of the Soil Thematic Strategy, 8 threats were identified representing the most important hazards endangering the functioning of soils. During 2003 and 2004, the Technical Working Groups of the Soil Thematic Strategy were established and operated to assess the soil-relevant DPSIR components with regard to these threats. The resulting reports provide substantial most up-to-date knowledge identifying and describing hazards (threats) to soils (Van Camp *et al.*, 2004a-f). In order to introduce operational focus to soil protection policy, further steps are required, such as the identification and quantification of risk.

The present report provides further ideas on the identification of risk areas in the European Union Member States. This has been done bearing in mind that country-level approaches will need to be based mostly on existing soil information or information likely to become available in the medium-term. The objective was to propose a minimum set of criteria to which all Member States could adhere.

3. Methodological aspects in risk area identification

3.1 Approaches to the identification of soil area at risk

The proposed framework of a soil directive may require the identification of area at risk to soil threats. Considering the requirements of risk assessment, the information needed depends on the methods in risk area identification. Three types of approaches can be distinguished (Figure 1):

1) **qualitative approach** is based on expert knowledge, for example land use in combination with “sensitive soils”, or within other political boundaries using other combined criteria, e.g. nitrate pollution, intensive cropping areas, urban areas, etc.;
2) **quantitative approach** relies on measured data from inventories/monitoring, and requires baselines and thresholds;
3) **model approach** predicts the extent of soil degradation from modelling considering site factors (soil properties, climate) and soil management.

Thresholds initially require that reasonable values are available beyond which degradation of soil properties limits sustainable functioning of the soil. In a further step, data from **soil inventories** or **monitoring** must be available showing where the observed values exceed the thresholds. Even if thresholds, status and trend become modelled, soil inventory/monitoring data are still needed. The **model** approach needs to be eventually supplemented by the quantitative approach, not only for model validation and calibration, but also in order to detect the area where the degradation actually occurs, and to observe the trend after the implementation of measures.

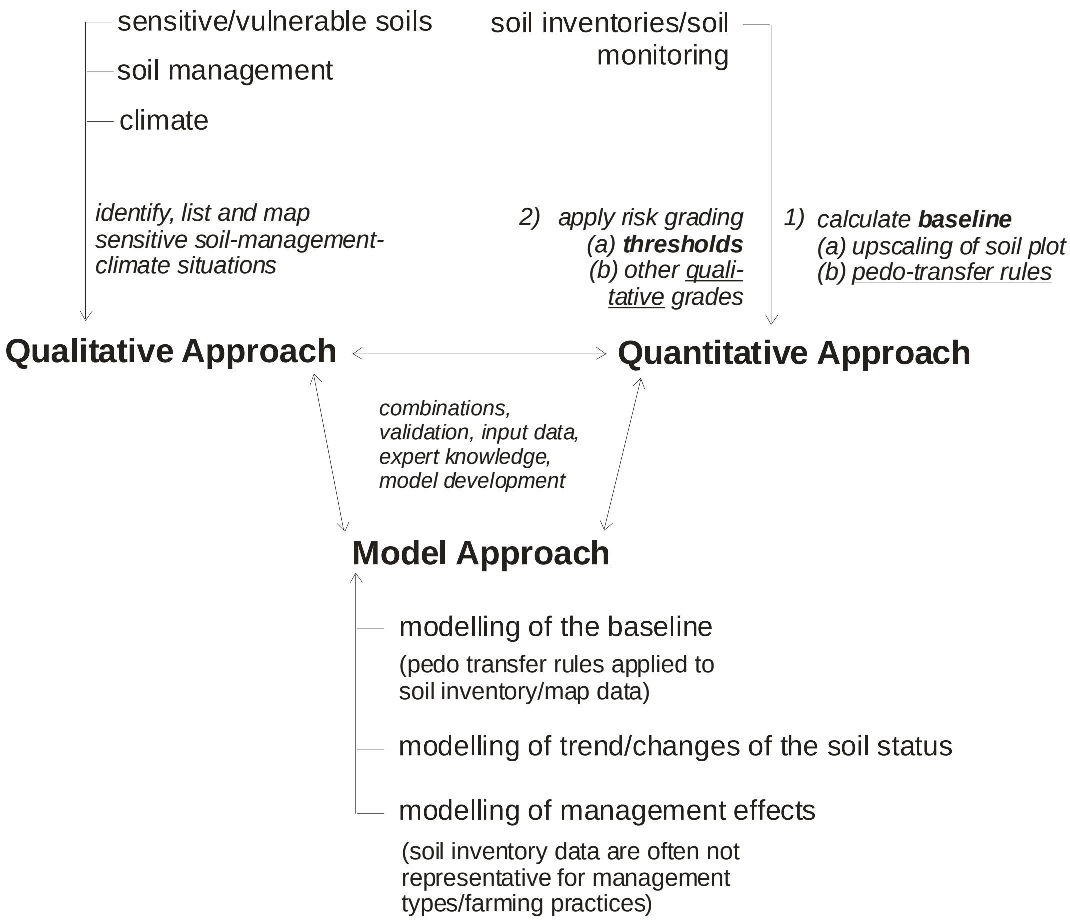

Figure 1: Approaches to Risk Area Identification

Models can also help in approach 1) and 2) to regionalize soil information, extrapolating from the plot-level to the landscape/regional level. On the other hand, models require **calibration** while allowing further stratification (improved consideration of management-level effects) e.g. modelling the effects of agricultural practices, for which monitoring cannot provide representative data due to the high cost involved with collecting the necessary data.

3.2 Method and quality hierarchy – 'Tiers'

The working group has intensively discussed the relationship between current and potential data availability, cost, and quality requirements. It has been found that in a first step to risk area identification, the general area at risk must be derived from existing information (or on data, which are expected to become available soon). The concept will provide broadly defined zones, within which specific measures have to be planned in order to combat the threats to soil. Outside these zones, no further measures would have to be taken, and no specific information about soils is needed in this context. The issue of data quality and map data resolution, political purpose and cost, has to be decided individually by each country. However, from a scientific point of view, changes of the state of soils (e.g. after management change during the implementation phase of a soil protection strategy) can only be detected if a certain quality of data and models becomes available.

These aspects affect the implementation of risk area assessment. Therefore, the concept of tiered approaches is proposed in which 'Tiers" correspond to different work steps, each requiring different data.

Table 1: Tiers in risk area identification

Tier	description	Characteristics
Tier 1	risk area identification	– data must be available – low spatial resolution (probably 1:1,000,000) – qualitative approach, or – model (with pedotransfer functions) approach combined with thresholds
Tier 2	measures/implementation plans to protect soils within the risk zones	– higher spatial resolution (e.g. improved soil maps) – any approach (or combinations) (acc. to Figure 1) – enhanced data need to allow model application

A clear improvement beyond Tier 1 is expected with the availability of soil inventory/monitoring data. In the case of larger scale soil maps such as the 1:250,000 soil map, the improved resolution better serves the requirements in environmental reporting and scenario modelling. At the current stage of data availability, Tier 2 was not further discussed as an alternative for risk area identification, rather referred to the measures/implementation within the risk zones identified using Tier 1.

3.3 Structure of the subgroup reports

Following the information discussed above, the writing task of the working group became structured according to Table 2:

Table 2: Topics to be covered for each threat

Activity	Rationale
1. Definition of threat	Definition of the type of threat; description of the protection concept
2. Identification of factors/hazards related to each threat	Identification of the relevant drivers/factors: environmental or human-induced factors, controlling forces/intensity of the threat
3. Characterization of “receptor” (soil)	Selection of relevant soil properties (including soil type, classification) and identification of the sensitivity towards each threat
4a. Decision on performance specification	Specification of the spatial/temporal resolution: e.g. map scales (1:1Mio, 1:250,000, national larger scales); Tiers relating to different input data, quality and resolution)
4b. Selection of model	Choice of the proper model/relevance of modelling; requirements of model calibration and validation; units of measurement, errors of prediction
4c. Input data availability and data quality requirements	Specification of model input parameters, input databases, cross-border harmonization, plot data density; analytical quality; method of soil data generation; investigation of the role of soil maps and national, regional and EU-wide data sets (e.g. LUCAS, DEM 90 m, climate 50 km grid, CORINE): role of such data as model input, as result validation; role of such data sets for national monitoring and EU-wide harmonization efforts
5. Validation of results	Importance of available long-term monitoring data, model testing/application in pilot areas
6. Definition of **common criteria** for risk area identification	Conclusions from 2), 3) and 4)
7. Grading and presentation	Reporting dimension, definition of risk categories with reference to decisions on performance specification (4a)

Each of the following chapters addressing the various soil threats has followed this structure.

3.4 Bibliography Chapter I

Bullock, P., Jones, R.J.A. and Montanarella, L. (eds.) (1999). Soil Resources of Europe. European Soil Bureau Research Report No.6, EUR 18991 EN, (1999), 202 pp. Office for Official Publications of the European Communities, Luxembourg.

Jones, R.J.A., Houskova, B., Montanarella, L. and Bullock, P. (eds). (2005). Soil Resources of Europe: including Neighboring Countries. European Soil Bureau Research Report No.9, EUR 20559 EN, (2005), 350 pp. Office for Official Publications of the European Communities, Luxembourg.

OECD (1993). OECD core set of indicators for environmental performance reviews. Environmental monographs No.83, Paris.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004a). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume I Introduction and Executive Summary. EUR 21319 EN/1, Office for Official Publications of the European Communities, Luxembourg, 126 pp.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004b). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume II Erosion. EUR 21319 EN/2, Office for Official Publications of the European Communities, Luxembourg, p. 127-309.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004c). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume III Organic Matter. EUR 21319 EN/3, Office for Official Publications of the European Communities, Luxembourg, p. 311-496.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004d). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume IV Contamination and Land Management. EUR 21319 EN/4, Office for Official Publications of the European Communities, Luxembourg, p. 497-621.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004e). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume V Monitoring. EUR 21319 EN/5, Office for Official Publications of the European Communities, Luxembourg, p. 653-718.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004f). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume VI Research, Sealing and Cross-cutting issues. EUR 21319 EN/6, Office for Official Publications of the European Communities, Luxembourg, p. 719-872.

II. Soil Organic Matter (SOM) Decline

Identifying Risk Areas for Soil Degradation in Europe by Soil Organic Matter (SOM) Decline

Members of the Task Group: Mark Kibblewhite (Lead), Rainer Baritz, Marko Zupan, Markku Yli-Halla

Advisors: Eric Van Ranst, Uwe Franko

'Soil organic matter comprises the organic fraction of the soil exclusive of undecayed plant and animal residues. An imbalance between the build-up of soil organic matter and rates of decomposition is leading to a decline in soil organic matter contents in many parts of Europe.'

1. Definition of threat

1.1 Concept

The main objective of soil protection is to maintain soil functions by appropriate land use and management. Protection against the threat decline of Soil Organic Matter (SOM) is critical to sustainable soil management because SOM supports many soil functions (Table 3). SOM levels in arable soils are already reduced or declining further (e.g. Sleutel *et al*., 2004; Lettens *et al.*, 2005). The reasons for this are complex but are likely to include lower inputs of organic manures, elimination of grass breaks in crop rotations and tillage disturbance. Intensification of grassland production may also be causing a decline in SOM levels, while substantial losses of SOM have been reported for higher SOM-containing upland soils (Bellamy *et al*. 2005).

Table 3: Principles for the protection of soils from SOM decline

	Indicator	Information sources/data needs
1	SOM levels under natural vegetation	➢ SOM of natural vegetation (under present conditions), data from forested plots and preservation areas as well as modelled data
2	"optimal" SOM values	➢ threshold values for sustainable soil functioning (may require 1 and/or 4); requires socio-economic data (e.g. crop productivity and cost curves with regard to soil properties and agricultural practices)
3	thresholds for damage due to SOM decline	➢ risk thresholds needed: acceptable level of SOM; socio-economic data needed
4	SOM under current management	➢ regionalization: SOM level and trend for the whole target area (risk area, investigated/reported area) ➢ values for strata (soil + climate + management) ➢ values from real measurements, and/or modelled

The definition of risk areas for SOM decline must take account of the various main factors controlling SOM levels in different European soils and should include at least those identified in Table 4. Ideally, data would be available for all the factors listed in Table 4, but this not realistic. To overcome this difficulty, within operational and cost-efficiency constraints, a pragmatic option is recommended in which information about current SOM levels is combined with expert knowledge on optimal SOM levels and on thresholds for unacceptable harm to soil functions (see also Table 3). This requires the development of a capability for a combination of monitoring and modelling to (a) define baselines, (b) fit available data to reporting schedules, and (c) estimate trends with known confidence.

1.2 Practical Conventions

Soil organic matter (SOM) comprises 'The organic fraction of the soil exclusive of undecayed plant and animal residues' (Soil Science Society of America, 2001)).

Soil organic carbon (SOC) or SOM is measured as a concentration, per unit of dry soil mass, which is often expressed as % by mass. It is essential to specify the compartment in the field to which the measurement refers, in terms of depth from the soil surface or the soil horizons included (e.g. 0-20 cm or 0-30 cm, or, A or Ap horizon). Bulk density is required to allow the estimation of mass of SOC or SOM per unit area (tonnes per hectare).

The following recommendations are made:

- ➢ The relevant soil compartment is 0-30 cm depth. This is consistent with the recommendations of the IPCC and is preferable for soils with deep A horizons and to allow inclusion of organic B horizons in Podzols. However, it should be noted that the mandatory soil depth of ICP Forests Level I and BioSoil inventories is only 0–20 cm.

- Testing methods for SOC should be based on dry combustion and measurement of combustion gases (if wet oxidation or a variant of the Walkley and Black method is used, conversions factors should be applied for more recalcitrant SOC which is not measured).
- The reporting units for SOC should be tonnes per hectare.

2. Identification of factors related to the threat SOM Decline

It is well-known that some agricultural practices cause SOM decline, but this is also occurring in natural and semi-natural areas where agricultural influences are weaker Baritz *et al.* (2004). Additionally, climate change and other indirect human-induced factors such as nutrient inputs from the atmosphere, may present additional man-made pressures on the SOM status of some soils. All these different pressures interact with the natural factors that control SOM status and trends, such as soil type and texture, prevailing climate and vegetation. Table 4 lists those factors that should be considered when defining risk areas for SOM decline.

Table 4: Factors influencing organic matter status of soils

Natural Factors	
climate	precipitation, temperature
parent material	clay/carbonate content, acidity/alkalinity, soil structure
vegetation (natural)	natural vegetation: (a) woodland (b) partially forested: peat/bogs, (c) open land: natural grassland, steppe, open mires
topography	slope, aspect, elevation/altitude

Anthropogenic Factors	
vegetation (managed) [land use and farming system]	a. forest, crop land, grassland, wetland, settlement/infrastructure b. vegetation cover/density, species composition Specific farming systems or land uses affect these factors: temporary or permanent grassland, forest/tree plantation or semi-natural woodland, cropping system (crop rotation)
land management	tillage system, irrigation; grazing intensity, fertilization, melioration practices, cropping system
land exploitation / pollution	sealing; mining; waste disposal, pollutant emissions

Soil type as a site factor is not listed in Table 4 since it is the outcome of all factors acting on the land surface. Nevertheless, *soil type* is important information for risk area identification.

3. Characterization of the receptor soil

Table 5 lists those soils for which there is a more acute risk to SOM decline given specific conditions of climate and land-cover. The list is preliminary and not definitive.

Table 5: Soil, land cover and climate combinations giving rise to higher risks of SOM decline

Soil Description	Land Cover	Climate	Description	Threat
soils with a histic (organic) top soil horizon	arable grassland	all	drained, current or formerly wet soils under arable crops or intensive livestock management	rapid SOM mineralization after drainage and / or tillage and / or nutrient additions
soils with a mollic (dark, base saturated and higher organic matter content) top soil horizon	arable	all	soil in exposed, large open fields (arable land with low proportion of adjacent forest cover)	SOM decline and linked to accelerated water and wind erosion
lowland soils subject to permanent or temporary wetness (Fluvisols, Gleysols, Vertisols)	arable grassland	all	wet soils with higher SOM contents, under arable crops or intensive livestock management	rapid SOM decline after cultivation, enhanced by field drainage
shallow or weakly developed soils, found mainly in upland areas (Leptosols and Regosols)	arable grassland forest	abrupt and heavy rainfall	bare, poorly structured soils on steeper slopes e.g. subject to overgrazing, inappropriate tillage or deforestation	loss of soil and SOM via erosion of top soil
sandy soils with naturally-low levels of SOM in topsoil (Arenosols, Regosols and Podzols)	arable grassland forest	all	tillage and intensification (e.g. by fertilizer applications) of agriculture and forestry on fragile soils	rapid loss of SOM because of weak stabilization of SOM
man-made soils (Anthrosols)	various	all	man-made soils in which SOM has accumulated under one land use, where the land use is changed.	rapid loss of SOM as the soil responds to altered land use and changed soil conditions e.g. water regime

4. Decision on performance specification / selection of model / validation of results

4.1. Qualitative approach

In principle, areas at risk to SOM decline could be identified tentatively, by reference to a list of “at risk” soils, such as that in Table 5. However, more knowledge is required to properly estimate which soils are at risk of SOM decline that leads to an unacceptable loss of soil functions. In particular, knowledge about regional or local conditions is needed. However, to identify areas where there is an enhanced risk of SOM decline, a first step could be to map the occurrence of the combinations of soil type, climate and land cover listed in Table 5. This would then require extension to capture soils where past land-use has significantly reduced SOM, even although the current land-use is not driving SOM decline, and where further land-use change could present high risks of SOM decline. Most importantly, extension is needed to consider chronic as well as acute risk of SOM decline (Table 5 is focused on those combinations leading to more rapid SOM decline, but slower decline is also of concern). For example, sandy-loam to loam soils in hilly or on the lower slopes of mountainous terrain (e.g. Luvisols and Cambisols) are less at risk of rapid SOM decline caused by agriculture, but over previous decades have lost SOM under arable production and may continue to do so.

This qualitative approach requires the following spatial data (see also Appendix III: Auxiliary Data):

- soil types (with soil texture as attribute information), from soil maps
- land cover (grassland, cropland),
- climatic areas.

Depending on the available data and expert knowledge, it may be advisable to combine this approach with specific thresholds derived from the quantitative approaches (see Section 4.2 below).

4.2 Quantitative approach

A quantitative approach to risk assessment for SOC decline requires data on the current spatial distribution of SOC. These 'inventory' data (which are also essential 'baseline' data for subsequent monitoring of changes in SOC) are an essential pre-condition for the objective identification of areas that are at risk of significant SOC decline.

4.2.1 Spatial Distribution of SOC

There are different possibilities for estimating the spatial distribution of SOC.

1. Where SOC is measured at geo-referenced points, statistical techniques can be used to estimate the distribution of SOC between these points. The accuracy of these estimations depends critically on the spatial density of the sampling points. Although adequate inventories exist in some member states to support this approach, at this time there is insufficient European-wide inventory data to support adequate statistical estimation of SOC levels across the continent as a whole.

Box 1: Soil Data Sources for Soil Maps – derivation of attribute data

Attribute data of soil mapping units are needed for the quantitative approach. Such data can be received in different ways:

1) 'standard' soil types describing the 'average"'soil of a mapping unit:
many soil profiles have been investigated, mostly inventories accompanying the production of the soil map; in many cases, profiles cannot be revisited, thus not used for future monitoring; in some case, expert knowledge about soil associations is combined with the evaluation of such plot data bases.
2) selection of a single soil profile typical for each soil mapping unit:
soil inventories such as soil monitoring may yield soil data after selecting typical locations for a certain soil-landscape; in some case not enough soil profile data are available which characterize a soil mapping unit.

2. The SOC content of soils can be estimated on the basis of relationships that have been observed between SOC levels and soil and land attributes (e.g. soil type and texture, terrain, land cover, climate, etc). This 'pedotransfer rules (PTR)' approach is inherently approximate (as it relies on statistical relationships between factors which are simplifications of reality). But it is able to produce valuable information efficiently, particularly where good quality input parameters are available already, which is substantially the case at the European scale. For example, the following information is accessible:
   - European Soil Database (EUSDB):
     (i) Soil Geographical Database of Europe (SGDBE) at an effective 1:1,000,000 scale identifies the distribution of Soil Typological Units (King *et al.* 1994, 1995; Heineke *et al.* 1998)
     (ii) Pedotransfer Rules (PTRs) have been developed to support the estimation of SOC using the SGDBE, although these have only been validated for some combinations of climate and land cover (Van Ranst *et al.* 1995; Jones *et al.* 2005).
   - National or Regional Databases:
     Many member states have databases of soil types and properties at effective scales better than 1:1,000,000 and in some, but not many, cases PTRs have been developed to support the estimation of SOC (examples see Van Camp *et al.* 2004c, p.329-352).

There is an existing “Map of Organic Carbon in Top Soils in Europe” (SP.I.04.72) based on the use of a PDR for SOC estimation from SGDBE, digital terrain mapping data, climate data and land cover data, which provides estimates of soil SOC contents on a 1 km grid (Jones *et al*., 2005).

It needs to be stressed that the risk assessment and the delineation of areas of higher risk of SOC decline cannot be done purely on the basis of the distribution of SOC. In addition, an estimation of the probability of further decline is needed.

4.2.2 Risk evaluation

The extent to which SOM decline is unacceptable depends on the consequences for soil functions and the services which these support, such as food production, groundwater protection, biodiversity conservation, etc. The acceptability of SOM decline can be evaluated by reference to Tier 1 threshold SOC levels. Mainly, such thresholds are useful to define a base content below which further SOM decline may lead to unacceptable damage to soil functions. In addition, because large absolute losses of SOC may occur from peaty and other highly organic soils even when the proportional loss is relatively small, it may be necessary to define ‘ceiling’ SOC threshold levels, above which the risk of absolute losses of SOC is a concern.

Thresholds should reflect soil type, land characteristics and land use, and the definition of binding common thresholds for all regions of Europe would be ineffective and lead to inefficient resource allocations. The Technical Working Group on Organic Matter of the Soil Thematic Strategy (Van Camp *et al*., 2004c) agreed that only very general thresholds can be proposed for SOM Decline (Table 6). Certainly, the definition of thresholds, upon which to base decisions about risk management, has to be subject to regional subsidiarity.

Table 6: Preliminary approach to identify first Tier thresholds for SOC levels

Soil < 2% SOC	Arable soils, in particular those that are managed in continuous arable production, especially where tillage is intensive
Soil > 8% SOC	Drained, current or formerly wet soils under arable crops or intensive livestock management

The definition of SOC thresholds is very problematic since some soils have naturally low SOC, with a very small likelihood of further SOC losses, while some soils with intermediate SOC contents may be at high risk of continuing losses. In addition, technology is available that supports sustainable management of soil with low SOC levels. Ideally, regionally defined and validated thresholds would exist, but this is not the case at present. Research to establish regional thresholds is a priority.

4.3 Model approach

The use of PTRs has been discussed above (4.2.1). This section explores the use of soil biophysical models. These can be used to estimate baseline values from input factors, but also allow forecasting of temporal trends. The most valuable feature of such models, for risk assessment, is that they support investigation of management effects on future SOC trends, although models that can simulate the turnover of organic carbon in soils have high input data requirements.

Criteria that are relevant to deciding which models are practical for informing risk assessment and management include the following.

- The quantity of input data required should be reasonable and accessible without excessive resource requirements

- The output from the model should be available without the need for complicated subroutines.

Table 7: Resolution and data requirements of the most common SOC/SOM models

Model	**EPIC** (includes CENTURY)	**ROTH-C**	**DNDC** (forest: Pnet N DNDC)	**CANDY-Carbon Balance**
temporal resolution	daily	monthly	monthly	annual
crop practices	plough type, chisel type, sequence of equipment used, etc. – exact timing of each practice	residue quality; residue C input	crop area, yield, planting and harvest date, percentage litter, till method	ploughing depth
other management data	element input from fertilizer; type and water amount of irrigation; crop rotations	soil cover, manure C input	➢ type and amount of fertilizer, fertilizer composition ➢ manure rate	➢ type and amount of fertilizer and manure ➢ crop productivity/crop rotation
other input data	➢ soil data per horizon/depth class (pH, textural class, slope, SOC, bulk density)	➢ pH, clay, SOC, bulk density, inorganic soil C) ➢ climate: rainfall, temperature, evapotranspiratio n	➢ soil data (pH, clay, SOC, bulk density) ➢ climate ➢ N deposition	➢ pools/fractions of SOC (constants are offered) ➢ initial value of SOC ➢ bulk density (can be derived using SOC and clay) ➢ clay content

DNDC: Kesik *et al.* 2005 (submitted); Candy: Franko (2005); EPIC: Izaurralde *et al.* (2001); Roth-C: Falloon and Smith (2002)

Data from representative long-term experimental plots are needed for calibration of models that are useful for interpreting the impacts of different soil management scenarios. As an example, 200 outputs were compiled from experiments running for more than 10 years by Kolbe and Prutzer (2003) to support application of the CANDY-Carbon Balance model for eastern German soils. The model was found to predict SOC changes for light and heavy soils, under different cropping and types and amounts of fertilizers, with varying adequacy. However, it clearly under- or over-estimated SOC changes for some combinations of soil type and land management.

The compilation of data for the application of a specific model requires considerable effort. The models included in Table 7, normally require information on the easily biodegradable and mineralized (labile) fraction of SOC, but this is only available for some soils in a limited number of locations. Even models with a low temporal resolution (e.g. CANDY-Carbon Balance), require estimation of different SOM fractions. For example: CANDY-CB derives the labile SOC content of organic manures from the applied amount, the amount of dry matter, the SOC concentration of the dry matter, and a specific synthesis coefficient. However, such information is not generally available, and experimental field research plots are preferred to provide data of sufficient quality for use in models.

The constraints on model use, described above, suggest that their use is not feasible to support Tier 1 risk assessment of SOC decline, certainly at the European scale. Nonetheless, they could be useful for higher Tier risk assessments and for evaluating the likely outcomes of different risk management measures.

4.4 Spatial and temporal resolution of model input and monitoring data

Soil Maps

The 1: 1,000,000 Soil Geographical Database (SGDBE) can be used initially, e.g. at Tier 1, to identify risk areas provided that other criteria for the identification of risk areas are met (see section 4.1).

Several baseline soil carbon maps (1:1,000,000) have been recently produced in various EU-25 Member States (e.g. Jones *et al*., 2004; Arrouays *et al*., 2001; Landscape Atlas of the Slovak Republic, 2002). A limited comparison of the results from different regional data resolutions is available (e.g. CarboInvent). Neufeld (2004) has used a 1:200,000 map of NUTS 1 Baden-Württemberg and compared the results with the data from a related 1:1,000,000 evaluation for the 2004 UNFCCC National Inventory Report (NIR) for Germany. The proportion of certain soils assigned to land cover classes is quite different. The 1:200,000 shows significant improvement over the 1:1,000,000. This suggests that for a higher Tier risk assessments e.g. within Tier 1 risk areas, a spatial resolution of 1:250,000 or higher is needed, because otherwise the errors in estimating areas of increased risk are too large.

Data requirements and resolutions for other data types are presented in Section 5.

4.5 Conclusions

4.5.1 Approaches

Prescription of one approach to SOM risk assessment for use in all EU-25 member states does not seem feasible. Rather, the approach should be justified by the following considerations.

- Input data should conform to a minimum spatial resolution appropriate to the level of risk assessment being made which increases progressively beyond Tier 1 (see below).
- The assumptions inherent in particular predictive models should be described and their validity for target areas assessed.
- The outputs from the application of models should be corroborated by validation data to the fullest possible extent.

4.5.2 Spatial resolution

A tiered approach is appropriate where representative regional data (medium-scale soil maps, monitoring data) are not yet available. At the coarse data level (Tier 1), adequate risk area identification may rely on 1:1,000,000 scale input and spatial data. The output from this can then be used to identify and delineate a target area for further, more detailed action (Tier 2) for which better data at a finer spatial resolution will need to be collected, typically at least in the range between 1:200,000 to 1:300,000.

A map of estimated SOC for a 1km grid across Europe has been produced (Jones *et al*., 2004, 2005). This is useful for Tier 1 risk assessment but for subsequent Tiers, Member States will need to at least use a PTR approach to prepare map at better (e.g. 1:250,000 or better) spatial resolution, which will require soil type information at adequate resolution, or otherwise estimate SOM levels by other means (such as statistical estimation from measured SOC).

4.5.3 Soil Monitoring

Soil monitoring for SOC changes is needed to evaluate the effects of risk management measures, such as land use change, on SOC decline.

4.5.4 Thresholds

The use of thresholds is an effective means for achieving a harmonized approach to risk assessment for SOM decline, particularly at Tier 1. However, the definition of lower and upper threshold values for Tier 1, and subsequent risk assessments, is complex and a single set that is applicable to all of Europe cannot be defined properly. Regional and local information is needed to define thresholds. This is not completely available and there is a need for research to properly define regional thresholds.

4.5.5 Synthesis

A qualitative approach to risk assessment is useful, but depends on the availability of adequate expert knowledge, particularly to allow proper regional interpretations. As such knowledge is difficult to validate, the qualitative approach should normally be considered to be preliminary.

A quantitative approach combined with thresholds provides a good basis for a Tier 1 assessment of the risk of SOM decline and evaluating its acceptability.

5. Summary

5.1 Criteria for risk area selection/Threat SOM Decline

1) **qualitative** approach (see Figure 1)	requires refined soil map – land use GIS map integration

and/or

2) **threshold** (e.g. SOC < 2%, and SOC > 8%)	requires a baseline calculated at national scale (SOC levels per country/risk area) based on soil data (inventory points with measurements) or modelling; modelling may also be needed to extrapolate the soil inventory data. Data on climate and land use is also needed for modelling.

Both approaches can be combined.

3) **model** approach	cannot be independent of 1) and/or 2) because it requires the definition of the actual risk; modelling provides SOC status and trend: *high*, *medium*, *low*, etc., related to soils, soilscapes, soil management, etc.

It is envisaged that Member States or possibly the Commission would identify broad areas that are at risk of SOM decline, based on a risk assessment linked to lower resolution spatial data. This Tier 1 outcome would then be followed by tier 2 assessment and actions that could take various forms, including risk assessment at a finer (regional / local) spatial scale and monitoring. For Tier 2, data are required at a resolution of 1:250,000 or better.

Data need/Level of detail:

Soil Maps: delineation of soil typological units (STU), generally through soil mapping units (SMU) for the whole country	**Tier 1**: identification of risk zones; reporting (1:1,000,000) **Tier 2**: action plans, monitoring (larger scale than 250,000)
Soil Classification: World Reference Base (WRB, 1998, 2006)	The comparability between countries can be improved if national soil data (including soil mapping data) are translated into WRB
Soil Map Data: typical profile descriptions and standard data for the soil typological units (STU)	Improve digital soil data availability for fully described soil profiles; set up information system to combine plot data with map data
Topography: 250 m	Digital Elevation Model exists based on SRTM 78m
Land Cover: 250 m	exists based on CORINE land cover for many countries. Ideally the spatially explicit distribution of crop types is known
Climate: 250 m	does not exist at the European level where only data on a 50-km grid exist (MARS project); National data are thus required

Land Use	➢ in contrast to land cover 250m, more accurate information about the abundance of land use categories (e.g. agricultural practices) is needed for soilscapes/administrative boundaries/250 m grid cells: at least, **NUTS Level III** should be considered
Soil Management	➢ litter input/production coefficients per crop ➢ crop-specific typical agricultural practices ➢ expert system for crop selection and soil properties (needed to more accurately spatially disaggregate soil-related statistical land use data)
Analytical Data	➢ soil depth: 0-30 cm, or A and B horizons with their depth ➢ parameters: SOC, soil inorganic carbon (SIC), pH, base saturation, N, P, bulk density, stone content, and thickness & weight of O layer horizons ➢ dry combustion/elementary analysis (wet oxidation does not fully detect SOC; loss on ignition needs a conversion factor, which also introduces error)

5.2 Risk categories

Risk categories define typical levels of risk: high risk means that a soil, which is susceptible and at the same time managed in a non-sustainable manner is likely to lose SOC. At some point, this loss will cause a threshold to be crossed at which the loss of soil functions is not acceptable.

It is clear that there are different possible approaches for defining risk categories and that consistent interpretation of these depends on well-defined procedures and protocols.

6. Bibliography Chapter II

Arrouays, D., Deslais, W. and V. Badeau (2001). The carbon content of topsoil and its geographical distribution in France. Soil Use and Management 17: 7-11.

Baritz, R., De Neve, S., Barancikova, G, Gronland, A., Leifeld, J., Katzensteiner, K., Koch, H-J., Palliere, C., Romanya, J., Schaminee, J. (2004). Land use practices and SOM. In: In: L. Van-Camp, B. Bujarrabal, A-R. Gentile, R.J.A. Jones, L. Montanarella, C. Olazabal and S-K. Selvaradjou (2004c). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume III Organic Matter. EUR 21319 EN/3, p.439-465. Office for Official Publications of the European Communities, Luxembourg.

Bellamy, P.H., P.J. Loveland, R.I. Bradley, R.M. Lark and G.J.D. Kirk (2005). Carbon losses from all soils across England and Wales 1978-2003. Nature 437: 245-248.

Falloon, P. and P. Smith (2002). Simulating SOC changes in long-term experiments with RothC and Century: model evaluation for a regional scale application. Soil Use and Management 18: 101-111.

Franko, U. (2005). Integrierte Methodik zur Bewertung der ökologischen und ökonomischen Entwicklung landwirtschaftlicher Bodennutzung im Bundesland Sachsen-Anhalt. Umweltforschungszentrum Halle-Leipzig (unpublished project report).

Hiederer, R., R.J.A Jones and L. Montanarella (2004). Topsoil Organic Carbon Content in Europe. Special Publication Ispra 2004 No.72, map in ISO B1 format. European Communities. SP.I.04.72..

Heineke, H.J., Eckelmann, W., Thomasson, A.J., Jones, R.J.A., Montanarella, L. and B. Buckley (1998). Land Information Systems: Developments for Planning the Sustainable Use of Land Resources. European Soil Bureau Research Report No.4, EUR 17729 EN, 545 pp. Office for Official Publications of the European Communities, Luxembourg.

Izaurralde, R.C., J.R. Williams, W.B. McGill, and N.J. Rosenberg (2001). Simulating soil carbon dynamics, erosion, and tillage with EPIC. 1st National Conference on Carbon Sequestration, U.S. Department of Energy – National Energy Technology Laboratory, 14-17 May, Washington, D.C. http://www.netl.doe.gov/publications /proceedings/01/carbon_seq/5c2.pdf.

Jones, R.J.A., Hiederer, R., Rusco, E., Loveland, P.J. and L. Montanarella (2004). The map of organic carbon in topsoils in Europe, Version 1.2, September 2003: Explanation of Special Publication Ispra 2004 No.72 (S.P.I.04.72). European Soil Bureau Research Report No.17, EUR 21209 EN, 26pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg.

Jones, R.J.A., M. Yli-Halla, A. Demetriades, J. Leifeld, M. Robert. (2004). Status and distribution of Soil Organic Matter in Europe. In: L. Van-Camp, B. Bujarrabal, A-R. Gentile, R.J.A. Jones, L. Montanarella,

C. Olazabal and S-K. Selvaradjou (2004c). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume II1 Organic Matter. EUR 21319 EN/3, p. 329-352. Office for Official Publications of the European Communities, Luxembourg,

Jones, R.J.A., Hiederer, R., Rusco, E. and L. Montanarella (2005). Estimating organic carbon in the soils of Europe for policy support. European Journal of Soil Science 56: 655-671.

Kesik, M., P. Ambus, R. Baritz, N. Brüggemann, K. Butterbach-Bahl, M. Damm, J. Duyzer, L. Horvarth, R. Kiese, C. Li, G. Seufert, D. Simpson, U. Skiba G. Smiatek, T. Vesala and S. Zechmeister-Boltenstern (2005). Inventory of N_2O and NO emissions from European forest soils. (submitted to Biogeosciences).

King, D., Daroussin, J. and R. Tavernier (1994). Development of a soil geographical database from the soil map of the European Communities. Catena, 21, 37-26.

King, D., Jones, R.J.A. and A.J. Thomasson (1995). European Land Information Systems for Agro-environmental Monitoring. Office for Official Publications of the European Communities, Luxembourg, EUR 16232 EN, 285 pp.

Kolbe, H. and I. Prutzer (2003). Überprüfung und Anpassung von Bilanzierungsmodellen für Humus an Hand von Langzeitversuchen des Ackerlandes. Sächsische Landesanstalt für Landwirtschaft, Leipzig (unpublished report).

Landscape Atlas of the Slovak Republic. (2002). 1st Edition. Bratislava: Ministry of Environment of the Slovak Republic. Banska Bystrica: Slovak Environmental Agency 2002, 344 pp. ISBN 80-88833-27-2.

Lettens, S.(2005). Assessing source-sink behaviour of soil organic carbon pools in a spatially-explicit bottom-up approach. Katholieke Universiteit Leuven, Department Landbeheer. PhD Thesis, 2005.

Neufeld, H. (2004). Carbon stocks and sequestration potentials of agricultural soils in the state of Baden-Württemberg, Southwest Germany. Journal of Plant Nutrition and Soil Science.

Sleutel, S., S. De Neve and G. Hofman (2004). Estimates of carbon stock changes in Belgian cropland. Soil Use and Management 19: 166-171.

Soil Science Society of America (2001). Glossary of Soil Science Terms. 170pp.

Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (2004c). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume III Organic Matter. EUR 21319 EN/3, Office for Official Publications of the European Communities, Luxembourg, p. 311-496.

Van Ranst, E., Thomasson, A.J., Daroussin, J., Hollis, J.M., Jones, R.J.A., Jamagne, M., King, D. and Vanmechelen, L. (1995). Elaboration of an extended knowledge database to interpret the 1:1,000,000 EU Soil Map for environmental purposes. In: European Land Information Systems for Agro-environmental Monitoring. D. King, R.J.A. Jones and A.J. Thomasson (eds.). EUR 16232 EN, p. 71-84. Office for Official Publications of the European Communities, Luxembourg.

WRB (1998). World Reference Base for Soil Resources. World Soil Resources Report No.84, FAO, Rome, 88 pp.

WRB (2006). World Reference Base for Soil Resources 2006. A framework for international classification, correlation and communication. World Soil Resources Report No.103, FAO, Rome, 142 pp. ISBN 9251055114

III. Soil Erosion

Identifying Risk Areas for Soil Degradation in Europe by Erosion

Members of the Task Group: R J A Jones (Lead), Christine Le Bas, Josef Kozak

Advisors: Olaf Düwel, Dominique King

'Erosion is a physical phenomenon that results in the removal of soil and rock particles by water, wind, ice and gravity. Most present-day concerns about soil erosion, leading to its perception as a process of degradation, are related to accelerated erosion, where the natural rate has been significantly increased by human activities

1. Introduction

The Final Report of the Technical Working Group (TWG) on Soil Erosion, convened by DG ENV as part of the consultation process for developing a Soil Thematic Strategy for Soil Protection in Europe, provides a comprehensive summary of the problem of soil erosion in Europe as it relates to the preparation of a draft Soil Framework Directive (1). The Mandate from DG ENV for this Task of SIWG specifies the need to identify risk areas (or zones) for soil erosion. The Task 2 Status report of the TWG Soil Erosion is the most relevant background document (2) in this context.

In the first instance, identification of a risk area or zone requires defining the spatial dimension (component) and secondly (in future) the temporal dimension. The following are key aspects of the risk assessment:

1. level of detail;
2. measurement or prediction of current level of risk;
3. prediction of future trend for that risk.

The Mandate for the ESBN SIWG specifies three options to define risk areas (zones):

1. empirical - on-site measurement;
2. modelling – calibrated with real data;
3. combination of 1 and 2 above.

An important deliverable is the definition of common criteria for the identification of risk areas (zones) and, to achieve this, the following need to be specified:

1. spatial resolution required to define risk areas;
2. risk measurements already undertaken;
3. modelling:
   - models available;
   - data requirements;
   - calibration/validation;
4. useful links to existing European data sets – CORINE (3), CIS (4), LUCAS (5), ICP Forest Focus (6), European Soil Database (7, 8) Agricultural Statistics data, e.g. from Eurostat (http://epp.**eurostat**.cec.eu.int/pls/portal), MARS Agroclimatic Database (http://mars.jrc.it/), NUTS (Nomenclature of Territorial Units for Statistics) as used by Eurostat (see also Appendix III: Auxiliary Data).

Important considerations remain:

1. subsidiarity should be optimized (9)
2. maximum use should be made of existing inventory and monitoring systems activities and other sources of information (10);
3. risk assessment, particularly the definition of areas at risk from the particular threat is the primary objective, not collection and harmonisation of soil data.

2. Definition of Soil Erosion

There are many definitions of soil erosion and a summary of the most relevant is included in Appendix I. The most appropriate for this task is:

> 'Soil erosion is the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere'.

This definition is very broad and, because soil erosion is normally a natural process occurring over geological timescales, only where (and when) the natural rate has been significantly increased by anthropogenic activity, should accelerated soil erosion be perceived as a process of degradation and therefore a threat in the context of soil protection (2).

The following types of erosion have been identified (2):

Water erosion, by rill and inter-rill, gully, snowmelt, and of banks in rivers and lakes;

Translocation erosion by tillage, land-levelling, harvesting of root crops, trampling and burrowing animals;

Wind erosion, by the action of strong desiccating wind;

Geological erosion: internal subterranean erosion by groundwater, coastal erosion and landslides.

Landslides, including debris flows, other forms of geological erosion are reported in another SIWG Task group report.

3. Factors (or Hazards) related to the threat of soil erosion

As for most threats to soil, there are natural and anthropogenic factors at work (Table 8).
These factors can:

- cause direct detachment of soil, determining *erosivity* and consequently the probability that the soil will be eroded; for example precipitation (by rainsplash, rainflow), river or stream flow, wind; in the case of rainfall *erosivity* will depend on duration and intensity;
- protect the soil from erosion pressures, generally by vegetation or crop *cover*;
- affect *runoff* and accelerate erosion, and or define the part of the landscape where sediment will be deposited; for example *angle of slope* and its *length*;
- modify the impact of other factors, e.g. by *ploughing*, *terrace construction*.

Table 8: Factors affecting erosion

Natural Factors	Anthropogenic Factors
climate: precipitation, evapotranspiration, temperature, wind speed & direction	climate change?
parent material/soil: particle size (sand, silt content), susceptibility to crusting, aggregate stability	tillage, cultivation translocation
vegetation/land cover: natural or climax	land use/land cover: arable, grassland/pasture, forest, semi-natural. land management: e.g. irrigation; grazing intensity; cropping systems
topography: slope angle, slope length, surface geometry	land levelling, terrace construction, burrowing animals

4. Characterisation of the receptor

For the assessment of risk, the receptor, in this case ‘soil’, must be characterized. With respect to erosion, this normally requires data on particle-size grade e.g. sand and silt contents and some recent approaches extend this data requirement to properties that can be used to estimate the tendency of soils to slake and cap, also called the sensitivity to *crust*. A sealed or crusted (capped) surface can increase runoff and encourage accelerated soil erosion (11, 12).

With a very slow rate of soil formation (13), any soil loss of more than 1 t/ha/yr could be considered as irreversible within a time span of 50-100 years. Losses of 5-20 t/ha/yr can have serious effects, both on- and off-site (14). Soil losses of 20-40 t/ha/yr can result from individual storms and, more extreme events that may occur once every two or three years, can lead to losses of more than 100 t/ha/yr (2). These large losses, computed from research studies, can have catastrophic effects at local level and serious off-site consequences.

5. Model selection, input data and performance specification

There is no single method that can be used to define the loss of soil caused by all the different types of erosion listed above in section 2. For example, models exist to estimate soil loss by water, through rill and inter-rill erosion, but some of these are not suitable for accurately assessing losses by gully erosion.

Soil loss by snowmelt erosion is restricted in extent, and modelling requires a different approach (15). Translocation (including by tillage) is anthropogenic and must also be treated separately (16). Models exist for wind erosion (17, 18) but the data on wind strength and direction, needed to run such models, are generally lacking at the required resolution.

For the purposes of legislation, it is essential to have a definition of erosion that is supported by a well-defined and comprehensible parameter, such as loss of soil (sediment) per unit area, backed up by an acceptable method of measurement. However, as the threat is not natural erosion, but increased erosion due to human activities, it is important to be able to distinguish between the natural soil loss in a certain area from loss of soil caused by human activities, for example, by a particular land use or land management practice. Validated and calibrated models can be used to distinguish between natural erosion and current erosion by simulating soil loss under the actual land use and comparing this with soil loss simulated under natural conditions of erosion.

A number of models for assessing the risk of erosion and predicting actual sediment loss have been developed over the last 40 years. Most of these models mainly address water erosion by attempting to combine:

1. likelihood of the soil to erode - the *erodability*;
2. effect of excess precipitation - the *erosivity*;
3. degree of protection provided by vegetation or crops - the *cover* factor;
4. geometry of the landscape - the *angle* of *slope* and its *length*.

Sediment loss can effectively be measured at a point (site), in a field, over a catchment or over another bounded area. For policy making and implementation purposes, consideration must be given to providing results integrated on a landscape or administrative unit basis, e.g. catchment (4), NUTS (2, 19), region or national level. An advisory as well as precautionary approach should be adopted, with some degree of standardization.

At the same time, there is a need to recognise that measurement of sediment loss cannot be made with the same accuracy or reproducibility as measurements of individual soil properties, such as content of clay, organic carbon, or metal content (10). Erosion is a complex phenomenon that results from the combined effect of a number of soil and other environmental properties acting on the land surface, and can only be quantified as actual soil (sediment) loss.

Water erosion, mainly rill and inter-rill erosion, is the most widespread form of physical soil loss (by removal) in Europe (2). A number of models for assessing water erosion, applied at European level have been reviewed (2, 14). At European level, the most widely applied model is the Universal Soil Loss Equation – USLE (20), although in some places the recently revised form – RUSLE (21) has been used.

In principle, the Pan-European Soil Erosion Risk Assessment model – PESERA (22) is considered to be more appropriate for European conditions than the USLE and its variants, because it computes runoff by a methodology that is more appropriate for European conditions. However, it has only become operational recently (in 2004) and further testing and validation would be desirable. Other models that have been applied include EUROSEM (23), the Morgan-Finney erosion Model (24) and the INRA expert approach of estimating risk class that can be related to soil loss (2).

6. Identification of areas at risk of erosion

Areas at risk of accelerated soil erosion could be identified primarily on the basis of soil loss predicted for a standard spatial unit. For example, this could be a grid of 1 km resolution (25), a catchment (4) or an administrative unit (NUTS). A 1 km grid is an appropriate spatial resolution for Europe as a whole (at *Tier 1*), at the present time, because most of the data needed to estimate soil losses already exist at this resolution. Table 9 lists the types of erosion that are thought to occur in EU Member States and Accession countries, based on (2) p.162.

Table 9: Types of erosion: occurrence at national level

Country	Rill & Interrill	Gully	Snow melt	Bank	Tillage	Animals	Wind	Land-slides	Ground water	Coastal
Austria	XX	X	XX	XX	X	N	?	XX	N	N
Belgium	XX	X	N	X	X	N	X	X	N	X
Bulgaria	XX	XX	XX	X	X	X	X	X	?	N
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
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
Malta	X	XX	N	N	N	X	N	X	X	X
Netherlands	X	N	N	?	N	?	X	N	N	?
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
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
United Kingdom	XX	X	X	XX	X	XX	X	X	X	X

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

An estimated soil loss > 2 t/ha/yr could be a more appropriate threshold for the delineation of risk areas at *Tier 1* than 1 t/ha/yr.

7. Validation of model results

Accelerated soil erosion can be assessed as:

1. measurement of soil loss from plots (26);
2. measurement of sediment loss from river basins or catchments (27);
3. estimation of soil (sediment) loss per unit area or class estimation by modelling;
4. expert judgement of the loss of soil from a plot, hillslope, river basin or catchment, or other spatial unit (e.g. administrative unit).

Measuring or estimating accelerated soil erosion, as sediment loss or by expert judgement, is different from measuring other parameters such as soil texture or organic carbon content because there are no agreed standard methods and the time dimension for erosion processes to operate is an order of magnitude less than that for other soil parameters. For example, a severe erosion event lasting a few hours can result in very large losses of soil whereas, unless soil is removed completely, a reduction in the organic carbon content normally only takes place over several years, or even decades and the formation of soil particles by natural weathering processes can take thousands of years.

Soil erosion has been measured sporadically throughout Europe, mostly at experimental research sites, but few good quality long-term erosion data sets have been collected and access to these data is often restricted by data copyright (28). Furthermore, erosion has been measured mainly at sites not only where erosion is noticeably a problem but also where research groups have been able to install equipment to make regular measurements.

Even if all the measurements of erosion (as sediment loss) obtained at these experimental sites were made available, they are far too sparse to provide a consistent picture of what is happening in the landscape, at regional, national or European level. Depending on the size of the measuring site, some eroded sediment may even be deposited within the experimental area so that soil loss is sometimes obscured. However, the results that do exist are the only quantitative information available to calibrate soil erosion models. Estimated soil losses obtained from models should be validated in future by progressively establishing (or re-establishing) fully instrumented measuring sites in the main agro-ecological zones of Europe, with a view to long-term operation (e.g. http://www.sowap.org).

Data sets

Common Criteria	Data Source/Type of Information	Data Quality / Resolution	
		Tier 1	Tier 2
soil typological unit (STU); soil mapping unit (SMU)	national soil databases	national level	regional level
soil texture (at STU level)	texture class; sand, silt and clay content	texture class	particle size
density, hydraulic properties (at STU level)	bulk density, packing density, water retention at field capacity and wilting point	pedotransfer rules or functions	measured data
topography	gradient (slope), length, geometry, Digital Elevation Models	250 m (SRTM)	90 m
land cover	localisation of land cover type (e.g. CORINE land cover data)	250 m	100 m
land use	land use, agricultural statistics (e.g. to distinguish between crop types)	NUTS3	NUTS4
climate	precipitation: rainfall, snowfall, number of rain days, storm events PET, temperature	10 km daily average 50 km daily average	1 km raster (modelled from national weather station network) daily – 30 years
hydrology	Catchment Information System Digital Elevation Model	10 km	1 km
agro-ecological zone	based on soil, climate & landscape	50 km	1 km

8. Common criteria for identification of areas at risk

These are:
1. soil criteria: particle-size, likelihood to form a crust (11, 12), drainage status/degree of water logging, organic carbon content;
2. topographic criteria: slope angle, length and geometry;
3. climatic criteria: rainfall (intensity and amount), evapotranspiration (amount), wind (speed and direction); temperature (maximum and minimum);
4. land cover criteria: land cover/land use.

9. Proposed approach

I. It is advisable that each Member State provides accurate information to update Table 9.

II. Each Member State may then delineate areas at risk of accelerated soil erosion by estimating soil loss, for each 1 km x 1 km unit falling wholly or partly within its national boundaries, as a result of:

1. *Water erosion*: (i) *rill and inter-rill* erosion using a standard model, such as PESERA or RUSLE, validated against erosion measurements (27) and harmonised standard input data. Member States should also be encouraged to use, for comparison, any national approach that is scientifically robust, fully documented and based on the most detailed data available at national level (e.g. 29).
   (ii) *Snowmelt* erosion using climatic and topographic criteria (together with expert judgement) where this form of erosion is known to be prominent (see Table 9).
2. *Upland (Peat) erosion* (30), often resulting from a combination of water and wind erosion, using the occurrence of susceptible soil types (e.g. Histosols), topography, rainfall, wind exposure, with the aid of expert judgement;
3. *Tillage and land leveling* (16), largely confined to southern Europe, identified from a combination of slope and agro-ecological zone;
4. *Wind erosion*: this is more difficult to assess but there are models such as WEELS (18) to estimate soil loss. Delineation of risk areas could be made on the basis of occurrence of sandy and silty soils with loose structure, in combination with relatively low rainfall and incomplete land cover at critical times of the year and likely to be exposed to strong desiccating winds. Further consultation is needed to finalise the best approach to estimating losses from wind erosion, but expert judgement and observation will undoubtedly play an important part.

III. Defining risk areas by these means will inevitably result in the inclusion of land that has been severely eroded already and the obscuring of local pockets of erosion because of scale. However, these problems must be accepted in the interests of harmonization at European level.

10. Future opportunities

Central to any pragmatic approach to combating soil erosion for soil protection should be the estimation of soil erosion using models that were already tested, and to some extent validated, at existing erosion monitoring sites. The selected model(s), e.g. PESERA (22), USLE (20), RUSLE (21) and/or a Member State model (29, 31-33), could be run periodically at a small number of fully instrumented sites, using appropriately detailed up-to-date soil, climate, topographic and crop/cover data, to obtain predicted sediment loss. Changes in climatic (meteorological) conditions and crop cover will result in different predicted sediment losses. It could then be demonstrated how much management of the land, through changing the crop/vegetation cover, could affect predicted sediment loss. Similarly, it could be demonstrated how much effect future climatic scenarios might have on predicted sediment loss. A land use scenario that resulted in lower predicted soil losses, as calculated by an approved model, could therefore be regarded as good land management (or good agricultural practice). It would be important to highlight climatic scenarios that could result in higher predicted losses of soil. The experience of the climate change research community should be utilised in this respect.

This strategy follows the approach adopted by the USDA during the 1980s and 1990s, when the erosion model EPIC was used to calculate predicted sediment losses for specific soil series in agricultural areas, to show the effect of different land management practices. Future administrations in Europe, planning more sustainable use of the land than is currently practiced, will need to know whether erosion is getting worse or not, if so how much worse and what can be done to reduce it.

Measuring soil erosion at field scale is a complex and expensive process. Sediment traps, storage tanks and other equipment must be installed at the experimental site (34). Automatic meteorological recording equipment is also essential to put the results into a climatic context. Managing such sites is time consuming and expensive, and they need to be operated over a several years, even decades, to provide sufficient replication. However, there is now an urgent need to quantify accurately the nature and extent of accelerated soil erosion in Europe and many more measuring sites (*Tier 3*) will be needed in the years to come.

11. Bibliography Chapter III

(1) Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S-K. (2004b). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume II Erosion. EUR 21319 EN/2, Office for Official Publications of the European Communities, Luxembourg, p.127-309.

(2) Jones, Robert J. A., Yves Le Bissonnais, Paolo Bazzoffi, Juan Sanchez Diaz, Olaf Düwel, Giosue Loj, Lillian Øygarden, Volker Prasuhn, Bengt Rydell, Peter Strauss, Judit Berenyi Uveges, Liesbeth Vandekerckhove, Yavor Yordanov. (2004). Nature and Extent of Soil Erosion in Europe. Soil Thematic Strategy, Technical Working Group on Soil Erosion, Task 2 Final Report, p.145-185. In: (1)

(3) CORINE Land Cover data at 100m resolution, for 1988-92 and 2000.

(4) Hiederer, R. (2001). European Catchment Information System for Agri-Environmental Issues. In: Proceedings of EuroConference 'Link GEO and Water Research'. Genoa, Italy, 7-9 February 2002. (http://www.gisig.it/eco-geowater; last accessed: 21.12.2004).

(5) Gallego, J. (ed). (2002). Building Agro-Environmental Indicators: Focussing on the European area frame survey LUCAS. EUR 20521 EN, 176 pp. Office for the Official Publications of the European Communities, Luxembourg.

(6) Van Ranst, E., Vanmechelen, L. and Groenemans, R. (1998). Elaboration of a European forest soil database to monitor atmospheric pollution. In: Land Information Systems: Developments for planning the sustainable use of land resources. H.J. Heineke, W. Eckelmann, A.J. Thomasson, R.J.A. Jones, L. Montanarella and B. Buckley (eds). European Soil Bureau Research Report No.4. Office for Official Publications of the European Communities, Luxembourg. EUR 17729 EN, 51-67.

(7) King, D., Daroussin, J. and Tavernier, R. (1994). Development of a soil geographical database from the soil map of the European Communities. Catena 21: 37-26.

(8) Heineke, H.J., Eckelmann, W., Thomasson, A.J., Jones, R.J.A., Montanarella, L. and Buckley, B. (eds). (1998). Land Information Systems: Developments for Planning the Sustainable Use of Land Resources. European Soil Bureau Research Report No.4, EUR 17729 EN, 545 pp. Office for Official Publications of the European Communities, Luxembourg.

(9) European Commission [EC] (2002). Communication of 16 April 2002 from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions: Towards a Thematic Strategy for Soil Protection [COM (2002) 179 final]. (http://europa.eu.int/scadplus/printversion/en//lvb/l28122.htm; last accessed: 11.11.2004).

(10) Van-Camp, L., Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S-K. (2004e). Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Volume V Monitoring. EUR 21319 EN/5, Office for Official Publications of the European Communities, Luxembourg, p. 653-718.

(11) Le Bissonnais, Y. (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. European Journal of Soil Science, 47, 425-437.

(12) Le Bissonnais, Y., Jamagne, M., Lambert, J.- J., Le Bas C., Daroussin, J., King, D., Cerdan, O., Léonard, J., Bresson, L.-M. and Jones, R.J.A. (2005). Pan-European soil crusting and erodibility assessment from the European Soil Geographical Database using pedotransfer rules. Advances in Environmental Monitoring and Modelling 2 (1): 1-15.

(13) Morgan, R.P.C. (2005). Soil erosion and conservation. Blackwell.

(14) Gobin, A., Govers, G., Jones, R.J.A., Kirkby, M.J. and Kosmas, C. (2002). Assessment and reporting on soil erosion: Background and workshop report, EEA Technical Report No.84, 131 pp. Copenhagen.

(15) Kværnø, S., and Øygarden, L. (2001). International Symposium on Snowmelt Erosion and related Problems. 28- 30 March, Oslo, Norway. Abstract book. 49 p. Jordforsk report. 41/01. ISBN; 82- 7467-394-8.

(16) Borselli L.; Pellegrini S., Torri D., Bazzoffi P. (2002). Tillage erosion and land levelling: evidences in Tuscany (Italy).Proccedings of the third International Confress "Man and Soil at the Third Millennium. J.L.Rubio, R.P.C. Morgan, S. Asins, V.Andreu (eds.). Geoforma Ediciones Logroño. p. 1341-1350.

(17) Warren, A. (ed.). (2002). Wind erosion on agricultural land in Europe. EUR 20370 EN, 76 pp, Office for the Official Publications of the European Communities, Luxembourg.

(18) Riksen, M., Arrue, J.L. and Lopez, M.V. (2002). What to do about wind erosion. In: Wind erosion on agricultural land in Europe. A Warren (ed.), EUR 20370 EN, p. 39-52. Office for the Official Publications of the European Communities, Luxembourg.

(19) Bullock, P. & Montanarella, L. (2005). Soil Information: uses and needs in Europe. In: Soil Resources of Europe, second edition. R.J.A. Jones, B. Houšková, P. Bullock and L. Montanarella (eds). European Soil Bureau Research Report No.9, EUR 20559 EN, (2005), p. 404. Office for Official Publications of the European Communities, Luxembourg.

(20) Wischmeier, W.H. and Smith, D.D. (1978). Predicting rainfall erosion losses –a guide for conservation planning. U.S. Department of Agriculture, Agriculture Handbook 537.

(21) Renard, K.G., Foster, G.R., Weessies, G.A., McCool, D.K., Yoder, D.C. (eds.) (1997). Predicting Soil Erosion by Water: A guide to to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook 703.

(22) Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. and Huting, J. (2004). Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). European Soil Bureau Research Report No.16, EUR 21176, 18 pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg.

(23) Morgan *et al.*, 1998. The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms 23: 527-44.

(24) Morgan, R.P.C, Morgan, D.D.V. and Finney, H.J. (1984). A predictive model for the assessment of soil erosion risk. Journal of agricultural engineering research 30: 245-253.

(25) S.P.I.04.73. (2004). Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Special Publication Ispra 2004 No.73, map in ISO B1 format. European Communities.

(26) Lundekvam, H., Skøien, S.,(1998). Soil erosion in Norway. An overview of measurements from soil loss plots. Soil Use Management. 14: 84-89.

(27) Van Rompaey, A.J.J., Vieillefont, V., Jones, R.J.A., Montanarella, L., Verstraeten, G., Bazzoffi, P., Dostal, T., Krasa, J. DeVente, J. and Poesen, J. (2003). Validation of soil erosion estimates at European scale. Office for Official Publications of the European Communities, Luxembourg. EUR 20827 EN, 26 pp.

(28) Cerdan, O, Gobin, A. & Govers, G. (2003). Deliverable 16: Database on long-term soil erosion measurements. PESERA [contract QLKS-CT-1999-01323] – see http://pesera.jrc.ir/ document 8 (last accessed 12/06/2005) and on CD: Nature and Extent of Soil Erosion in Europe EUR 20972 EN.

(29) Sánchez, J.; Recatalá, L.; Colomer, J.C. and Añó, C. (2001) Assessment of soil erosion at national level: a comparative analysis for Spain using several existing maps. In: Ecosystems and Sustainable Development III. Y. Villacampa, C.A. Brevia and J.L. Usó (eds). Advances in Ecological Sciences 10: 249-258. WITT Press, Southampton.

(30) Birnie, R.V. (1993). Erosion rates on bare peat in Shetland. Scottish Geographical Magazine 109: 12-17.

(31) Hennings,V. (2003). Erosionsgefährdung ackerbaulich genutzter Böden durch Wasser (Karte im Maßstab 1:2,750,000). In: Nationalatlas Bundesrepublik Deutschland, Bd. 2: Relief, Boden und Wasser. Inst. für Länderkunde [Hrsg.]. Spektrum. Akademischer Verlag. Heidelberg-Berlin.

(32) Schaub, D. and V. Prasuhn (1998). A soil erosion map of Switzerland as a planning tool for sustainable land use. In Towards Sustainable Land Use - Furthering Cooperation Between People and Institutions (Blume, H.-P., Eger, H., Fleischhauer, E., Hebel, A., Reij, C. and K.G. Steiner eds.), Advances in GeoEcology 31: 161-168.

(33) Landscape Atlas of the Slovak Republic. (2002). 1st Edition. Bratislava: Ministry of Environment of the Slovak Republic. Banska Bystrica: Slovak Environmental Agency 2002, 344 pp. ISBN 80-88833-27-2.

(34) Jones, R.J.A. and Montanarella, L. (2001) End-user involvement. PESERA [contract QLKS-CT-1999-01323] Second Annual Report p. 109-110, see http://pesera.jrc.ir/ document 11 (last accessed 12/06/2005) and on CD: Nature and Extent of Soil Erosion in Europe EUR 20972 EN.

12. Annex I: Definitions of the Threats: Erosion

Prepared by DG ENV [Classification of the definitions by the source]

Legislative Sources	Scientific Sources
Saxony, Minister for Agriculture and Environment Unter Bodenerosion versteht man die Ablösung, den Transport und die Ablagerung von Bodenmaterial. Durch Wasser oder Wind werden Bodenpartikel von der Bodenoberfläche zunächst abgelöst und transportiert. Zur Ablagerung gelangen die Bodenpartikel, wenn die Transportkraft nicht mehr ausreicht, um die vorherrschenden Widerstände, wie z.B. die Oberflächenrauhigkeit, zu überwinden. Under Soil erosion you would understand the separation, the transport and the deposition of soil material. Wind and water separate soil particles from the soil surface and transport them away. They are deposited once the transport force is not sufficient any more to compensate the dominating resistance, such as roughness of the surface, etc. *Definition Wassererosion* Verlagerung von Bodenmaterial an der Bodenoberfläche durch Wasser als Transportmittel. Es werden Bereiche mit vorwiegendem Abtrag und Auftrag voneinander unterschieden. *Definition Water-erosion* Transport of soil material at the surface due to water as transport medium. Areas with dominant loss and dominant receipt are distinguished. *Definition Wind erosion* Verlagerung von Bodenmaterial an der Bodenoberfläche durch Wind als Transportmittel. Dabei werden Bereiche mit vorwiegendem Abtrag und Auftrag unterschieden. *Definition Wind erosion* Transport of soil material at the surface due to wind as transport medium. Areas with dominant loss and dominant receipt are distinguished ***UK, Draft soil strategy for England, A consultation paper*** Soil erosion is a natural process, caused by the action of wind and water removing soil particles and transporting them elsewhere. Some soil types are more prone to erosion than others, and it can be increased by human activities such as inappropriate cultivation and crop management, overgrazing, forestry and construction activity.	*Reports of WG, Volume II: Erosion; Soil Thematic Strategy* Erosion is a physical phenomenon resulting from the removal of soil particles by water or wind, transporting them elsewhere. A main consequence is that ecological, technical; industrial and socio-economic functions of soil become threatened. *Bob Jones, NSRI Cranfield University and Luca Montanarella, (European Soil Bureau)* 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. Soil erosion by water is a widespread problem throughout Europe. With a very slow rate of soil formation, any soil loss of more than 1 t/ha/yr could 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. The following types are included: water erosion, by rill and inter-rill, gully, snowmelt, and bank erosion in rivers and lakes; translocation erosion by tillage, land levelling, harvesting of root crops, trampling and burrowing animals; wind and coastal erosion, landslides and debris flows, and internal subterranean erosion by groundwater. *EIONET (GEMET, General Multilingual Environmental Thesaurus)* The general process or the group of processes whereby the materials of Earth's crust are loosened , dissolved, or worn away and simultaneously moved from one place to another, by natural agencies, which include weathering, solution, corrosion, and transportation, but usually exclude mass wasting. (Source: BJGEO, Glossary of Geology, American Geological Institute) Soil Erosion: Detachment and movement of topsoil or soil material from the upper part of the profile, by the action of wind or running water, especially as a result of changes brought about by human activity, such as unsuitable or mismanaged agriculture (Source: BJGEO, Glossary of Geology, American Geological Institute). *EEA-Definitions* Soil erosion consists in the removal of soil material by water or wind. It is a natural phenomenon but it can be accelerated by human activities. *EEA, Technical work, assessment and reporting on soil erosion* Natural process occurring over geological time. Most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activities such as changes in land cover and management. Erosion may be caused by water and by wind. *World Bank. Glossary of Municipal Solid Waste Management Terms.* The wearing away and removal of weathered land surfaces by natural agents such as rain, running water, wind, temperature changes and bacteria. *Guidance Specifying Measures for Sources of Non-point Pollution in Coastal Waters, EPA.* Soil erosion can be characterized as the transport of particles that are detached by rainfall, flowing water, or wind. The types of erosion associated with agriculture that produce sediment are (1) sheet and rill erosion and (2) gully erosion. Eroded soil is either re-deposited on the same field or transported from the field in runoff. *EPA, Terms of Environment* Erosion: The wearing away of land surface by wind or water, intensified by land-clearing practices related to farming, residential or industrial development, road building, or logging. *Soil Science Society of America, Internet glossary of soil science terms.* The wearing away of the land surface by rain or irrigation water, wind, ice, or other natural or anthropogenic agents that abrade, detach and remove geologic parent material or soil from one point on the earth's surface and deposit it elsewhere, including such processes as gravitational creep and so-called tillage erosion; (ii) The detachment and movement of soil or rock by water, wind, ice, or gravity. Accelerated erosion: Erosion in excess of natural rates, usually as a result of anthropogenic activities.

IV. Soil Compaction

Identifying Risk Areas for Soil degradation in Europe by Compaction

Members of the Task Group: Christine Le Bas, Beata Houšková, Stanislaw Bialousz, Pavel Bielek

Advisors: Guy Richard, Dominique King

Compaction is a process of densification and distortion in which total and air-filled porosity and permeability are reduced, strength is increased, soil structure partly destroyed and many changes are induced in the soil fabric and in various behaviour characteristics.

1. Definition of threat

Soil compaction occurs when soil is subject to mechanical stress often through the use of heavy machinery or overgrazing, especially in wet soil conditions. In sensitive areas, walking tourism and skiing also contribute to the problem. Compaction reduces the coarse pore space between soil particles, thereby increasing the bulk density with the result that the soil partially or fully looses its capacity to absorb water. Compaction is most obvious in the surface horizon but increasingly subsoil layers are affected. Compaction in the subsoil is now widespread in areas under continuous arable cultivation and it is very difficult to alleviate (CEC, 2002).

The overall deterioration in soil structure caused by compaction restricts root growth, water storage capacity, fertility, biological activity. Moreover, when heavy rainfall occurs, water can no longer easily infiltrate the soil. Resulting large volumes of run-off water increase erosion risk and are considered by some experts to have contributed to some recent flooding events in Europe.

The threat 'soil compaction' can thus be defined as a reduction of soil porosity induced by any human activity applying a mechanical stress on soil, which can modify soil properties and lead to the deterioration of one or more soil functions.

2. Risk assessment of soil degradation by compaction

The Risk Assessment of soil degradation by compaction has to:

1. identify the factors that can lead to the application on soil of a mechanical stress which can cause a reduction of soil porosity and adverse effects to soil, i.e. a deterioration of one or more soil functions;
2. characterise the relation between mechanical stress and intensity of the reduction of soil porosity and the adverse effects, i.e. the sensitivity of soil to compaction;
3. characterise the exposure of soil to the threat, i.e. on which soil compaction is occurring and the intensity of the resulting adverse effects.

3. Identification of factors related to soil compaction

The factors that can lead to the application on soil of a mechanical stress, such as the use of heavy machinery, or the passage of draught or grazing animals or of human beings, causing soil compaction will vary according to soil wetness. Each factor should be characterized by i) the mechanical stress applied to the soil and ii) the duration of application in relation to the soil moisture content.

Many studies on soil compaction have been made and have shown that the main human activities that are responsible for soil compaction in Europe are agriculture and forestry, because of the large areas they affect (Van den Akker, 1999; Van den Akker and Canarche, 2001). Nevertheless, other activities can have severe impacts on soil compaction such as recreation (walking, camping and skiing) and tourism etc. These activities must then be taken into account in regions where they affect significant areas. Road and building construction, mining, transport networks and waste disposal (e.g. burying) can also cause severe soil compaction. These latter activities are generally included under the soil sealing threat whereas this report will focus on compaction resulting from agricultural and forest activities.

For agriculture and forestry, the main harm comes from the use of machines which have become heavier and heavier since the middle of the 20th century (Imeson *et al.*, 2004). Compaction of the soil is caused directly through the passage of wheels, tracks or rollers. The wheel loads for agricultural machines can reach 130 kN for some sugar beet harvesters (Poodt *et al.*, 2003). According to Alakukku *et al.* (2003), soil compaction will thus depend on:

- type of machine, especially wheel load and size of the tyre contact area with soil,
- size of the area affected by the machine in the field,
- number of passes which causes cumulative effect of stresses,
- period of use of the machine, in relation to the soil wetness.

As details of machinery used are generally very scarce, information about agricultural systems and practices will be used to determine their damaging effect. The type of crop will determine the type of operations and the periods when they are performed, and also the depth of cultivation (Chamen *et al.*, 2003). For example, the depth of tillage and the weight of harvesters for sugar beet are greater than for cereals. Furthermore, the harvesting period is later for sugar beet than for cereals and generally, where sugar beet is grown in northern Europe, the soil is wetter than during the cereal harvest. Many studies have been undertaken for annual and perennial crops, showing the consequences of agricultural practices on soil compaction in Europe (Boizard *et al.*, 2002; Poodt *et al.*, 2003; Van Dijck and Van Asch, 2002).

Alakukku *et al.* (2003) present a first attempt to determine operations for several countries with a medium to high risk of damage to subsoil by compaction, based on expert knowledge. For each country, criteria were based on type of operation (e.g. ploughing, harvesting, etc.), crop for which the operation can be critical for subsoil compaction (e.g. sugar beet, potatoes, cereals, olives, etc.) and the machine that can caused soil compaction (e.g. tractor, harvester, spreader, etc.). Other agricultural practices, such as irrigation and drainage, can also exacerbate soil compaction by modifying the soil moisture content. It is also important to take account of the field operations in some countries, especially application of fertilisers and spreading of slurry using heavy tankers.

In the absence of sufficient direct information at European level about the characteristics of machines used in agriculture, a typology of farming systems and their likely damaging effect through compacting the soil is offered below, based on expert judgement and available information about:

- type of crops, especially distinguishing crops on criteria based on type of operations, type of machine and period of application;
- field pattern: the use of heavy machinery requires relatively large sized fields;
- size of farms: intensive agriculture has lead to an increase in farm-size in Western Europe;
- type of farming systems: to differentiate farm types of arable crops from those that are more focused on animal grazing, to identify farms with animal housing which produce a lot of slurry manure, etc.;
- use of specific agricultural practices: no-tillage, irrigation, drainage, etc.

Forestry machinery is also becoming heavier and more powerful, with axle loads that can reach 300 kN. Several studies have shown that the problem of compaction in forest systems is equivalent to that of agricultural systems (Vossbrink and Horn, 2004). Thus, criteria concerning the degree of mechanisation in forests are also needed and could be used to make a typology for forest systems. Depending on tree species, on characteristics of landscapes (relief) and on age of trees, the operations performed vary in type, number and frequency. Thus, the machines used for clearing operations are different from those used in harvesting. Forests on flat land are more mechanised than forests in the mountains, where steep slopes prevent the use of very heavy machinery. In some regions, forest activies are more mechanised in coniferous than in deciduous forests.

Agricultural, machinery is not the only cause of soil compaction. The increase of livestock numbers and the decrease of permanent or ley pasture since the 1960's in Europe has resulted in an increase of cattle stocking densities in fields. The hooves of cattle deform and penetrate the soil surface – a process called poaching – which can cause large stresses on soil and soil homogenisation by shear effects (Warren *et al.*, 1986). Several studies have shown that trampling by grazing animals (cows, sheep, pigs) can cause serious soil compaction in Europe (Mulholland and Fullen, 1991; Pietola *et al.*, 2005).

The degree of soil compaction will vary according to soil wetness. As the moisture content increases, soil compactibility increases until the moisture content approximates to field capacity. At higher moisture contents, the soil becomes increasingly incompactible as water, which is not compressible at atmospheric pressure, fills an increasing proportion of the total porosity and further loss of air-filled porosity becomes impossible. However, although the compaction may be minimal, the saturated soil is subject to plastic flow resulting in complete destruction of soil structure and macro pores (Imeson *et al.*, 2004).

Thus, it is important to know when the stress will be applied to thesoil and to characterise the soil moisture content during such a period. Factors that drive the soil water balance are thus important and can be deduced not only from climatic data, such as rainfall and potential evapotranspitation (PET), but also from land cover types. Some agricultural practices such as irrigation are additional considerations.

4. Characterisation of sensitivity of soil to compaction

The previous section dealt with the factors that can lead to the application of a mechanical stress on soil. Thus, it is also important to know how the soil will react to this stress, i.e. its sensitivity to compaction. Soil reaction will vary depending on its strength. Some soils are sufficiently strong to resist to all likely applied loads (low compactibility), and others are so weak that they are compacted even by light loads (high compactibility) (Imeson *et al.*, 2004).

To assess the sensitivity of soil to compaction, it is necessary to be able to predict the degree of soil compaction due to an applied stress and thus to determine the critical stress above which soil will be compacted. Many studies have been undertaken to measure soil compaction related to an applied stress, mainly due to machinery. These studies showed that soil compactibility depends on soil mechanical properties which are variable in time with soil water content. Models based on soil mechanical properties have been developed to predict soil deformation according to stresses (Défossez and Richard, 2002).

However, this modelling approach has several limitations. Firstly, these models were generally developed for prediction of soil compaction for annual crops. Thus, their use for prediction of soil compaction due to grazing, in forestry or in vineyards, where stresses and soil physico-chemical conditions are different, need to be validated. Secondly, in general these models have been validated on local sites only. To apply them more widely would necessitate more rigorous validation. Thirdly, the models require as input the mechanical properties for a large range of soils.

Although studies have been undertaken in some countries (Trautner *et al.*, 2003; Arvidsson and Keller, 2004), generally, information about soil mechanical properties is scarce or restricted to only a few experiment sites. It is thus necessary to make indirect assessment using more readily available data and soil properties, such as pedotransfer functions (van den Akker, 1997; Horn and Fleige, 2003). However, a direct relationship between some mechanical properties (e.g. preconsolidation stress) and soil compactibility, as proposed by van den Akker (1997) for The Netherlands, is not so obvious and must be validated first (Arvidsson and Keller, 2004).

In the absence of an appropriate model and sufficient information about soil mechanical properties, assessment based on expert knowledge can be made using other soil properties, such as soil texture, organic matter content, structure, bulk density, etc. which are available in many soil survey databases or that can be easily estimated from these databases using pedotransfer functions (Jones *et al.*, 2003). Generally, soils with large amounts of clay (>35%) are more susceptible to deformation than sandy soils, but the fact that sandy soils naturally have a larger proportion of coarse pores than clay soils can make them more susceptible to significant compaction.

For mineral soils, organic matter decreases susceptibility of soils to compaction in all textural categories. Peat soils, however, are very sensitive to compaction because bearing strength is low. Soils with single grain, granular and weakly developed blocky structure are susceptible to compaction. This assessment must be based on the knowledge of the soil behaviour to loads given by field experience.

As the soil mechanical properties change with soil moisture content, water retention properties are needed for predictive purposes. Soil water retention data can be used for estimating some mechanical stability of soil through pedotransfer functions (Wösten *et al.* 1998; Horn and Fleige, 2003). These data are generally needed to determine, in relation to climate and water abstraction by plants, the periods during the year when soil moisture content is near, at or above field capacity).

The critical periods for field operations can be determined using different methods:

- climatic zoning with characterisation of seasons in terms of wetness;
- climatic water balance based on rainfall and potential evapotranspiration – PET – (Rounsevell and Jones, 1993);
- simple soil water balance based on available water capacity, rainfall and PET (irrigation can be included; per day or per 10-days).
- crop growth models for annual or perennial crops, or forests.

Models can be used to estimate the soil water balance. To account for climatic variability, data that cover at least 20 to 30 years should be used. The problem of spatial variation of climate must be taken into account, for example in the choice of meteorological stations.

5. Exposure assessment

The risk of degradation of soil due to compaction results from the occurrence of compressive stress on a soil where this stress will cause damage. For example, a very sensitive soil with little or no stress applied will have a low risk whereas a less sensitive soil exposed to a high stress will suffer a higher risk. Three types of information are thus needed:

- characterisation of the stress that can be applied;
- sensitivity of soil to compaction;
- periods when soil moisture is above a critical soil water content.

By combining these three types of information, the critical situations can be identified. Several approaches are available depending on data availability, spatial and temporal resolution of the data, and the availability of validated and calibrated models:

- spatial components: (1) the occurrence of a stress type affecting soils and (2) the link between climatic data and soil to be able to determine the soil water balance. Further investigation these components require spatial overlay between soil and climatic data. The method of spatial overlay will depend on resolution, comparability and quality of the georeferencing (administrative limits, functional limits, grids, soil associations) of the data;
- temporal components: (1) the period when the stress type acts on the soil, and (2) the soil water status during this period. The time interval for the climate data depends on the method for estimating the soil water balance.

6. Risk assessment at Member State level: common criteria

The risk assessment can be best realised at the Member State level, and the required data must be available at that level as well. An important limiting factor for the comparability of the risk assessments is expected to be caused by the availability of data and models, which may deviate between Member States.

For each point of the risk assessment, two types of information are needed: (1) spatial data, which provide information about the localisation of soils and factors, and (2) thematic data to characterise factors and soil sensitivity. A list of minimum requirements to make a risk assessment at the Member State level is proposed. Table 10 presents the list of the minimum data required with the distinction of two Tiers according to data availability.

6.1 Stress characterisation

Spatial data:

These data are necessary to determine the location where machines are used or grazing animals predominate. Three basic data types of input data can be distinguished:

- land cover: distinction between arable land, grassland, forest, natural vegetation, recreation areas, etc.; main data source available at the European level is CORINE land cover ;

- land use: provides detailed information about the type of crop within arable land, the type of grasslands or forests, etc. Additional data needed is the type of practice which causes stress. Generally, only statistical data are available, spatially referenced to administrative units. They could be used to characterise the land cover data more precisely in terms of type of agriculture or forestry, area per crop type, etc.;
- topography: important to define the area where e.g. mechanisation is not possible for forestry or agriculture.

Thematic data:

These data will characterise the level of stress that could appear in the located areas, for example information about farming systems or forestry management systems. Date can be derived from expert systems, statistics or detailed surveys if available. Essential information is the type of operations, type of machines and period of use, the stocking ratios, etc., which requires the definition of a typology of farming and forest systems that could be compatible with the spatial data.

6.2 Soil sensitivity

Spatial data:

If looking at the existing data on soils, the Soil Geographical Database of Europe can be used, which delineates Soil Mapping Units (SMU) comprising one or more Soil Typological Units (STU). At small and medium overview scales (i.e. 1:1,000,00 and 1:250,000), the STUs were not delineated directly but information about the percentage area of each STU within each SMU is available.

Thematic data:

The data for each STU contain topsoil and subsoil properties, such as soil texture, soil structure, organic matter content and soil water content. Using pedotransfer rules and functions, additional mechanical properties can be derived.

6.3 Period of critical soil wetness

Spatial data:

If possible, climatic data should be spatially explicit, and the variability of rainfall and PET at the Member State level should be determined. It is necessary to have a resolution compatible with land cover and soil data. Two types of data can be distinguished:

- point data (meteorological stations) for which the representative area must be defined (this area can be an administrative unit if it is compatible with the spatial variability of rainfall and PET);
- interpolated data (mostly raster-based): the resolution should be comparable with land cover and soil data. The interpolation method used should at least be valid and comparable for the whole territory of the respective Member State (special attention must be paid to mountainous areas).

Thematic data:

Rainfall and PET may have at least a monthly or 10-day resolution for an average year (calculated over a 20 to 30 year interval to reflect the time variability of climate)

Table 10: Minimum data required information to identify area at risk for compaction

Common criteria	Type of information	Data Quality /Resolution Tier 1	Tier 2
land use	statistical data about agriculture and forestry: crop types and forest areas, types of farming systems (annual crops, vineyards, animal breeding, etc.), type of forests	NUTS 3	NUTS 4
farming and forest systems	typology of farming systems or forestry systems in relation to land use data	expert knowledge	survey data
land cover	localisation of agricultural and forest areas, etc. using data such as CORINE land cover	250 m	100 m
slope	Digital Elevation Model	250 m	90 m
SMU/STU delineation	National Soil Geographical Data Base	national	regional
STU topsoil and subsoil texture	texture class or mean silt, clay and sand content	texture class	particle size
STU description	bulk density, other parameters according to availability in soil inventories: water retention, organic matter content, structure, hydraulic conductivity, air capacity	pedotransfer functions or rules	measurements and soil morphological descriptions from representative soil profiles
climate	rainfall and PET	average year, data on a month or 10-day basis NUTS 3 or 50 km	20 to 30 years one day basis 10 km

7. Updating of the risk assessment:

It can be regarded as good reporting practice if the risk assessment is updated after improved higher resolution data become available, and in order to take into account the evolution of the hazard, for example the area under conventional agriculture, or changes in the machinery used.

8. Validation of results

Validation of risk assessment requires additional information. Important data sources are statistical updates, questionnaires and inventories, as well as data from soil measurements through monitoring are important. Reference sites may be a good means to obtain data from direct measurements of compaction effects due to various site types, climate areas and land uses. In order to be cost efficient, it may be advisable to establish a network of cross-border observation sites. Such sites should then be maintained for long observation periods.

9. Bibliography Chapter IV

Alakukku, L., P. Weisskopf, W.C.T. Chamen, F.G.J. Tijink, J.P. van der Linden, S. Pires, C. Sommer and G. Spoor (2003). Prevention strategies for filed traffic-induced subsoil compaction: a review. Part 1. Machine/soil interactions. Soil and Tillage Research 73(1-2): 145-160.

Arvidsson, J. and T. Keller (2004). Soil precompression stress I. A survey of Swedish arable soils. Soil and Tillage Research 77: 85-95.

Boizard, H., G. Richard, J. Roger-Estrade, C. Dürr and J. Boiffin (2002). Cumulative effects of cropping systems on the structure of the tilled layer in northern France. Soil and Tillage Research 64: 149-164.

Chamen, W.C.T., L. Alakukku, S. Pires, C. Sommer, G. Spoor, F. Tijink and P. Weisskopf (2003). Prevention strategies for field traffic-induced subsoil compaction: a review. Part 2. Equipment and field practices. Soil and Tillage Research 73(1-2): 161-174.

CEC (2002). Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions. Towards a Thematic Strategy for Soil Protection. Commission of the European Communities, 35 pp.

Défossez, P. and G. Richard (2002). Compaction of tilled topsoil due to traffic: a review of models tested in field conditions. Soil and Tillage Research, 67: 41-64.

Horn, R. and H. Fleige (2003). A method for assessing the impact of load on mechanical stability and on physical properties of soils. Soil and Tillage Research 73(1-2): 89-99.

Imeson, A., C. Ritsema and R. Hessel (2004). Research, Sealing and Cross-cutting issues. Task Group 1 on Research for erosion, compaction, floods and landslides. In: Van-Camp, L., B. Bujarrabal, A.-R. Gentile, R.J.A. Jones, L. Montanarella, C. Olazabal and S.-K. Selvaradjou (eds.). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. Volume VI. Research, Sealing and Cross-cutting issues. EUR 21319 EN/6, 872 p. Official Publications of the European Communities, Luxembourg. p. 723-740.

Jones, R.J.A., G. Spoor and A.J. Thomasson (2003). Vulnerability of subsoils in Europe to compaction: a preliminary analysis. Soil and Tillage Research 73: 131-144.

Mulholland, B. and M.A. Fullen (1991). Cattle trampling and soil compaction on loamy sands. Soil Use and Management 7(4): 189-193.

Pietola, L., R. Horn and M. Yli-Halla (2005). Effects of trampling by cattle on the hydraulic and mechanical properties of soil. Soil and Tillage Research 82: 99-108.

Poodt, M.P., A.J. Koolen and J.P. van der Linden (2003). FEM analysis of subsoil reaction on heavy wheel loads with emphasis on soil preconsolidation stress and cohesion. Soil and Tillage Research 73(1-2): 67-76.

Rounsevell, M.D.A. and R.J.A. Jones (1993). A soil and agroclimatic model for estimating machinery work-days: the basic model and climatic sensitivity. Soil and Tillage Research 26: 179-191.

Trautner, A., J.J.H. van den Akker, H. Fleige, J. Arvidsson and R. Horn (2003). A subsoil compaction database: its development, structure and content. Soil and Tillage Research 73(1-2): 9-13.

Van den Akker, J.J.H. (1997). Construction of a wheel-load bearing capacity map of the Netherlands. Proc. 14th ISTRO conference, Pulawy, Poland, 1997. Bibliotheca Fragmenta Agronomica Vol 2A/97: 15-18.

Van den Akker, J.J.H. (1999). Description of the Concerted Action "Experiences with the impact of subsoil compaction on soil, crop growth and environment and ways to prevent subsoil compaction". In: Experiences with the impact of subsoil compaction in the European Community. Report 168, DLO-Staring Centre, Wageningen, The Netherlands, pp. 8-27.

Van den Akker, .J.J.H. and A. Canarache (2001). Two European concerted actions on subsoil compaction. Landnutzung und Landentwicklung / Land Use and development Vol. 42 (1): 15-22.

Van Dijck S.J.E. and T.W.J. van Asch (2002). Compaction of loamy soils due to tractor traffic in vineyards and orchards and its effect on infiltration in southern France. Soil and Tillage Research 63: 141-153.

Vossbrink J. and R. Horn (2004). Modern forestry vehicles and their impact on soil.

Wösten, J.H.M., A. Lilly, A. Nemes and C. Le Bas (1998). Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and land use planning. SC-DLO Report 156, 106 pp. Wageningen, The Netherlands.

9.1 Additional references not quoted here

Hakansson, I. (editor) (1994). Subsoil compaction by high axle load traffic. Special Issue of Soil and Tillage Research 29: 105-306.

Tijink, F.G.J., H. Döll and G.D. Vermeulen (1995). Technical and economic feasibility of low ground pressure running gear. Soil and Tillage Research 35 99-110.

V. Salinisation/Sodification

Identifying Risk Areas for Soil degradation in Europe by Salinisation/Sodification

Members of the Task Group: G. Várallyay (Lead), G. Tóth

Advisor: T. Tóth

Salinisation is the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced.

1. Definition of threat salinisation/sodification

1.1 Definitions

Salinisation

Salinisation is the process that leads to an excessive increase of water-soluble salts in the soil. The accumulated salts include sodium, potassium, magnesium and calcium, chloride, sulphate, carbonate and bicarbonate. A distinction can be made between primary and secondary salinisation processes. Primary salinisation involves accumulation of salts through natural processes due to high salt contents in parent materials or groundwater. Secondary salinisation is caused by human activities, such as inappropriate irrigation practices, for example. with salt-rich irrigation water and/or with insufficient drainage to wash away the excess salts.

Sodification

Accumulation of Na^+ in the solid and/or liquid phases of the soil as crystallised $NaHCO_3$ or Na_2CO_3 salts (salt 'efflorescens'), ions in the highly alkaline soil solution (alkalisation), or exchangeable ion in the soil absorption complex (exchangeable sodium percentage – ESP).

Types of salinisation/sodification

Salt-affected soils can be classified as:

c1) Soils in which high salt content dominates the problems (Saline soils)

c2) Soils in which high sodium content dominates the problems (Sodic soils)

c3) Soils with specific characteristics in certain environmental conditions may be in risk of salinisation (acid sulfate soils, etc.)

Risk in the context of the threat of salinisation/sodification

Risk of salinisation/sodification:
A measure of the probability and severity of the salinisation/sodification due to human activities, that adversely affects one or more *soil functions*. Thus the main threat in this conext is the process of secondary salinisation or sodification.

1.2 Risk elements

These are:

- plant life (soil fertility, agricultural productivity: cultivated crops and their biomass yield; natural vegetation | ecosystems);
- life and function of soil biota (biodiversity);
- soil deteriorations (increased erosion potential, desertification, structure destruction, aggregate failure, compaction);
- hydrological cycle, moisture regime, (increasing hazard – frequency, duration, severity - of extreme moisture events as flood, water logging, over-moistening and drought);
- biogeochemical cycles of elements (plant nutrients, pollutants, potentially harmful elements and compounds).

The preconditions of salt accumulation are as follows:

- salt source (primary: weathering, volcanic activities; secondary: parent material, surface- and subsurface waters);
- transporting agents (wind, surface water, subsurface water) lead to accumulation of salts (a) from a large water catchment area to a relatively small accumulation territory, or (b) from a thick geological deposit to a relatively thin accumulation horizon;

- Driving forces regarding salt mobility:
  - relief for surface runoff;
  - suction gradient for seepage in the unsaturated zone;
  - hydraulic gradient for groundwater flow;
  - concentration gradient for solute transport;
- negative water balance (at least for certain period of the year);
- vertical and horizontal drainage limitations.

2. Identification of factors/ hazards related to threat of salinisation / sodification

Environmental (natural) factors result in salinisation/sodification:

- transgressions and regressions that under some particular geological conditions bring about an increase of the concentration of salts in groundwater and consequently in soils;
- rise of salt-rich groundwater due to natural factors or human intervention (see below) up to the surface, near to the surface or to the overlying horizons;
- groundwater seepage into areas lying below sea level, micro-depression with no or limited drainage;
- fluvial waters flooding from areas with geological substrates that release large amounts of salts;
- wind action, that in coastal areas blows moderate amounts of salts inland;

Human-induced factors may lead to salinisation/sodification:

- irrigation of waters rich in salts;
- rising water table due to human activities (filtration from unlined canals and reservoirs; uneven distribution of irrigation water; poor irrigation practice, improper drainage);
- use of fertilizers and other additions, especially where land under intensive agriculture has low permeability and limited possibilities of leaching;
- use of wastewaters rich in salts for irrigation;
- salt-rich wastewater disposal on soils;
- contamination of soils with salt-rich waters and industrial by-products.

3. Characterization of ‘receptor’ (soil)

The characteristics of soil (i.e. their response to anthropogenic factors) depend on ‘internal’ soil properties and other ‘external’ natural factors of the area.

Natural characteristics of the area:

- climate (temperature, rainfall, evaporation, wind characteristics, with their spatial distribution and temporal variability);
- geology (potential salt sources, sequence and thickness of aquifers and the vertical and horizontal transmissibility of geological layers);
- relief;
- vertical and horizontal drainage conditions;
- hydrology (quality and quantity of surface waters, groundwaters, deep-waters and their fluctuations).

Natural characteristics of the soil:

- texture;
- structure (aggregate status and stability; cracking, shrinkage – swelling characteristics);
- clay mineral composition;

- compaction state – porosity (preferably differential porosity and pore-size distribution);
- hydrophysical properties (infiltration rate, water storage capacity, water retention, saturated and unsaturated hydraulic conductivity);
- salt content (profile, regime, balances, ion composition).

Therefore, the characterization of soil as the receptor within a risk assessment should integrate natural non-soil factors with soil factors.

In the World Reference Base for Soil Resources (WRB, 1998), saline soils occur mainly in the Reference Soil Group of Solonchaks. However, some other Reference Groups may also have a salic horizon (indication of certain degree of salinisation) such as Histosols, Vertisols and Fluvisols.

Sodic soils occur mainly in the Solonetz, and Solonetz Reference Groups but they may be associated with Histosols, Gleysols, Chernozems, Kastanozems, Vertisols and Solonchaks.

4. Decision on performance specification/ selection of model/ input data (availability) and data quality requirements

Saline/sodic and potentially saline/sodic regions in Europe are amongst areas having most detailed soil descriptions (profile and analytical databases) with map representations (for example, the Map of European Salt Affected Soils at 1:1,000,000 scale (Szabolcs, 1971,1974,) – see Figure 2). Maps are also available at detailed scale for the regions considered at risk of salinisation/sodification (Szabolcs, 1979, 1989). However, since the map in Figure 2 dates back to 1974, it may need updating, and ongoing updating at regular intervals, if it is to be used in risk area identification. The most extensive salt-affected regions in the geographical Europe can be found in the Pre-Caspian Lowland, in the Ukraine, in the Carpathian Basin, in the Romanian Plain and in the poorly-drained river valleys on the Iberian Peninsula (Quadalquivir delta, etc.) and in France (Camargue) (Table 11).

In addition to the present (actual) salt-affected areas, huge territories are threatened by salinity–alkalinity–sodicity and may be defined as ‘potential salt-affected soils’. These regions are also indicated in Figure 2.

Maps of salt affected soils have been used efficiently in several research and policy-oriented projects, and in the decision-making mechanisms at various scales. Consequently, all these materials are suitable for use in the EU Soil Thematic Strategy Programme.

4.1. Spatial resolution of salinisation/sodification risk assessment

Upscaling – downscaling for various decision-making levels [minimum 2 (continent–country) or 3 (continent–country–field) levels]

1) ‘Hot-spot’ map:
   Scale: Continental map: 1:1,000,000; country map: 1:500,000
   indicating the most significant salt-affected regions using only 3 main classes:
      i. saline soils
      ii. sodic soils
      iii. potential salt affected soils
         1. soils salty/sodic in the deeper horizons
         2. potentially salt affected soils
2) Medium scale maps: 1:500,000 – 1:100,000 for more detailed classification (distinguish and delineate 5–7 classes e.g. Hungary (Szabolcs, 1974)).
3) Large scale maps for practical operations (only for the hot spots) 1:50.000 – 1:10,000 (Szabolcs, 1979).

4.2 Temporal resolution of salinisation/sodification risk assessment

1) ~ 1,000,000 scale - only up-dating is necessary;
2) ~ 100,000 scale - 5-10 years; only in special cases and for environmental control;
3) ~ 10,000 scale 1-3-6 years, depending on the changeability of the areas soil characteristics (monitoring system) (Várallyay, 2005).

Table 11: Distribution and extent (x 1000 ha) of salt affected soils in Europe (Szabolcs 1974)

Country	Mapping unit					Total area x1000 ha
	Saline soil	Alkali soil			Potential salt-affected soil	
		without	with			
		structural B-horizon				
			non-calc.	calc.		
Austria	0.5	–	–	–	2.5	3.0
Bulgaria	5.0	–	20.0	–	–	25.0
Czechoslovakia	6.2	7.5	2.7	4.3	85.0	105.7
France	175.0	–	75.0	–	–	250.0
Greece	…	…	…	…	…	3.5
Hungary	1.6	58.6	294.0	31.9	885.2	1,271.6
Italy	50.0	–	–	–	400.0	450.0
Portugal	…	…	…	…	…	25.0
Romania	40.0	100.0		110.0	–	250.0
Spain	…	…	…	…	…	840.0
U.S.S.R.	7,546.0	1,616.0	20,382.0	–	17,781.0	47,325.0
Yugoslavia	20.0	50.0	110.0	75.0	–	255.0

5. Definition of common criteria for risk area identification

Risk areas (of salinisation/sodification) are identified by reference to soluble salt concentrations predicted from available databases. For delineation at Tier I, the Soil Map of Europe database can be applied. At Tier II, the Map of European Salt Affected Soils, national soil monitoring data and other (auxiliary) data can be used (Problem Soil Database, FAO; Szabolcs, 1971, 1974, 1979, 1989).

Figure 2 shows that the threats of salinity–sodicity, as a regional problem in European soils, occur almost exclusively in Central and Southern Europe, south of a SW-NE line from Gibraltar to St. Petersburg. Some thematic maps for the identification of potential salt-affected soils in European Countries have been published by Szabolcs (1971, 1974, and a book on the salinity problem in the Mediterranean Basin (Szabolcs, 1979). The input-data requirements for the characterization of the salinity–sodicity state of soils and the risk area identification of salinisation–sodification processes are summarized in Table 12.

6. Grading and presentation

Grading is influenced by three main factors:

i. the primary purpose of land use practices in salt-affected regions;
ii. the degree and type of salinity;
iii. micro-regional/local conditions and priorities.

The priority objective of land use practices in salt-affected regions has been changed radically in Europe, especially in the EU, during the last 10-15 years from intensive and high-input food production to soil/land conservation and environmental protection. These two basic systems of land management require greatly differing approaches towards the rational use of salt-affected lands, including grading and presentation:

a) *Intensive production*: improvement/reclamation/amelioration of salt-affected lands; prevention (or at least radical reduction) of salinisation–sodification processes; increasing the fertility/agricultural productivity even with high investments and input applications.

b) *Conservation/protection*: conservation of the present state or re-establishment of a desirable previous or current natural state: saline lakes, wetlands, saline lands with special ecosystems (flora, fauna, biotop) → national parks, protected areas, gene-reservoirs, man and biosphere reserves.

Table 12: Required input data for the characterization and risk identification of salinisation/sodification (Várallyay 2005)

Soil characteristics		**at start t_o**	**yearly**	**3 yearly**	**6 yearly**	**Remarks**
morphological description of the soil profile		+				
particle-size distribution		+				
texture		+				
total water storage capacity (WC_T –pF_0)		+				on undis-turbed soil cores
field capacity (FC– pF 2.5)		+				
wilting percentage (WP – pF 4.2)		+				
available moisture range (AMR = FC–WP)		+				
saturated hydraulic conductivity		+				
$CaCO_3$ content	if > 5 %	+			+	
	if 1 - 5 %	+		+		
	if < 1 %	+	+			
pH(H_2O)	if $CaCO_3$ > 1 %	+		+		
	if $CaCO_3$< 1 %	+	+			
pH(KCl)	if $CaCO_3$ > 1 %	+		+		
	if $CaCO_3$ < 1 %	+	+			
total water-soluble salts (in salt-affected soils)		+	+			
1:5 water extract analysis [pH, EC; CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+]		+			+	
Phenolphtalein alkalinity		+		+		
depth of the humus horizon		+			+	profile
organic matter content		+	+			
CEC (cation exchange capacity)		+			+	
exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^{2+})		+			+	
depth, fluctuation and chemical composition of the groundwater [pH, EC, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+, K^+]		+	+			

The two systems are based on greatly different activities for which different gradings, classifications, ratings, evaluation systems (with consequent limit values) are required. A good example is the re-establishment of saline lake ecosystems, starting with the re-establishment of the original salt concentration and ion composition of their waters.

The 'Hortobágy' and 'Kiskunság' National Parks in Hungary have endured several decades of both positive and negative experiences in this respect. Each protected area, however, necessitates site-specific management and standardization that may lead to adverse effects and some undesirable or harmful consequences.

7 Bibliography Chapter V

Bellino, F. and G. Várallyay (2004). Task Group 4 on Salinization. In: Van-Camp. L., Bujarrabal, B., Gentile, A-R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S-K. (2004). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. EUR 21319 EN/6, 872 pp. Office for Official Publications of the European Communities, Luxembourg. p. 767-769.

Commission of the European Communities (2002). Towards a Thematic Strategy for Soil Protection. Communication from the Commission to the Council, the European Parlament, the Economic and Social Ciommittee and the Committeee of the Regions. Brussels. 16.4.2002. COM(2002) 179 final.

International Source Book on Irrigation and Drainage of Arid Lands in Relation to Salinity and Alkalintiy. FAO-UNESCO, (1967), 664pp.

Kovda, V. A. and I. Szabolcs (eds.) (1979). Modelling of Soil Salinization and Alkalization. Agrokémia és Talajtan. Suppl. 208pp.

FAO. 'Problem Soils Database'. FAO Land and Water Development Division. Rome. http://www.fao.org/landandwater/agll/prosoil/default.htm

Salinity as a factor for agricultural productivity in the Mediterranean Region. Proc. Trans-National Meeting, Naples, INRC–ONR–CIHEAM Publ. Napoli.

Szabolcs, I. (ed.) (1971). European Solonetz Soils and their Reclamation. Akadémiai Kiadó. Budapest. 204 pp. (Including a detailed bibliography of salt-affected soils in Europe, prepared by G. Várallyay, 40pp.).

Szabolcs, I. (1974). Salt-Affected Soils in Europe. Martinus Nijhoff – The Hague and RISSAC – Budapest. 63 pp. + 1:1,000,000 scale Map of Salt Affected Soils in Europe.

Szabolcs, I. (1979). Review of Research on Salt Affected Soils. UNESCO. Natural Resources Research XV. Paris. 137 pp. (including a detailed bibliography prepared by G. Várallyay, 37pp.)

Szabolcs, I. (1989). Salt Affected Soils. CRC Press. Boca Raton. Florida. 274pp.

Várallyay, G. (1974). Hydrophysical aspects of salinization processes from the groundwater. Agrokémia és Talajtan. 23. Suppl. 29-44.

Várallyay, Gy. (2002). Environmental stresses induced by salinity/alkalinity in the Carpathian Basin (Central Europe). Agrokémia és Talajtan 51 (1–2): 233–242.

Várallyay, Gy. (2005). Soil survey and soil monitoring in Hungary. In: Jones, R. J. A., Houshkova, B., Bullock, P., Montanarella, L. (2005). Soil Resources of Europe (2nd ed.) EC JRC, Ispra. 420pp.

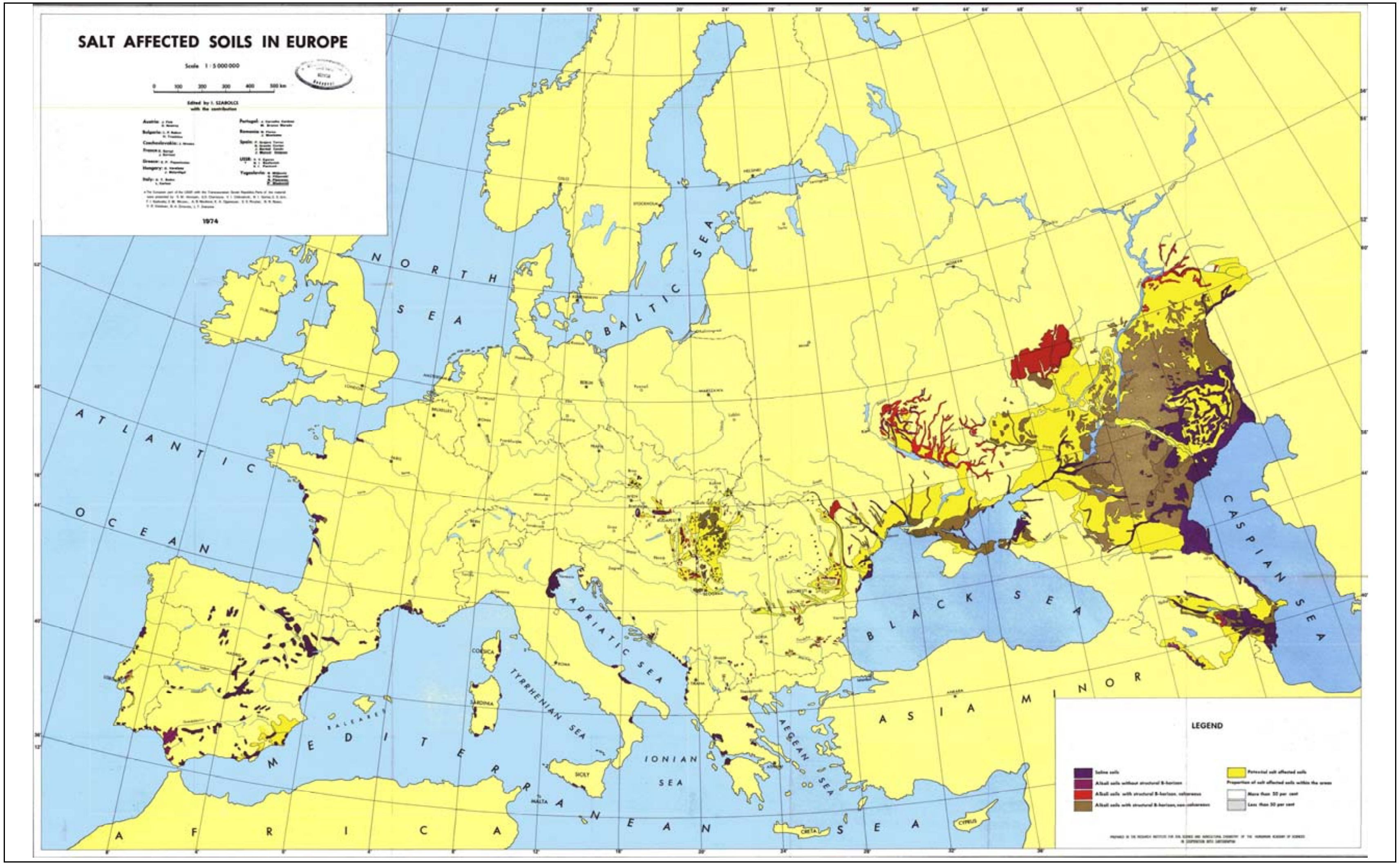

Figure 2 Distribution of salt-affected soils in Europe [

[according to Szabolcs (1974); 1. saline soils (dark blue); 2. alkali soils without structural B horizon (purple); 3. alkali soils with structural B horizon, calcareous (red); 4. alkali soils with structural B horizon, non-calcareous (brown); 5. potentially salt-affected soils(yellow)]

VI. Landslides

Identifying Risk Areas for Soil degradation in Europe by Landslides

Members of the Task Group: F. Carré

Advisors: D. Seebach, N. Filippi, M. Pizziolo, G. Bertolini, A. Poschinger, J. Fortuny-Guasch, M. Gemmer

A landslide is the movement of a mass of rock, debris or earth down a slope, induced by physical processes such as excess rainfall or snow melt, earthquakes or caused by human interference on slope stability.

1. Basic Terminology

In this report the term *landslide* is used to describe 'the movement of a mass of rock, debris or earth down a slope' (Cruden and Varnes, 1996). Based on this definition, both ground subsidence and sink holes will be excluded.

The various types of landslides can be classified by the types of material involved and the mode of movement. A commonly-used classification based on these parameters is shown in Table13.

Table 13: Types of landslides (Cruden and Varnes 1996)

TYPES OF MOVEMENT		**TYPE OF MATERIAL**		
		Bedrock	**Soils**	
			Coarse	**Fine**
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slides	Rotational	Rock slide	Debris slide	Earth slide
	Translational			
Lateral spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow	Debris flow	Earth flow
Complex				

2. Common Driving Factors

Although there are multiple causes of landslides the most common causes in Europe are heavy rain fall events and snow melt. This is because saturation by water is a primary cause of landslides. Landslides and floods are closely allied because both are related to heavy precipitation, and slope-runoff, and the saturation of ground by water. In addition, debris flows and mudflows usually occur in small, steep stream channels and often are mistaken for floods; in fact, these two events often occur simultaneously in the same area.

It is possible to distinguish driving factors for the susceptibility on the one hand and directly triggering factors for landslide events on the other.

Driving factors
Geology/bedrock material
Slope
Land Management
Land cover
Depth profile of water permeability

If water permeability is decreasing with depth, increased water accumulation near the surface in case of rapid snowmelt or intense rainfall may facilitate/promote landsliding (and vice versa). Hydrological conditions are of general consideration.

Landslides are local phenomena. They are usually detected by field surveys and when they cause loss of human life or destruction of infrastructure. As first slope failure events are very difficult to predict, landslide mapping consists mainly of surveying existing landslides. In this case, the density of landslides (i.e. 'area covered by landslides / km²') is the proxy parameter for the threat Landslide.

Triggering mechanisms
Rapid snowmelt
Intense rainfall
Water level changes
Volcanic eruptions
Earthquake tremors
Changes in land use/ land cover
Climate change
Human activities: Excavation, construction (esp. 'cut and fill'), mining, irrigation, abandonment of land)

3. Characterisation of receptor (soil)

Soil can be described as a receptor being affected by landslides. Landslides can affect all soil types. Usually, as landslides result in soil loss in case of shallow landslides or in soil transfer in other cases, particular soil physical properties such as structure, bulk density, water permeability and retention can be affected. This can result in loss of soil functions and an increase in vulnerability of the soil to other threats, mainly to further erosion and compaction.

4. Performance specification; selection of model input data and data quality requirements

4.1 Tier II Approach

Up to now, historical landslide inventories have been undertaken in most Member States prone to landslides by means of field surveys. The density of landslides can be used as an indicator of the degree of risk.

The main stakeholders behind the establishment of present landslides inventories are Civil Protection Agencies in Member States. Therefore, most landslides present in these inventories are those endangering human life and infrastructure.

A local approach to predicting landslide occurrence has been proposed by McInnes (2000). It consists of the following components:

1. review of available records, reports and documents about the location/area;
2. survey of natural and human factors in the area listed as driving factors from reports, geomorphological surveys, and analytical photogrammetry;
3. investigation building on preliminary stability analyses;
4. gathering of physical data on landslide activities (intensity, types of landslides, frequency, etc.);
5. import of the physical data into a geographical information system;
6. analysis of the factors influencing the distribution of contemporary movements and those related to the frequency;
7. development of a ground behaviour map which, combined with land use, enables the prediction of landslides and planning of landslide management strategies.

4.2 Tier I Approach

Since landslides in Europe have mainly a local cause and impact, it is difficult to map landslide hazard at the coarse resolution needed for the European scale. One possible approach is to produce a landslide-hazard map at European scale by upscaling existing local survey maps where these exist, with the necessary amalgamation or elimination of areas too small to delineate at small scale.

5. Definition of common criteria for risk area identification

Tier II approach: as outlined before inventory of historical landslides (area covered by landslides / km^2)

6. General comments on Technical Annex of the draft Soil Framework Directive related to Landslides

Many of the factors and processes related to the threats Erosion and Compaction are correlated with Landslides.

7. Bibliography Chapter VI

Australian Geomechanics Society, Sub-Committee on Landslide Risk Management (2000). Landslide Risk Management Concepts and Guidelines. URL: http://www.australiangeomechanics.org/LRM.pdf

Cruden, D. M. and D.J. Varnes (1996). Landslide Types and Processes, in Landslides – Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council, p. 36-75, National Academy Press, Washington, D.C.

USGS National Landslide Hazards Mitigation Strategy (U.S. Geological Survey Circular 1244). Online Version 1.0). URL: http://pubs.usgs.gov/circ/c1244/c1244.pdf

Partnerships for Reducing Landslide Risk: Assessment of the National Landslide Hazards Mitigation Strategy (2004). Committee on the Review of the National Landslide Hazards Mitigation Strategy, National Research Council, Washington, URL: http://www.nap.edu/books/0309091403/html

Glade T., Diekau R. and R. Bell (2003). National Landslide Susceptibility Map for Germany, Geophysical Research Abstracts, Vol. 5: 12692.

Appendix I: Definitions and terms in risk assessment

Members of the Task Group: Christine Le Bas

1 Hazard

'*Inherent property of an agent or situation having the potential to cause adverse effects when an organism, system or (sub) population is exposed to that agent*' (OECD 2003).

'*A property or situation that in particular circumstances could lead to harm*' (EEA, 1999).

2 Risk

'*The probability of an adverse effect in an organism, system or (sub) population caused under specified circumstances by exposure to an agent*' (OECD 2003).

'*The combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence*' (EEA 1999).

3 Risk Assessment

'*A process intended to calculate or estimate the risk to a given target organism, system or (sub)population, including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system*' (OECD, 2003).

The Risk Assessment process includes four steps:

1. hazard identification
2. hazard characterisation (related term: dose-response assessment)
3. exposure assessment
4. risk characterization.

Risk assessment is the first component in a risk analysis process (OECD, 2003); it has also been defined as the 'Procedure in which the risks posed by inherent hazards involved in processes or situations are estimated either quantitatively or qualitatively' (EEA 1999).

The response to risk assessment may be to initiate categorisation of the risk and/or introduce measures to manage it. In some cases, the risk may be accepted, in other cases, the priority will be to adopt a mitigation strategy (Jones, 2001).

3.1 Hazard Identification

'*The identification of the type and nature of adverse effects that an agent has as inherent capacity to cause in an organism, system or (sub) population*' (OECD 2003). Hazard identification is the first stage in hazard assessment and the first step in the process of Risk Assessment.

3.2 Hazard Characterization

'*The qualitative and, wherever possible, quantitative description of the inherent properties of an agent or situation having the potential to cause adverse effects*' (OECD 2003). This should, where possible, include a dose-response assessment and its attendant uncertainties.

[related terms: dose-Effect relationship, effect assessment, dose-response relationship, concentration-effect relationship]

3.3 Exposure Assessment

'*Evaluation of the exposure of an organism, system or (sub) population to an agent (and its derivatives)'* (OECD 2003).

3.4 Risk Characterization

'The qualitative and, wherever possible, quantitative determination, including attendant uncertainties, of the probability of occurrence of known and potential adverse effects of an agent in a given organism, system or (sub) population, under defined exposure conditions' (OECD 2003).

4. Bibliography Appendix I

EEA (1999). Environmental risk assessment. Approaches, Experiences and Information sources. Environmental Issues Series. No 4.

Jones, R.J.A. (2002). Assessing the vulnerability of soils to degradation. Advances in GeoEcology 35, p.33-44, Catena Verlag, Reiskirchen, Germany.

OECD (2003). Description of selected key generic terms used in chemical hazard/risk assessment. OECD series on testing and assessment. No 44.

Appendix II: Summary Table: Common Criteria

SOM Decline

Common criteria	Data source/type of information	Minimum data quality /resolution	
		Tier 1	Tier 2
soil typological unit STU (soil type)	soil type: provide	1:1,000,000 (1:250,000)	1:250,000 or larger
soil texture/clay content	standard textural analysis; textural classes according to official classification	*not required for Tier 1*	national profile data base; soil inventory/monitoring
soil organic carbon (concentration)	analysis: dry combustion, [g/kg], or pedo-transfer function	*not required for Tier 1*	forest floor, peaty layers, 0-30 cm
soil organic carbon (stock)	[kg/m^2], [t/ha]; requires: - stone content - bulk density	*not required for Tier 1*	forest floor, peaty layers, 0-30 cm
climate	annual average precipitation; annual average temperature	10 km grid climatic data	1 km raster size (modelled from national weather station network)
slope, exposition, position in relief	DEM	250m	*same or higher*
land cover/land use	CORINE; LUCAS SSU extended by soil type; management statistics	250m NUTS III	*same or higher*

Soil Erosion

Common criteria	Data source/type of information	Data Quality /Resolution	
		Tier 1	Tier 2
soil typological unit (STU) (soil type)	European/national soil databases	national level	regional level
soil texture (STU level)	sand, silt, clay content	texture class	particle size class
soil density, hydraulic properties (STU level)	bulk density, packing density, water retention at field capacity and wilting point	pedo-transfer-rules (PTR) or functions (PTF)	measured data
topography	gradient (slope), length	250m (SRTM)	90m
land cover	land cover type	250m	100m
land use	land use, agricultural statistics	NUTS 3	NUTS 4
climate	precipitation, rainfall, snowfall, number of rain days, storm events, PET, temperature	10 km daily average 50km daily average	1 km raster (modelled from national
hydrological conditions	catchment information system, digital elevation model (DEM)	10km	1km
agro-ecological zone	based on soil, climate, landscape	50km	1km

Soil Compaction

Common criteria	Data source/type of information	Data Quality /Resolution	
		Tier 1	Tier 2
SMU/STU delineation	national soil databases	national	regional
STU topsoil and subsoil texture	texture class or mean silt, clay and sand content	texture class	particle size
STU description	bulk density, other parameters according to availability in soil inventories: water retention, organic matter content, structure, hydraulic conductivity, air capacity	pedotransfer functions or rules	measurements and soil morphological descriptions from representative soil profiles
climate	rainfall, potential evapotranspiration (PET)	average year with monthly or 10-day data NUTS 3 or 50 km	20 to30 years with one day data 10 km
land use	statistical data about agriculture and forestry: crop types and forest areas, types of farming systems (annual crops, vineyards, animal breeding, etc.), type of forests	NUTS 3	NUTS 4
farming and forest systems	typology of farming systems or forestry systems in relation to land use	expert knowledge	survey data
land cover	localisation of agricultural areas, forest areas, etc. using data like CORINE land cover	250 m	100 m
slope	digital elevation model	250 m	90 m

Salinisation/Sodification

Common criteria	Data source/type of information	Data Quality /Resolution	
		Tier 1	Tier 2
soil typological unit (STU)	European Soil Database; national soil databases	1:1,000,000 Europe (1:200,000 to 500,000 national)	regional (1:25,000 to 1:100,000)
soil texture	texture class; sand, silt, clay content	texture class	particle size distribution, porosity
soil chemical properties	salt content, profile distribution, ion composition, pH, cation exchange capacity (CEC), exchangeable sodium rate (ESP)	not required for in Tier 1	national soil profile data base; soil inventory / monitoring
soil hydraulic properties	infiltration rate, hydraulic conductivity, water retention (pF) curves (total water storage capacity, field capacity, available moisture content), vertical and horizontal drainage	not required for in Tier 1	national soil profile data base; soil inventory / monitoring

Salinisation/Sodification (continued)

Common criteria	Data source / type of information	Data Quality /Resolution Tier 1	Tier 2
irrigation areas and chemical properties of irrigated water	irrigated area, irrigation intensity, salt content, sodicity, SAR, alkalinity of irrigation water	national registries	regional registry
groundwater information	depth, salt content, sodicity, alkalinity	European/National Groundwater Database (salt concentration, type of salt, SAR, pH)	regional database
climate	annual rainfall, annual potential evapotranspiration	1 km raster size (modelled from national weather station networks)	same or higher

Landslides

Common criteria	Data source / type of information	Data Quality /Resolution Tier 1	Tier 2
occurrence/density of existing landslides	statistics	NUTS 3	larger-scale regional / local assessments
bedrock[1)]	nature of material + presence of fissures and pores	Map of Geology 1:1,000,000	higher resolution maps
soil properties	texture, structure, permeability	not required for Tier 1	classification/grouping according to?
slope	classes: 0-10°; 10°-30°; >30°	250m	same or higher
land cover/land use	infrastructure; cultivation density/pressure, mining	not relevant for Tier 1	100m
climate	likelihood of heavy rainfall events	daily events (e.g. < 10, 10-70, >70 mm/day)	same or higher
seismic risk		threshold?	threshold?

1) for example, sensitive bedrocks can be Gault Clay and Flysh

Appendix III: Auxiliary Data for Risk Area Assessment in Soil Protection

Members of the Task Group: S. Bialousz, R. Baritz
Advisors: J. Chmiel, S. Rozycki, R. Zielinski, M. Fuchs

This Appendix complements Chapters 1-VI on Common Criteria for Risk Area Identification. Several types of geographical soil and non-soil data are proposed for use within the approaches for risk area identification for the specific threats mentioned in the Soil Thematic Strategy.

The criteria listed in Appendix II of the SIWG report (Tier 1) are meant to be based on existing data as far as possible.

Appendix III thus presents the availability and resolution of the currently available data – most of which is freely accessible.

Rather than solely building on the continental-wide data presented here, or supplementing national data, Member States should be encouraged to utilize more accurate data on regional and/or national scale, in particular improved soil inventory (map) and climatic data.

The development of Appendix III was supported by the European Commission's FP6 research project **INSEA** (Integrated Sink Enhancement Assessment; EC Contract No. SSP1-CT-2003-503614).

1. European Soil Geographical Database 1:1,000,000

This database covers all European countries ((King *et al.*, 1995; Heineke *et al.*, 1998). While the geometry is provided as soil mapping units (SMU), soil typological units (STU) contain more than 20 *attributes* describing the *properties* of the dominating and co-dominating soils. STU's are assigned to the respective SMU's based on area proportions. The mapping concept follows that of soil associations typical for overview mapping scales. The soil properties have been estimated on the basis of nationally available soil inventory data. The country borders have been harmonized to some degree. However, the database is still the product of individual national maps with specific methodologies and data densities. The average size of a soil polygon is about 150 km^2. Particularly in regions with heterogeneous soil cover, this resolution cannot be considered sufficiently accurate for the modelling of soil threats, in the context of soil protection at European scale.

The 1:1,000,000 soil database has been made available to the public through a web mapping service hosted by the EU Joint Research Centre (JRC), Ispra, at http://eusoils.jrc.it. For 73 attributes of the European Soil Database v2, a raster archive has been produced. Cell sizes are 10km x 10km. The following soil attribute data are available:

- limitation to agricultural use
- FAO soil code 1974 (all three levels), FAO 1990 and WRB
- Presence of an impermeable layer
- dominant parent material
- obstacle to roots
- slope class
- textural change
- textural class
- land use
- Presence, type of an existing water management system
- soil water regime class
- elevation above sea level

The following data are available from the JRC, Ispra, in 1 km raster format, derived from the Soil Geographical Database for Europe, combined with the pedotransfer rules database(PTRDB), both databases being part of the European Soil Database Version 2:

- base saturation
- cation exchange capacity
- clay, silt and sand content
- depth to rock
- organic carbon
- soil packing density
- stone volume

2. Regional Soil Data Base 1:250,000

These databases, with a full set of soil pedological attributes, exist only for few territories in Europe. However, various national mapping campaigns have produced soil maps at related scales, such as 1:200,000. A manual dedicated to 1:250,000 soil mapping has been created by the European Soil Bureau with the intention to harmonize the mapping as much as possible (Manual of Procedures, Finke *et al*. 1998).

The manual proposes a set of attributes similar to the database 1:1,000,000, but the geometrical part corresponds to a resolution of 1:250,000. The size of polygons ranges from 25 to 50 ha. For example, this resolution is considered sufficient for modeling purposes intended to reflect management effects on soil carbon dynamics (for example: Franko 2005), or inventory C sequestration in the soil (e.g. Neufeld 2004; see also report on SOM Decline). Current standing of the 1:250,000 mapping in EU25 is presented in Figure 3.

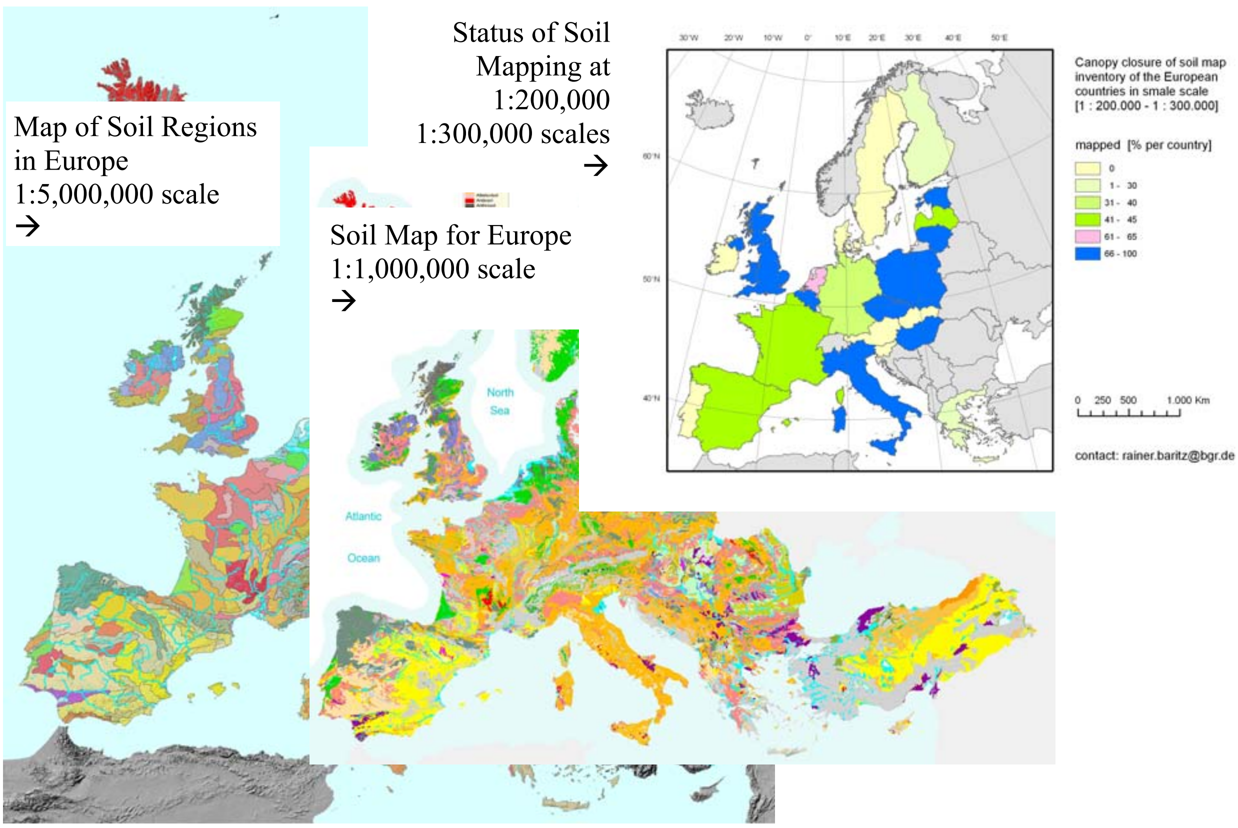

Figure 3. Soil Maps for Europe

Figure 3, Top right: status of soil mapping 1:200,000 – 1:300,000 (derived from Jones et al., 2005); Centre: Soil Map for Europe, derived from the Soil Geographical DataBase of Europe 1:1,000,000; Bottom left: Map of Soil Regions in Europe 1:5,000,000 scale (BGR 2005)

In order to allow harmonized regional stratification of the 1:250 000 soil mapping units, and to allow for comparable definitions and resolutions across Europe, the Manual of Procedures also contains Soil Regions 1:5,000,000. Version 2.0 of this map shown above was recently prepared by BGR (2005).

The first compilation of the status of the soil survey and inventory data in Europe was prepared by Bullock *et al*., 1999). An updated status report for the EU-25, former EFTA and Candidate Countries was produced by Jones *et al*., (2005) which shows that national efforts to produce larger scale soil maps (1:200,000 to 1:300,000) have progressed. Italy has now completed the 1:250,000 scale Ecopedologica map for the whole country and Germany has increased cover of 1:200,000 scale soil maps (see Figure 3).

To back up these efforts, and to improve the comparability of such data, the European Soil Bureau (ESBN) has not only developed mapping guidelines for the soil 1:250,000 (Finke *et al*. 1998), but also established a Digital Soil Mapping Working Group, http://eusoils.jrc.it/projects/soter/Meetings/Digital_Function/Miskolc_Presentations.htm).

Bibliography Sections 1 and 2

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) (2005). Map of Soil Regions in the European Community and Adjacent Countries 1:5,000,000. BGR Hannover, 2005.

Bullock, P., Jones, R.J.A. and Montanarella, L. (eds.) (1999). Soil Resources of Europe. European Soil Bureau Research Report No.6, EUR 18991 EN, (1999), 202 pp. Office for Official Publications of the European Communities, Luxembourg.

Finke, P.A., Hartwich, R., Dudal, R., Ibàñez, J.J., Jamagne, M., King, D., Montanarella, L. and Yassoglou, N. (1998): Georefernced Soil Database for Europe, Manual of Procedures, Version 1.0. - European Soil Bureau Research report No. **5,** EUR 18092 EN, 170pp. Office for Official Publications of the European Communities, Luxembourg

Franko, U. (2005). Integrierte Methodik zur Bewertung der ökologischen und ökonomischen Entwicklung landwirtschaftlicher Bodennutzung im Bundesland Sachsen-Anhalt. Umweltforschungszentrum Halle-Leipzig (unpublished project report).

Heineke, H.J., Eckelmann, W., Thomasson, A.J., Jones, R.J.A., Montanarella, L. & Buckley, B. (eds). 1998. Land Information Systems: Developments for Planning the Sustainable Use of Land Resources. European Soil Bureau Research Report No.4, EUR 17729 EN, 545pp. Office for Official Publications of the European Communities, Luxembourg.

Jones, R.J.A., Houskova, B., Montanarella, L. and Bullock, P. (eds). (2005). Soil Resources of Europe: including Neighbouring Countries. European Soil Bureau Research Report No.9, EUR 20559 EN, (2005), 350pp. Office for Official Publications of the European Communities, Luxembourg.

King, D., Jones, R.J.A. and Thomasson, A.J. (1995). European Land Information Systems for Agro-environmental Monitoring. Office for Official Publications of the European Communities, Luxembourg, EUR 16232 EN, 285pp.

Neufeld, H. (2004). Carbon stocks and sequestration potentials of agricultural soils in the state of Baden-Württemberg, Southwest Germany. Journal of Plant Nutrition and Soil Science.

3. Digital Terrain Elevation Data

(source http://www.usna.edu/)

3.1 DTED data

In support of military applications, the USA National Imagery and Mapping Agency (NIMA) has developed standard digital datasets (Digital Terrain Elevation Data (DTED®)) which is a uniform matrix of terrain elevation values that provides basic quantitative data for systems and applications that require terrain elevation, slope, and/or surface roughness information. Using existing cartographic data, NIMA in cooperation with NATO countries has developed 3 levels of DETED (0, 1 and 2).

DTED Level 0 elevation post spacing is 30 arc second (nominally 1 km). It was determined that DTED®0 could be made available to the public (within copyright restrictions) at no charge through the Internet. DTED Level 0 may be of value to scientific, technical, and other communities for and applications that require terrain elevation, slope, and/or surface roughness information. It allows a gross representation of the Earth's surface for general modelling and assessment activities.

DTED Level 1 is the basic medium resolution elevation data source systems that require landform, slope, elevation, and/or gross terrain roughness in a digital format. DTED1 is a uniform matrix of terrain elevation values with post spacing every 3 arc seconds (approximately 100 m). The information content is approximately equivalent to the contour information represented on a 1:250,000 scale map (DTED level 1 file size: 1 degree x 1 degree geographic tiles; this corresponds to a file size of roughly 2.9 megabytes).

Over 65% of the earth's land mass is classified with Level 1 DTED. Complete information on availability can be found in NIMA's Catalog of Maps and Related Products, Part 7 – Volume 1: Digital Data Products, "Terrain, Feature and World Vector Shoreline Data". In EU 25 countries, this product can be available via military topographic services.

DTED level 2 is the basic high resolution elevation data source for all military activities and civil systems that require landform, slope, elevation, and/or terrain roughness in a digital format. DTED 2 is a uniform gridded matrix of terrain elevation values with post spacing of one arc second (approximately 30 meters). The information content is equivalent to the contour information represented on a 1:50,000 scale map. Nominal vertical precision is estimated as ± 20 m and horizontal ± 26m. Real precision of DTED Level 2 estimated by comparison of height of points calculated from DTED and measured by GPS was much better. Differences for the flat area were about 1m. DTED Level 2 file size: 1 degree x 1 degree geographic tiles. This corresponds to a file size of about 25 megabytes. Generally, EU 25 countries are covered by DTED Level 2. NIMA has planned rapid collection of DTED Level 2 for 80% of the earth with Space Shuttle Radar Topography Mission (SRTM).

It's necessary to transform original DTED data to format adapted for GIS analysis. After this transformation all types of operation like determination of slopes, aspect, main landforms, dissection are easy to perform using typical GIS software. For soil cover analysis special value have slope maps and relief shaded maps underlying morphological units (Figure 4).

3.2 SRTM radar data

The SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The National Imagery and Mapping Agency (NIMA), the German Space Agency (DLR), and the Italian Space Agency (ASI) also contributed to this project. It is managed by NASA's Jet Propulsion Laboratory (JPL), Pasadena, CA, for NASA's Earth Science Enterprise, Washington, D.C.

Interferometric synthetic aperture radar (InSAR) is a modern technology for DEM generation. The SRTM data flight, a dedicated InSAR mission, occurred Feb. 11-22, 2000 on STS-99 and created the topographic data at a world range. Nevertheless, potential users have been aware that the outputs, namely DEM - digital elevation models (or 'terrain height maps') and images, were unedited and intended for scientific and evaluation purposes. The Shuttle Radar Topography Mission obtained a digital, three-dimensional model of the landmass of the Earth between 60N and 57S (Europe: see Figure 5).

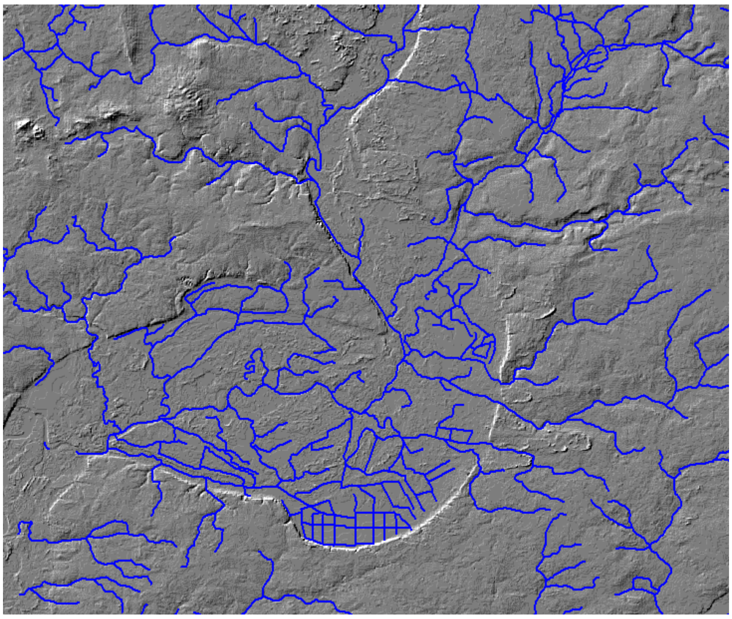

Figure4: DTED Level 2 and Hydrology Layer from VMAP Level 1, valley of Narew

Unedited SRTM data is released to the public. For areas outside the United States 3 arc-sec (~90 m) resolution data is available (via ftp at: ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/) while for the US, full resolution 1 arc-sec (~30 m) have been released (source: http://www.jpl.nasa.gov/srtm/). At the present time this is not available for Europe as free source (see www.dlr.de).

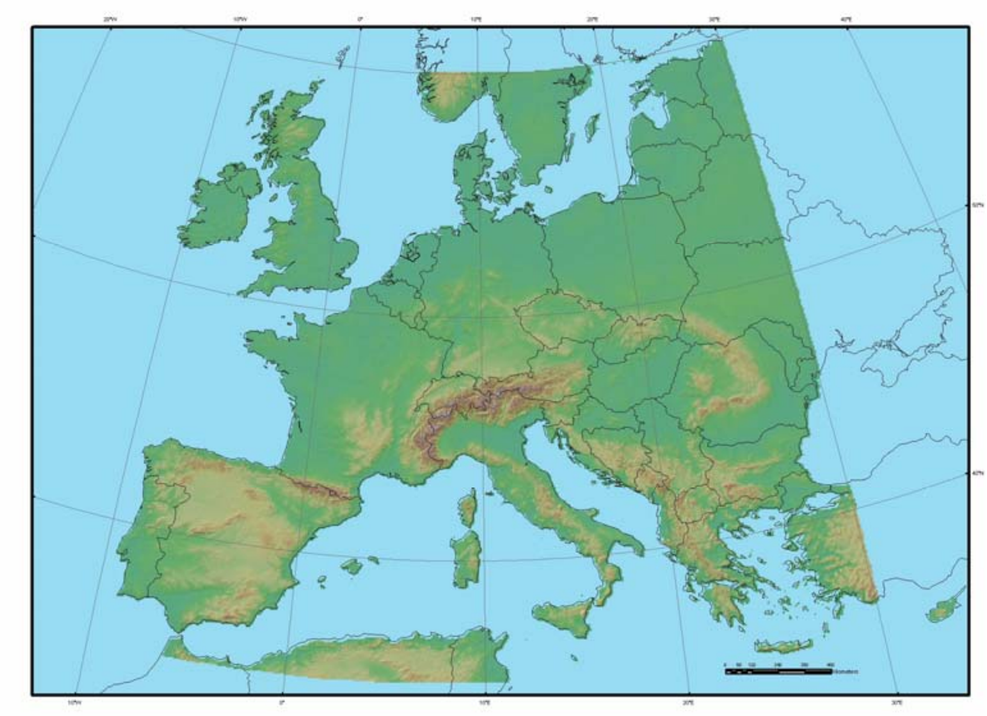

Figure 5: The SRTM data (area between 15° W and 30° E and from 35° N to 60° N)

A simple pre-processing should be made to the SRTM raw data and a mosaic covering AOI should be produced. The very simple automatic corrections should been applied to all HGT (standard SRTM format) files SRTMFill, available on http://www.3dnature.com/srtmfill.html. The corrected HGT data files should be converted to (e.g. GeoTiff) by a freeware, 3DEM: (http://www.visualizationsoftware.com/3dem.html).

Citing the official SRTM homepage, the interferometric terrain height data specifications refer to 30x30 meter spatial sampling (referenced to the WGS84 EGM96 geoid - as documented at http://www.nima.mil/GandG/wgsegm/) with 16 m absolute vertical height accuracy; 6 m relative vertical height accuracy and 20 m absolute horizontal circular accuracy and 90mx90m spatial sampling (referenced to the WGS84 EGM96 geoid with 16 m absolute vertical height accuracy; 10 m relative vertical height accuracy and 20 m absolute horizontal circular accuracy.

3.3 SRTM/DEM applications

SRTM data are in integrative component in a variety of applications: telecommunications, navigation, hydrology, disaster management, transportation, weather forecast, remote sensing, geodesy, land cover classification and many more.

Hydrology
The modelling of river catchment areas necessitates high-precision DEMs that are homogeneous and not confined to areas of the respective water authorities (see also Ch. 10 this report). Only the combination of exact topographic data, situational information, data on precipitation, water retention and storage capacities enables precise statements as to the duration and extent of floods caused by rivers. Aside from such extreme situations, a continuous monitoring of hydrological phenomena is useful in agriculture, for example, in helping making decisions on the need for irrigation. In coastal zones, DEMs can be used to assess in advance the dangers in areas exposed to potential inundation, and help governments in their task of maintaining open shipping routes.

Disaster management (prevention, relief, assessment)
Disaster management is often impeded by missing, incorrect or simply imprecise information about the location of hazards and damages. Up-to-date and precise data are imperative in order to assess potential risks (posed by floods, for example), in employing relief personnel effectively, in disaster aid (e.g. locating adequate spots for dropping of relief supplies) and in analyzing damages and changes.

3.4 Other radar images

The ability of radar to sensitively differentiate various backscatter characteristics of vegetation, due to differences in height, density and growth structure allows a distinction of diverse vegetation communities. This way, it is possible to quantitatively record the dramatic effects of forest fires and clear cutting, of soil erosion, desert expansion, air pollution and inundation, and it is possible to monitor their impacts globally.

In the years 1992 through 1996, the satellites and missions ERS-1, ERS-2, JERS-1, RadarSAT and SIR-C/X-SAR, among others have acquired a wealth of images, which, in total, covers the Earth almost completely. However, at present, Germany is the only country in the world having produced a complete radar map, a result of a long-term research study. There are a number of reasons hindering a continuous and uniform mapping of the Earth via radar sensors, consequently a satisfying documentation of land covers has yet to be undertaken.

One of the problems is the diversity of existing radar images. A mosaiced product varies in resolution, frequency, incidence angle, backscatter characteristics, and acquisition dates. The mosaicing of the different subsets is very costly and time consuming (e.g., an ERS-1 scene of 100 km^2 comes to approximately US$ 1,000). Another problem is the overpassing of neighbouring regions at very different times of the year.

Depending on the seasonal growth period of vegetation (mature or harvested crop, fallow, snow cover), areas with the same land use may yield completely different backscatter characteristics. This complexity alone inhibits a uniform global classification. X-SAR/SRTM, however, will render a homogeneous data set acquired in only a few days eliminating many of the problems we still face today.

3.5 GTOPO30

An easily available solution to cover the gaps in the SRTM is to use the GTOPO30 DEM. GTOPO30 is a global digital elevation model (DEM), produced by the U.S. Geological Survey's EROS Data Center. Elevations in GTOPO30 are regularly spaced at 30-arc seconds (approximately 1 kilometer). GTOPO30 was developed to meet the needs of the geospatial data user community for regional and continental scale topographic data. GTOPO30 is available via GISCO, the Geographic Information System for the European Commission (see Ch. 5.2 for further information).

Bibliography Section 3

Bamler, R. (1997). Digital Terrain Models from Radar Interferometry, Photogrammetric Week'97, Wichman.

Bamler, R. (1999). The SRTM Mission: A World Wide 30 m Resolution DEM from SAR Interferometry in 11 Days, Photogrammetric Week'99. Wichman.

DMA (1996). Performance Specification Digital Terrain Elevation Data (DTED), MIL-PRF-89020A, 19. April 1996, Superseeding MIL-D-89020

Dusart, J. (2004). Pan-European DEM based on SRTM data, v. 1.0, IES/JRC, Soil & Waste Unit.

Farr, T.G. and M. Kobrick (2000). Shuttle Radar Topography Mission produces a wealth of data, Amer. Geophys. Union Eos, v. 81, p. 583-585.

Kay, S., Chmiel, J. and P. Spruyt (2004). Orthorectification and Geometric Quality Assessment of Very High Spatial Resolution Satellite Imagery for Common Agricultural Policy Purposes, IPSC/JRC, AGRIFISH Unit.

Lemoine, F.G. *et al.* (1998). The Development of the Joint NASA GSFC and NIMA Geopotential Model EGM96, NASA Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A., July 1998.

NIMA (1994). Military Standard WGS84.

Rabus, B., M. Eineder, A. Roth and R. Bamler (1998). The shuttle radar topography mission—a new class of digitalelevation models acquired by spaceborne radar, German Aerospace Center (DLR), Oberpfaffenhofen, D-82234 Wessling, Germany.

Rosen, P.A., S. Hensley, I.R. Joughin, F.K. Li, S.N. Madsen, E. Rodriguez and R.M. Goldstein (2000). Synthetic aperture radar interferometry, Proc. IEEE, v. 88, p. 333-382.

Zielinski, R. (2004). Usefulness of SRTM data for orthocorrection VHR satellite images. MSc thesis, Warsaw University of Technology.

Other Web sites of interest:

NASA/JPL SRTM: http://www2.jpl.nasa.gov/srtm/
NIMA: http://164.214.2.59/nimahome.html, http://www.nima.mil/GandG/wgsegm/
STS-99 Press Kit: http://www.shuttlepresskit.com/STS-99/index.htm
Johnson Space Center STS-99: http://spaceflight.nasa.gov/shuttle/archives/sts-99/index.html
German Space Agency: http://www.dlr.de/srtm
Italian Space Agency: http://srtm.det.unifi.it/index.htm
U.S. Geological Survey, EROS Data Center: http://edc.usgs.gov/
http://164.214.2.59/publications/specs/printed/WGS84/wgs84.html

4. Land Cover Databases

4.1 CORINE Land Cover (CLC 90)

(EEA Data service - CORINE Land Cover (CLC90)- www.eea.eu.int)

Remote Sensing has been established as one of the key data sources for updated land cover information. Classified satellite images are the source for landscape vegetation cover. However, the quality of the maps depends on the quality of the classification algorithms and the filter techniques. CORINE land cover is a land cover map that has been carried out with common specifications on most European countries (Gallego 2002).

One of the major tasks undertaken in the framework of the CORINE programme has been the establishment of a computerized inventory on land cover. Data on land cover is necessary to support Environment policy as well as for other policies such as Regional Development and Agriculture. At the same time it provides one of the basic inputs for the production of more complex information on other themes. The objectives of the CORINE Land Cover project are:

- to provide quantitative data on land cover, consistent and comparable across Europe;
- to prepare one single comprehensive land cover database for the EC Member States and other European and North African countries, at an original scale of 1:100,000, using 44 classes of the 3-level CORINE nomenclature. The minimum area digitized was 25 hectares (ha) of homogeneous cover of one single class.

The geometric component of the CORINE Land Cover comprises polygons delineating the borders of land cover classes (Table 14). The size of a spatial unit (or polygon) is at least 25 ha, which leads to some restrictions when connecting to statistical land use data. However, from the geographic (GIS) overlay of these classes on the borders of administrative units (e.g. NUTS, see below), some further statistical evaluations within administrative boundaries become possible. Specific disaggregation procedures of statistical data have to be considered (e.g. Vidal *et al*. 2001, Kempen *et al*. 2005).

4.2 CORINE Land Cover 2000 (CLC2000)

Within the framework of the European CLC2000 project, the database of the first survey 1990 was updated for all of Europe using the year 2000 as a base year, and changes with respect to CLC1990 are being mapped. Identification of land use changes was accomplished by visual interpretation supplemented by automated processes in a GIS supported system. The basis of the data for the year 2000 is uniformly ortho-rectified Landsat-7 data from 1999-2001 for all of Europe (responsible institution: JRC, Ispra, in the Image2000 project). The minimum area digitized in the updated version, CORINE 2000 is 25 ha. However, changes that have occurred between 1990 and 2000 are mapped at 5 ha (Figure 6). Additional work was undertaken on the level 4 & 5 sub-division of grassland and peat land. The methodology involved the assessment and correction of the 1990 land cover database and imagery for geometric and thematic content.

This was followed by mapping land cover changes using satellite imagery and ancillary data from 2000. Changes in the land cover were identified and interpreted visually and digitized, using GIS software, to create the 2000 database. Some countries started to work out the CORINE Land Cover level 4 (containing about 80 classes) for the whole territory (e.g. Hungary).

Table 14: CORINE land cover nomenclature
(Nature/land cover information package, NATLAN CD-ROM, EEA,2000)

1. Artificial surfaces	1.1. Urban fabric	1.1.1. Continuous urban fabric
		1.1.2. Discontinuous urban fabric
	1.2. Industrial, commercial and transport	1.2.1. Industrial or commercial units
		1.2.2. Road and rail networks and associated land
		1.2.2. Road and rail networks and associated land
		1.2.3. Port areas
		1.2.4. Airports
	1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites
		1.3.2. Dump sites
		1.3.3. Construction sites
	1.4. Artificial, non-agricultural vegetated areas	1.4.1. Green urban areas
		1.4.2. Sport and leisure facilities
2. Agricultural areas	2.1. Arable land	2.1.1. Non-irrigated arable land
		2.1.2. Permanently irrigated land
		2.1.3. Rice fields
	2.2. Permanent crops	2.2.1. Vineyards
		2.2.2. Fruit trees and berry plantations
		2.2.3. Olive groves
	2.3. Pastures	2.3.1. Pastures
	2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops
		2.4.2. Complex cultivation
		2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
		2.4.4. Agro-forestry areas
3. Forests and semi-natural areas	3.1. Forests	3.1.1. Broad-leaved forest
		3.1.2. Coniferous forest
		3.1.3. Mixed forest
	3.2. Shrub and/or herbaceous vegetation associations	3.2.1. Natural grassland
		3.2.2. Moors and heathland
		3.2.3. Sclerophyllous vegetation
		3.2.4. Transitional woodland/shrub
	3.3. Open spaces with little or no vegetation	3.3.1. Beaches, dunes, and sand plains
		3.3.2. Bare rock
		3.3.3. Sparsely vegetated areas
		3.3.4. Burnt areas
		3.3.5. Glaciers and perpetual snow
4. Wetlands	4.1. Inland wetlands	4.1.1. Inland marshes
		4.1.2. Peatbogs
	4.2. Coastal wetlands	4.2.1. Salt marshes
		4.2.2. Salines
		4.2.3. Intertidal flats
5. Water bodies	5.1. Inland waters	5.1.1. Water courses
		5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons
		5.2.2. Estuaries
		5.2.3. Sea and ocean

4.3 Image 2000 & CORINE Land Cover 2000 Project

(http://image2000.jrc.it)

Image2000 is part of the I&CLC2000 Project (Image 2000 and CORINE Land Cover 2000). This site is hosted by the Land Management Unit of the Joint Research Centre (JRC), which is responsible for Image2000. I&CLC2000 consists of two connected components :

- Image2000 - covering all activities related to satellite image acquisition, ortho-rectification and production of the European and National Mosaics
- CLC2000 - covering all activities related to the update of the CORINE Land Cover Database, based on Image2000 data, and the detection of land cover changes

Image2000 products currently cover the entire European Union plus Bulgaria, Romania, Liechtenstein, Croatia. In 2005, additional countries will join the project. Image2000 data are multi-user and multi-purpose, covering a wide range of potential applications. The archive of imagery from the Image2000 project is publicly accessible via Internet. Image2000 is a related project to CORINE Land Cover 2000, and provides the necessary Landsat 7 imagery (spatial resolution 30m) for the updating of this European Land Use / Land Cover database.

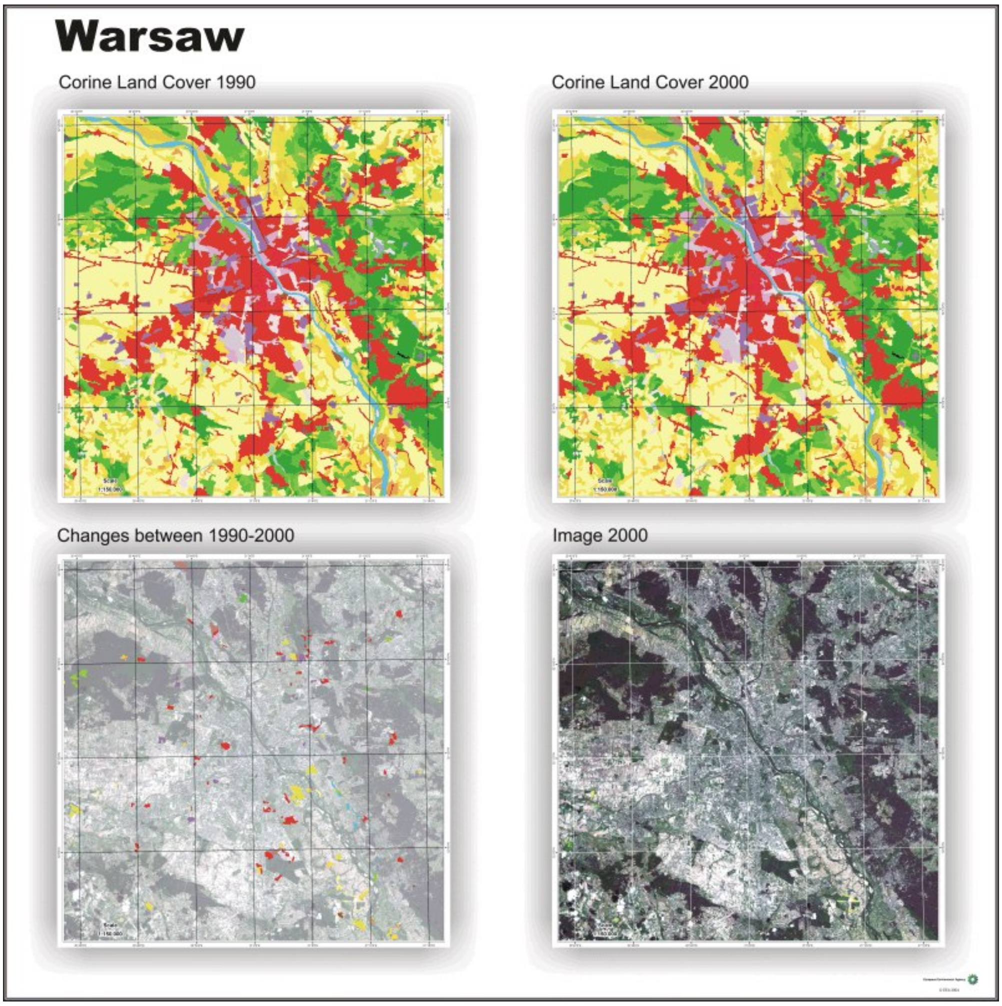

Figure 6: Changes in CORINE Land Cover between 1990-2000

4.4 PELCOM land cover

PELCOM (the Pan-European Land Cover Monitoring project) is a 1-km pan-European land cover database, covering the period 1996-1999 (http://www.geo-informatie.nl/projects/ pelcom/). The objective of the PELCOM project is to develop a consistent methodology, and to produce up-to-date and reliable information on land use and land cover (LULC). It aims at the establishment of a 1-km pan-European land cover database that can be updated frequently, and which is based on the integrative use of multi-spectral and multi-temporal NOAA-AVHRR satellite imagery and ancillary data (see also above-mentioned project URL). The project was financed under the Environment & Climate section of the European Union 4th Framework RTD Programme as a three-year shared cost action.

The PELCOM grid and final project report are available through the Environmental Protection Agency (EEA) data service [http://dataservice.eea.eu.int/dataservice/metadetails. asp? id=550]. Figure 7 shows the combined CORINE 1990 and PELCOM map. PELCOM was used where CORINE is not available (see overview map at the bottom-right).

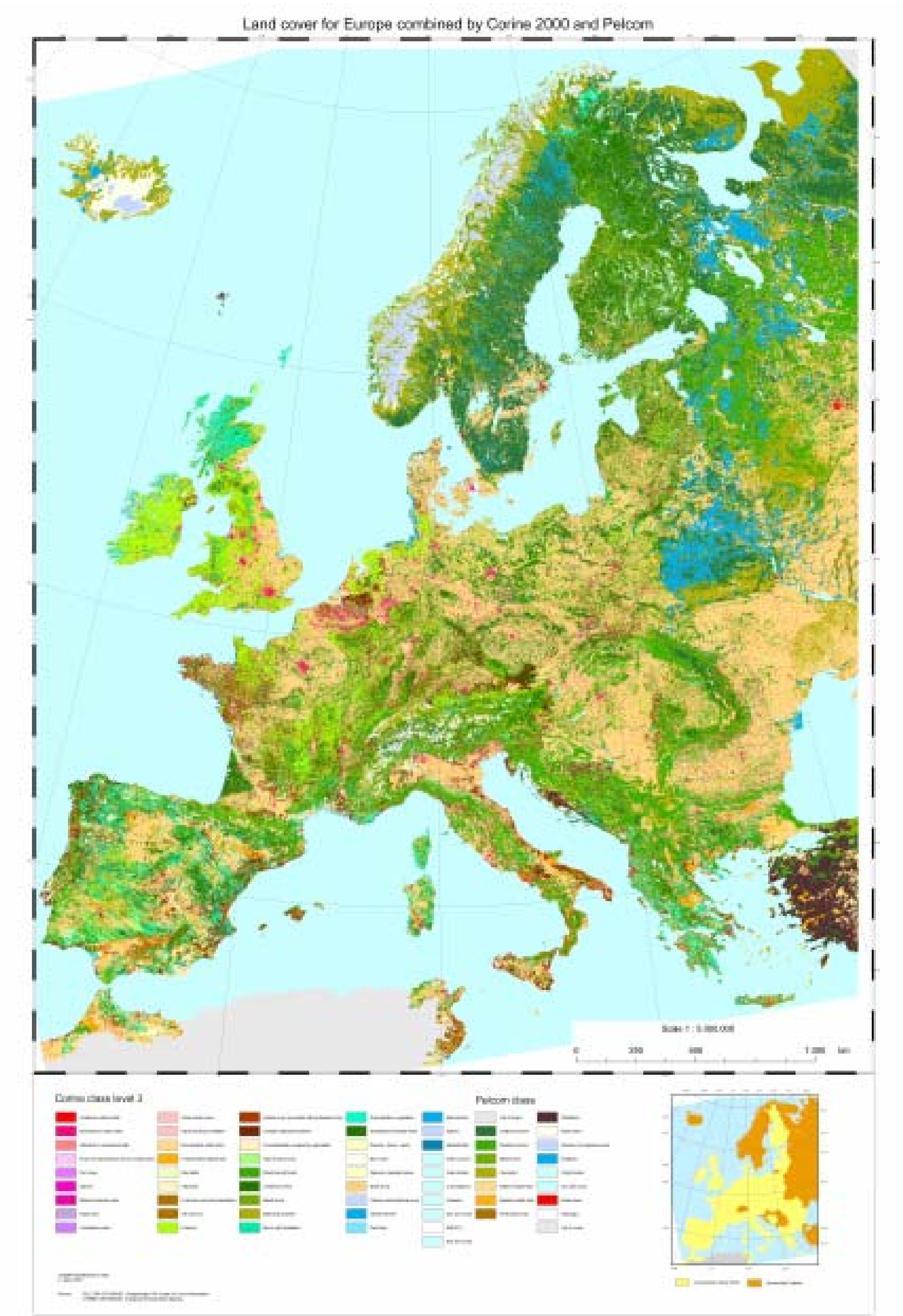

Figure 7: Combined CORINE and PELCOM land cover map of Europe

4.5 Land Use/Cover Area Frame Survey (LUCAS)

Agricultural land use is one of the most important pressures in the context of erosion, compaction, salinization, and SOM decline. CORINE and PELCOM provide geo-referenced information on land cover. However, data on the distribution on crop species is still missing. LUCAS fills this gap, but only so far with pilot inventories in 2001 and 2003.

The LUCAS inventory was initiated and financed by DG AGRI. EUROSTAT is responsible for the methodological issues and project management, with the technical support of DG JRC (CEC 2000, 2001). LUCAS is an area frame survey which consists of 2 phases. During Phase 1, data on land cover/land use and environmental features were collected in the field at around 100,000 observation points in EU15 (Figure 8). The sampling design is 2-stage: at the first level, so-called Primary Sampling Units (PSUs) are defined as cells of a regular grid with a size of 18 × 18 km, while the Secondary Sampling Units (SSUs) are 10 points regularly distributed (in a rectangular of 1500 × 600 m side length) around the centre of each PSU. Phase 2 consists of ca. 5,000 farmer interviews in order to obtain additional technical and environmental information.

While the survey provides geo-referenced data on agricultural land use including main cropping species, no information on cropping shares (or rotations) is available. In several evaluations towards disaggregating regional agricultural statistics to soil mapping units, LUCAS data have been proven useful to improve the soil biophysical information within administrative statistical zones (http://www.agp.uni-bonn.de/agpo/ rsrch/dynaspat/dynaspat_e.htm; http://www.insea-eu.info/;). An additional example to demonstrate the use of LUCAS in the context of soil inventories is provided by Hartwich *et al*. (2005).

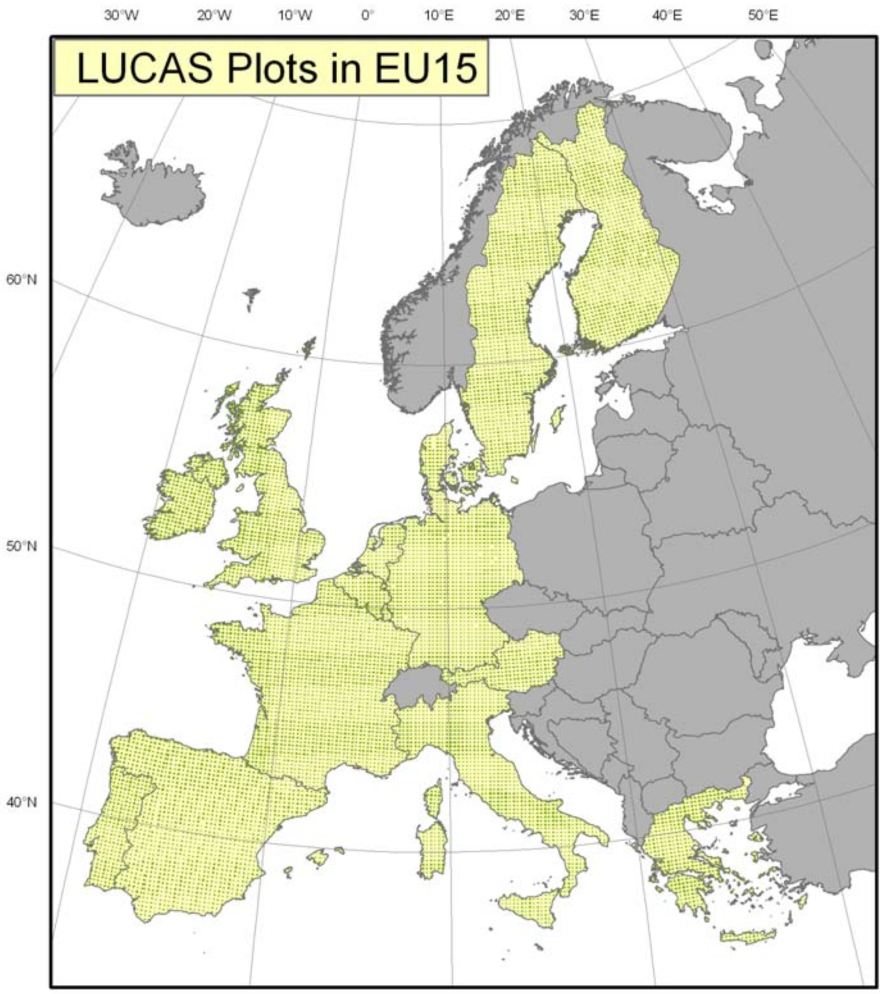

Figure 8: Map of LUCAS survey plots

Bibliography Section 4

CEC [Commission of the European Communities] (2001): Statistical Information needed for Indicators to monitor the Integration of Environmental concerns into the Common Agricultural Policy Communication from the Commission to the Council and the European Parliament COM(2001) 144.

CEC [Commission of the European Communities] (2003): The Lucas survey. European statisticians monitor territory. Theme 5: Agriculture and fisheries, Series Office for Official Publications of the European Communities, Luxembourg, pp. 24

EEA [Environment Protection Agency] (2001). Towards Agri-Environmental Indicators – Integrating Statistical and Administrative Data with Land Cover Information. Topic Report 6. Office for Official Publications of the European Communities, Luxembourg, 2001, pp. 133. (http://europa.eu.int).

EUROSTAT (2000). Manual of Concepts on Land Cover and land Use Information Systems. Theme 5: Agriculture and Fisheries: Methods and Nomenclatures. Series Office for Official Publications of the European Communities, Luxembourg, 2000, pp. 110.

Gallego, J. (2002). Fine scale profile of CORINE Land Cover classes with LUCAS data, in European Commission (ed.): Building Agro Environmental Indicators. Focussing on the European area frame survey LUCAS, Vol. EUR Report 20521 EN.

Hartwich, R., S. Thiele, R. Baritz, M. Fuchs and D. Krug (2005). The Soil Regions Map of the European Union Die Bodenregionenkarte der Europäischen Union and Adjacent Countries 1:5,000,000 (version 2.0). German text version: Arbeitshefte Boden (submitted), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover. English text version: European Soil Bureau Research Reports (submitted), Office for Official Publications of the European Communities, Luxenbourg.

Kempen, M., T. Heckelei, W. Britz, A. Leip and R. Koeble (2005). A Statistical Approach for Spatial Disaggregation of Crop Production in the EU. (In press).

Mücher, C.A., K. Steinnocher, J.L. Champeaux, S. Griguolo, K. Wester and P.Loudjani, (1998). Land Cover Characterization for environmental monitoring of pan-Europe. In: Proc. 18th EARSEL Symp. on Operational Remote Sensing for Sustainable evelopment, ITC, Enschede, 11-13th May 1998, pp 107-113. http://www.geo-informatie.nl/projects/pelcom/public/index.htm

Vidal, C., J. Gallego and M. Kayadjanian (2001). Geographical use of statistical data. In: EEA (2001). Towards Agri-Environmental Indicators – Integrating Statistical and Administrative Data with Land Cover Information. Topic Report 6. Office for Official Publications of the European Communities, Luxembourg, 2001, pp. 133. (http://europa.eu.int).

5. Topographical Database

Information concerning topographical features such as hydrography, terrain relief, road and railway networks, land cover, built up areas is required for any geographical data evaluation and condition assessment. Classical topographical and geographical maps are the most frequent source of information needed. In some countries (e.g. in France, Poland), the precision of topographical data bases (e.g. BDTopo) corresponds to the graphical and thematic precision at the scale 1:10,000. National survey and mapping agencies are responsible for the development and updating of such data bases (also called "core data"). International civil and military organizations have developed common standards to assure compatibility and transfer of data for large regions. In EU 25, the INfrastructure for SPatial Information in Europe (INSPIRE) project is expected to provide such a frame for compatibility.

EU 25 surveying and mapping agencies have profited from the experience of US NIMA during its work on national and European topographic maps and cartographic databases. In some countries national agencies have developed digital topographic maps and databases, but for projects at European continental as well as national level, it is recommended to use general geographical database developed by NATO military services. The most common example is the 'Vmap data base' which contains four levels of precision.

Another easily accessible but coarser resolution topographic information can be received from the GISCO reference data base (e.g. Rivers, Lakes, Infrastructure, GTOPO30).

5.1 VMap databases

Overview

The Vector Smart Map (VMap) family of databases (see Table 15) is a set of digital vector product databases. VMap Level 1 (VMap1) data correspond to the geometry and content of maps in the scale of 1:250,000, The VMap Level 2 (VMap2) data base contains information roughly equivalent to the scale 1:50,000. The VMap1 and VMap2 data bases consist of 10 feature classes: administrative borders, data quality, elevation, hydrography, industry, physiography, population, transportation, utilities and vegetation. The Vmap family is completed by the low resolution VMap Level 0 (VMap0) and the high resolution Urban VMap data.

Table 15: The VMap family of databases and their status of availability

Product Level	Equivalent Map Scale	Status
VMap Level 0	1:1.000.000	Available world-wide as the DCW (Digital Chart of the World), 2nd ed.
VMap Level 1	1:250.000	Available world-wide in 2001
VMap Level 2	1:50.000	Produced on request only
Urban VMap	City Maps	Produced on request only

Sources of VMap are existing analogue topographic and thematic maps, image data and national databases. The VMap data are stored in the Vector Product Format (VPF) according to specification MIL-STD-2407 of the U.S. National Imagery and Mapping Agency (NIMA, 1996) which is a subset of the Digital Geographic Information Exchange Standard – Feature Attribute Coding Catalogue (DIGEST-FACC). The VMap1 database is being populated as a co-production of the different NATO nations. The VMap1 data have a horizontal accuracy of 125 m and a vertical accuracy of 20 m in most parts of the world. The VMap2 data have a horizontal accuracy of 25-50 m. Vmap 2 is available for the majority of European countries, for instance to Poland, since 2005.

VMAP0 and VMAP1

The following information has been derived from "Explore the best free dataset in the world" http://www.mapability.com/index1.html.

VMAP 0

Vector Map (VMap) Level 0 is an updated and improved version of the National Imagery and Mapping Agency's (NIMA) Digital Chart of the World (DCW®). The VMap Level 0 database provides worldwide coverage of vector-based geospatial data which can be viewed at 1:1,000,000 scale, i.e. 1 cm = 10 km. It consists of geographic, attribute, and textual data stored on CD-ROM or as files for download. The primary data source is the 1:1,000,000 scale Operational Navigation Chart (ONC) series co-produced by the military mapping authorities of Australia, Canada, United Kingdom, and the United States. The complete data base contains more than 1,800 megabytes of vector data organized into 10 thematic layers (four CD-ROM's). VMap Level 0 includes major road and rail networks, hydrologic drainage systems, utility networks (cross-country pipelines and communication lines), major airports, elevation contours, coastlines, international boundaries and populated areas.

VMap Level 0 includes an index of geographic names facilitate identification of target/study areas. Some layers of this database (hydrology, elevation contours, coastlines, populated places) can be useful for soil threats inventory at the European scale.

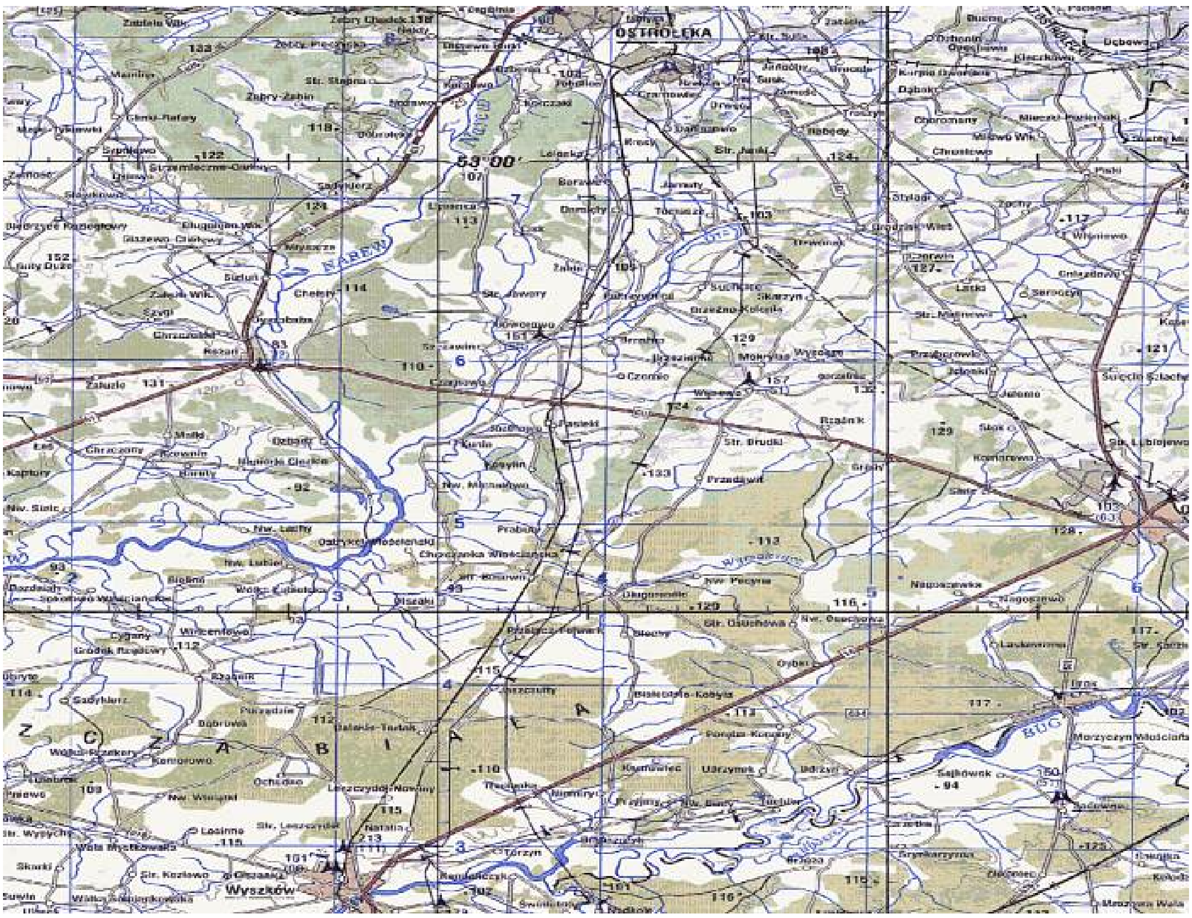

Figure 9: VMAP Level 1 – Wyszkow region, POLAND

VMAP 1

Vector Map Level 1 is based on a 1:250,000 map scale source, i.e. 1 cm = 2.5 km. The horizontal datum for this VMap product is WGS84, the vertical datum is mean sea level (MSL). The unit of measure for VMap is metric. The geographic extent of the VMap Level 1 product is global and consists of multiple regional databases. Each VMap thematic layer is stored as a single coverage within a VPF library. There are two reference coverages and ten thematic coverages in the data library level.

For public application the VMap 1 is available in topographic sections of military service of each of European country in paper or digital form (Figure 9). Vmap1 is considered as a good topographic basis for analysis, modelling and visualization of soil properties at regional scale. Some experience is necessary to pass from raw data to the formats accepted by GIS software.

5.2 GISCO reference database

GISCO is the Geographic Information System for the European Commission. Originally conceived as a prototype GIS that would serve a wide spectrum of users and uses, the GISCO project has developed a service-oriented dimension, namely in geographical database development, thematic mapping, desktop mapping and dissemination of data. Providing these types of services is directly related to key parts of the GISCO mandate.

Within the framework of the GISCO project, a large geo-referenced database has been developed. One of the main topics of the GISCO mandate is to extend, maintain and update this database. The numerous data sets offered by GISCO include:

Topographical data:

- hydrography (e.g. water patterns, lakes)
- altimetry (digital elevation model)
- infrastructure data (ports, airports, roads, rail networks, etc.)
- administrative entities (countries, regions, etc.)

Thematic data:

- land resources (land cover, soil data, vegetation, climatic conditions, etc.)
- EU support frameworks (structural funds, INTERREG, etc.)
- environmental data (coastal erosion, soil erosion, etc.)
- industrial themes (e.g. energy transport networks, location of nuclear power stations)

Bibliography Section 5

Baranoswki, M. (2004). The general Geographic Data base of Poland – An Element of National Spatial Data Infrastructure. Abstract of 10-th EC-GI-GIS Workshop, Warsaw.

Białousz, S. *et al*. (2004). The General Geographic Data Base. Report of pilot project. Warsaw University of Technology.

DMS (2002). Aeronautical Cartography Lecture Notes, DMS of NGA, USA ESRI (2000). MPS User Guide and MPS JOG-A Production Guide, ESRI Inc.

Frye, C., C.L. Eicher (2003). Modeling Active Database-Driven Cartography within GIS Databases, 21st ICA Conference Proceedings, Durban, S.Africa.

NGA (1995a) 1. Military Specifications MIL-V-89033 (DMA) Vector Smart Map (VMAP) Level 1.

NGA (1995b). Military Specifications MIL-J-89100 (DMA) Joint Operation Graphics 1501A and 1501 (JOG Air and Ground).

NGA (1995c). Military Specifications MIL-STD-2402 (DMA). (Draft). Mapping Charting &Geodesy.

NIMA (1993). Military Specification MIL-V-89032 Vector Smart Map (VMap) Level 2.

NIMA (1995). Military Specification MIL-V-89033 Vector Smart Map (VMap) Level 1.

NIMA (1996). DoD Interface Standard MIL-STD-2407 for Vector Product Format (VPF).

Ohlhof, T., T. Emge, W. Reinhardt, K. Leukert, K. Heipke and K. Pakzad (2000). Generation and Update of VMAP Data Using Satellite and Airborne Imagery. Proceedings of ISPRS 2000, Vol XXXIII, Part B4, Amsterdam.

STANAG 3675 (2000). Edition 2. Symbols on Land Maps. Aeronautical Charts and Special Naval Charts.

Torun, A. and A. Ulubay (2004). Database-driven cartographic visualization of Vmap database. www.isprs.org/istanbul2004/comm4/papers/361.pdf

6. Statistical Data on Land use

(Information about type of agriculture, kinds of crops, number and type of heavy machines used in agriculture)

Five main groups of statistical information and information sources can be distinguished in agriculture (Ahner 2004):

1) **General agricultural statistics**: farm structure survey (FSS), land use statistics, economic accounts and the Farm Accountancy Data Network (FADN);
2) **Information for market management**: market prices, production, including herd sizes, area and yields;
3) **Administrative information on aid granted** to the farm sector which we receive through the Integrated Administration and Control System (IACS);
4) **Statistics on rural development** including monitoring reports from Member States;
5) Other types of information such as **agri-environmental statistics** or information on quality products.

These data are accessible from agricultural statistics, national census' and agricultural economic and statistical studies. Data corresponds to administrative units (e.g. NUTS regions) and can be aggregated for larger territorial units. Despite a large variety of statistical information, EU-wide and for whole countries, it is still difficult to receive accurate geo-information about crop rotation, agricultural technology, number and types of machines used in agriculture. The alternative data source to the above-mentioned large scale administrative statistics is cadastre-based. Cadastral data connects to the land owner in a high resolution, spatially explicit way. From cadastral data, it is possible to generate analysis showing size of parcels and size of farms. It can be expected that in the mid-term future, IACS will provide spatially explicit data on land management, which can be combined with large-scale soil maps. IACS (Integrated Administration and Control System) is an anti-fraud and expenditure control mechanism, operated in all Member States, for payments made to farmers under the CAP.

6.1 EUROSTATS NUTS REGIONS

The Nomenclature of Territorial Units for Statistics (Nomenclature des unités territoriales statistiques, NUTS) was established by EUROSTAT in the beginning of the 1970s (applied since 1988) in order to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union (EUROSTAT 1999). It also led to the creation of EUROSTAT's REGIO (regional statistics).

The idea is to document and track managed changes in the administrative structures of Member States in a three level hierachical nomenclature, so as to minimise the impact of such changes on the availability and comparability of regional statistics. The borders and codes of administrative units (communes, cantons, NUTS 1, 2, 3; see Figure 10) in digital form are available at the national statistical offices or at the national surveying and mapping agencies. NUTS 4 and 5 were introduced in the 1990s and refer to the Commune level (or national equivalent) of the Member States, and provide the framework for the European infra-regional database (SIRE). NUTS regions comprise all EU and EFTA (Switzerland, Norway, Iceland) countries. The standard scale of data availability of European statistics is NUTS 2 (EC 2004).

6.2 FARM STRUCTURE SURVEY (FSS)

FSS is a EUROSTAT census organized every ten years, with sample surveys every two to three years. The first survey was conducted in 1966/67. Data from agricultural holdings (< 1 ha) are gathered by national statistical agencies according to a harmonized data scheme. The following data are gathered:

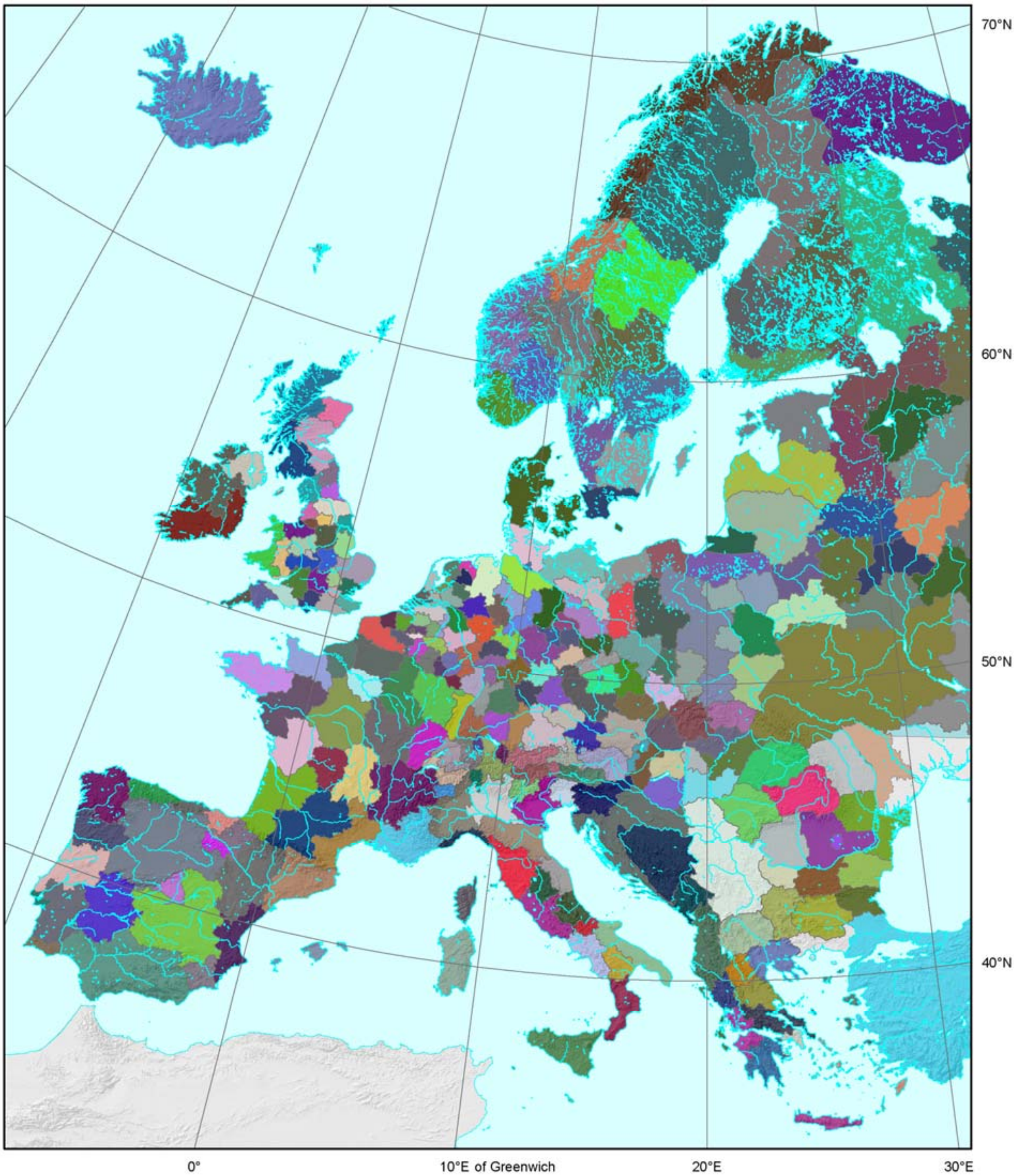

Figure 10: NUTS 2 regions in Europe

- land use [ha] (e.g. grassland, permanent crop land)
- information on the holding (e.g. legal status)
- livestock [density] (e.g. cattle, poultry)
- agricultural machinery
- labor force
- standard gross margin

Information on land use is broken down into more detailed land use classes, with the secondary heading referring to crop types. For confidentiality, data are provided at the district rather than the commune level. For evaluations, data are often aggregated to NUTS 2 or 3. As with all statistical data, the actual location of land use information within the administrative boundary is not known.

6.3 New Cronos

NEW CRONOS is one of the main EUROSTAT public databases. It contains socio-economic and macroeconomic data of the EU Member States, in some cases also Japan, USA, central European countries and important trade partners of the EU. Depending on the statistical field, monthly, half-annual or annual data are available, partly since 1960. http://europa.eu.int/comm/employment_social/health_safety/docs/cronos_en.pdf. There are several themes, of which 'Agriculture, Forestry and Fisheries' is one of them, as well as 'Environment'. Under the theme General statistics, regional statistics (REGIO) can be found.

REGIO is a sub database of NEW CRONOS, existing since 1975. It contains data about 21 statistical themes (population, migration, macro-economics, employment, energy, traffic, agriculture, etc.) (see also EC 2004). The part on Agricultural Statistics contains information about the following areas:

- land use
- crop production (e.g. area harvested, production and yield); milk production
- agricultural accounts, structure of agricultural holdings
- livestock: cows, etc.

6.4 Farm Accountancy Data Network (FADN)

FADN is an instrument of DG AGRICULTURE of the European Commission for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy (CAP) (Council Regulation 79/65/EEC of 15 June 1965). The services responsible in the Union for the operation of the FADN collect every year accountancy data from a sample of the agricultural holdings in the European Union (ca. 80,000 holdings per year). The total population of farms included in the network covers ca. 90 % of the utilized agricultural area (UAA) in EU25. The aim of the survey is to gather accountancy data from sample farms for the determination of incomes and business analysis of agricultural holdings (http://europa.eu.int/ comm/agriculture/rica/concept_en.cfm). The annually selected farms are stratified by region, economic size and type of farming.

Since the data are confidential, only aggregated results for a group of farms and for farms within regions and Member States are published. NUTS regions are a common basis for data aggregation. Standard results are a set of statistics, computed from the farm return data ('*Betriebsbogen*'). It contains information about:

- location, crop area
- type of occupation
- labour
- number and value of livestock
- livestock purchases and sales
- cost
- land and buildings
- debts, VAT, subsidies, , direct payments
- quotas
- production

The FADN is the only source of micro-economic data that is harmonised, i.e. the book-keeping principles are the same in all countries supplying these data.

Bibliography Section 6

Ahner, D. (2004). Agricultural statistics and the Common Agricultural Policy - a long-term perspective. 26th CEIES seminar „European agricultural statistics — Europe first or Europe only? Brussels, 9/10. 09.2004. In: EUROPEAN COMMISSION, THEME 1, General statistics. Office for Official Publications of the European Communities, 2004, ISBN 92-894-8295-8.

[CEIES: *The European Advisory Committee on Statistical Information in the Economic and Social Spheres*]

EC [European Communities] (2004). European Regional Statistics – Reference Guide. Office for Official Publications of the European Communities, 2004, Cat. No. KS-BD-04-001-EN-N

EUROSTAT (1999). NUTS regions of the EU: Systermatics of regional units for statistics version 7 (1999), 1,000 regions, 4 hierarchical levels. In. GISCO - Geographical Infiormation System of the European Commission (1999).

7. Climatic Data

7.1 MARS Meteorological data

The DG JRC project Monitoring of Agriculture with Remote Sensing (MARS) has been gathering meteorological data received from the European Centre for Medium-Range Weather Forecasts (ECMWF) for the past two decades. The task of the MARS project relates to the following topics, with the general objective to support the Commission's agricultural policy:

- Statistics (e.g. area frame sampling)
- Image processing and interpretation (satellite or air-borne)
- GIS management & web-based information technology
- Geomatics and GPS (orthophotos, large scale mapping, parcel measurement)
- Agrometeorological models (crop growth / yield)
- Standardisation and Quality Control

More information can be found on the JRC AGRIFISH Unit web page(http://agrifish.jrc.it/).

Currently, the MARS FOOD action continues the work with the climatic data used to forecast yields of the major arable crops in Euorpe). The Agrifish Unit receives daily, 10-daily and monthly outputs of the ECMWF atmospherical model. While the original global data set at a 1 degree resolution has been preprocessed by Meteoconsult (NL), it becomes finally transformed into 0.5 degree grids, provided to JRC. A time series for more than 40 years (start: 1979) is now available thanks to the ERA40 reanalysis project. The data can be downloaded for the full MARS 50km x 50 km grid.

Figure 11 presents the grid cell identification system, each cell having a unique identification number. The following data are accessible:

- precipitation sum
- evapo-transpiration sum (ES0, bare soil; E0, over water; ET0, Penman-Monteith)
- global radiation sum
- snow depth (average, maximum, minimum)
- climatic water balance (not available yet)
- temperature (average, maximum, minimum)

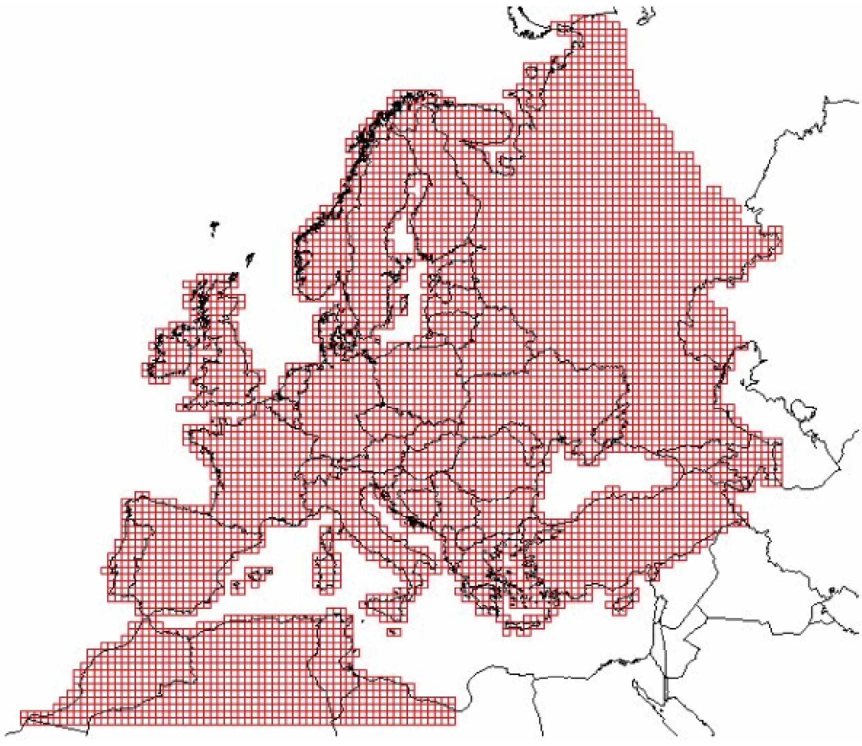

Figure 11: Grid cell identification system of MARS meteorological data

7.2. Tyndall East Anglia climatic data

The Tyndall Centre for Climate Change Research has compiled a significant databank for climatic data, called the East Anglia database. The data are presented as point data in a defined grid, at intervals of 0.5° or 10'. In some cases, data are available for the whole globe, in some other cases only for Europe (http://www.cru.uea.ac.uk/~timm/data/index-table.html). Currently, there are 12 data sets including scenario models. The coverage of the time series data ranges from 1901 to 2002. Figure 12 presents the 0.5° (50 kilometre) grid for Europe. The basic data available are daily mean temperature, diurnal temperature range, precipitation, vapour pressure and cloud cover. In some cases, frost-day frequency, relative humidity, sunshine duration, wet day frequency and wind speed are also available.

The observed grids are based on extensive databases of monthly measurements of climate at individual stations. No satellite information or remote sensing information is included. The climate databases are the product of an intensive data capture campaign of the Climate Research Unit (http://www.cru.uea.ac.uk/) over many years (New *et al*. 2002; Mitchell *et al*. 2003). The underlying station databases are not publically accessible. Weather station coverage is denser over the more populated parts of the world, including Europe.

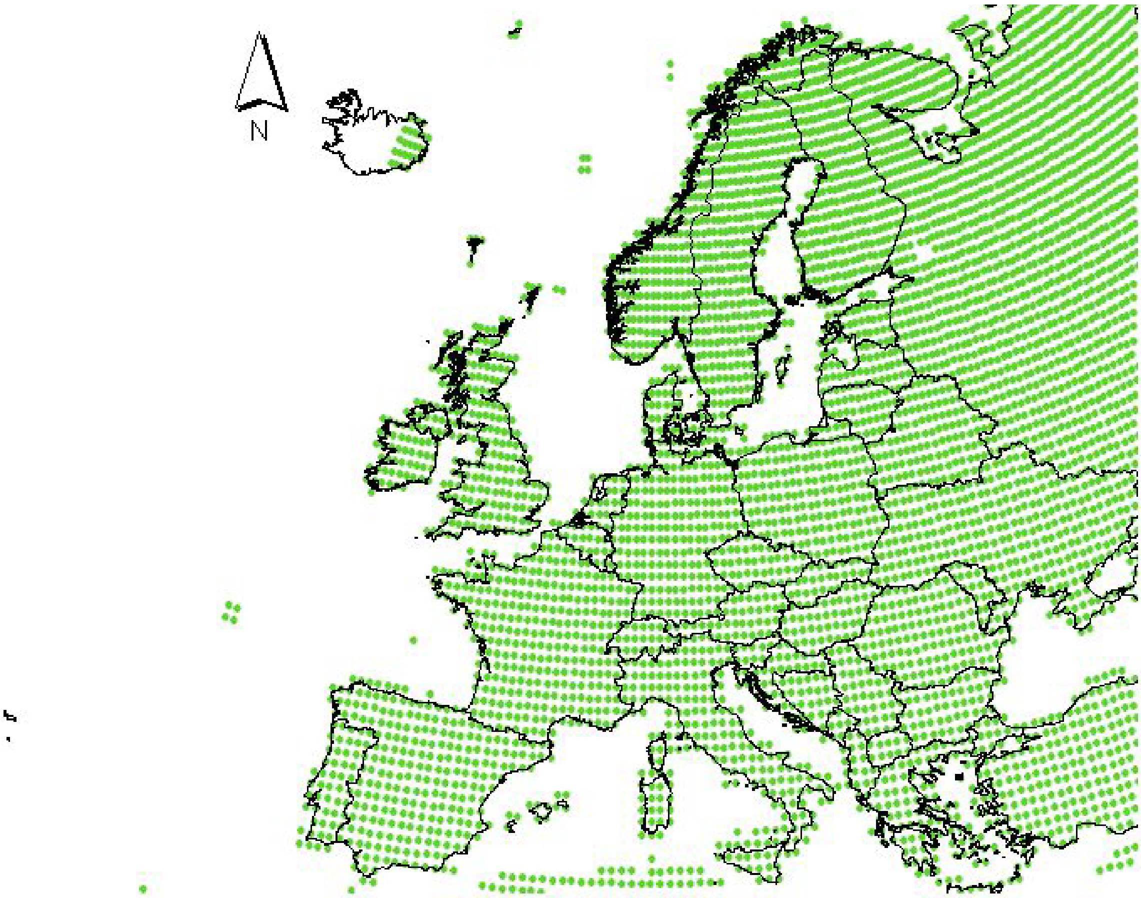

Figure 12: Tyndall climate data plot network

Bibliography Section 7

Mitchell, T.D., T.R. Carter, P.D. Jones, M. Hulme and M. New (2003). A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Journal of Climate.

New, M., D. Lister, M. Hulme and I. Makin (2002). A high-resolution data set of surface climate over global land areas. Climate Research 21.

8. Parent Material/Geology

8.1 Parent material associations in the Map of European Soil Regions 1:5,000,000

Geology, which includes parent material, is the basic driver for the development of relief and altitudinal structure of a landscape. Mineral composition, chemistry and structure of soils are closely connected to it. The parent material influences soil texture, and has a significant effect on soil fertility and nutrient availability. Thus, parent material is also related to the use and cultivation of soils. In the context of the Soil Regions Map, parent material has not been described at the level of types or sub-types, but in main classes (Figure 13), as suggested by Finke *et al.* (1998). Associations reflect a basic aggregation scheme, e.g. the distinction between sedimentary and igneous rocks, magmatites, metamorphites. In some cases, information about the chemical nature of the main stone – acidic, intermediary or basic – and about the texture – clayey, sandy or loamy – supplements the parent material group. The *International Geological Map of Europe and the Mediterranean Region 1:5.000.000* (BGR and UNESCO 1971) and the *International Quaternary Map of Europe 1:2.500.000* (BGR and UNESCO 1967 - 1989) have been used to add additional information for the definition of the parent material associations.

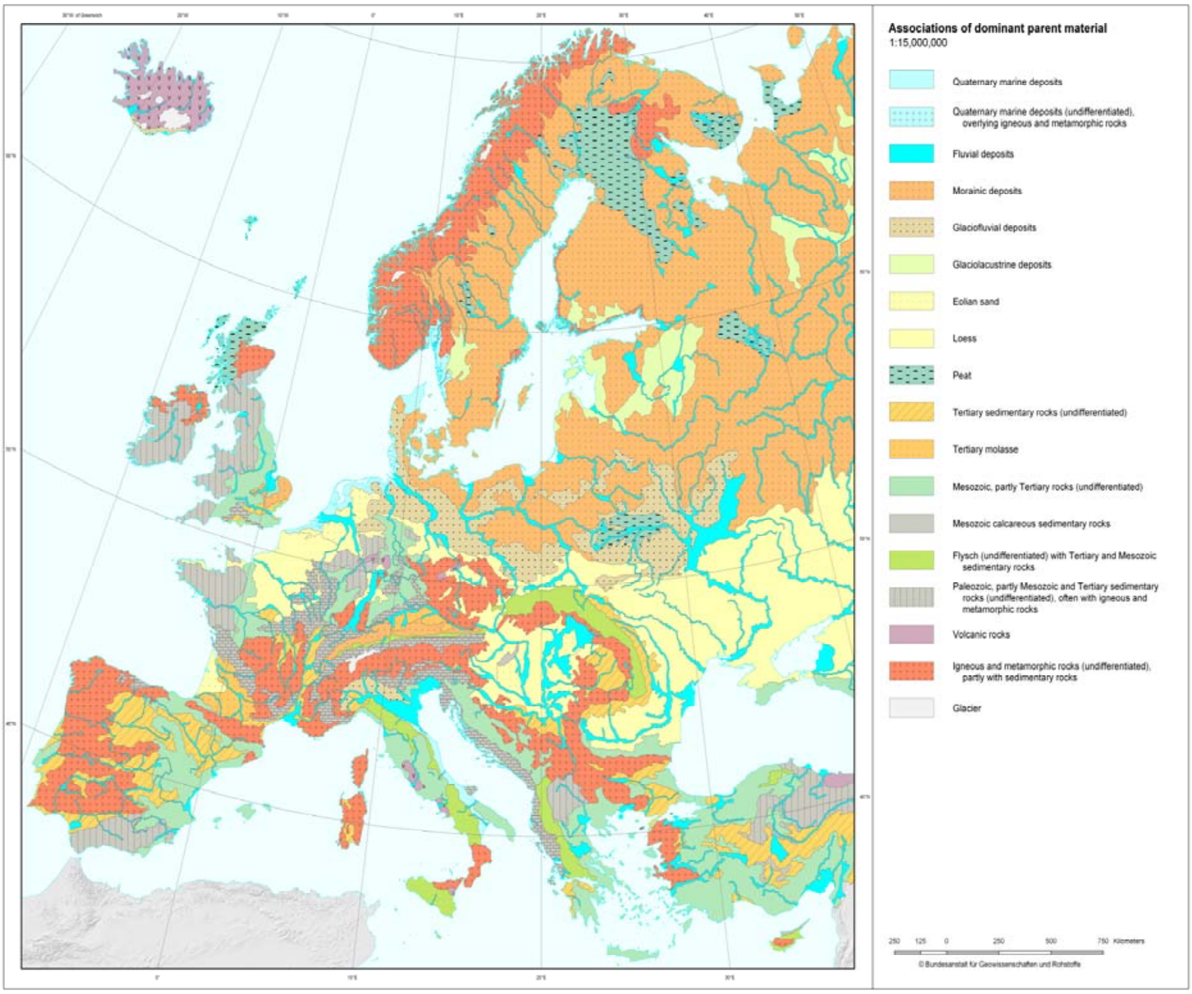

Figure 13: Parent Material Groups in the Map of Soil Regions in Europe 1:5,000,000 (Hartwich *et al*. 2005)

8.2 IGME 5000 (Geology 1:5,000,000)

The latest, most accurate and comprehensive digital data available for Europe is the 1:5 Million International Geological Map of Europe and Adjacent Areas - IGME 5000 (Asch 2005). This spatial database in GIS format contains a full set of attributes on age, lithology, metamorphism, regional nomenclature, tectonic and genetic features for each of the mapped units (Asch, 2003). This is significantly more information than contained in the parent material groups (see Section 8.1), which was derived from the European Soil Regions Map (1:5,000,000). The IGME 5000 (Figure 14), which covers the pre-Quaternary of both on- and off-shore domains, is a collaborative European BGR-led project involving 48 countries.

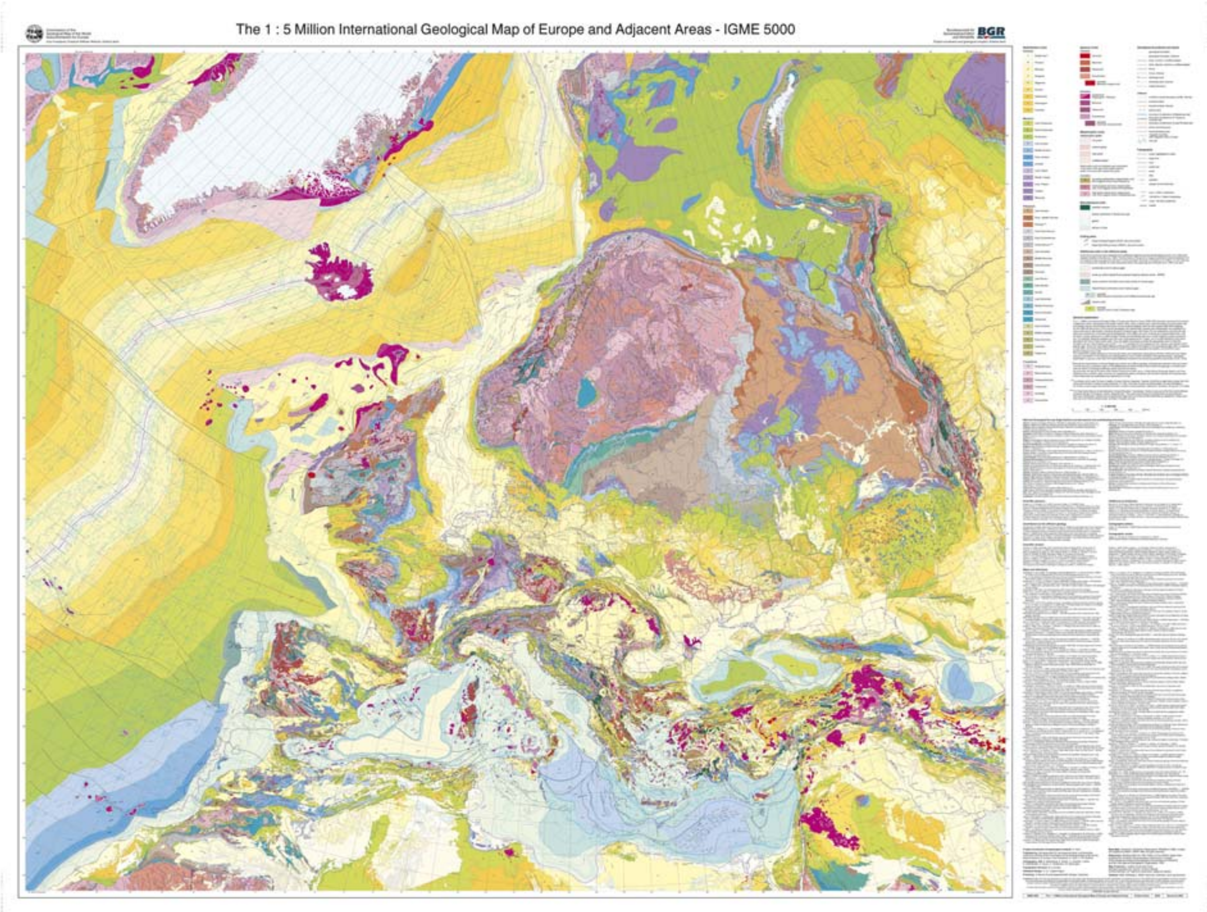

Figure 14 The 1:5,000,000 International Geological Map of Europe and Adjacent Areas IGME 5000 (Asch 2005)

8.3 IHME 1500 (Hydro-Geology 1:1,500,000)

The **International Hydrogeological Map of Europe**, scale 1:1,500,000 (Figure 15) is an ongoing project of the Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). It started in 1960 and is still ongoing. Currently, 22 map sheets (out of a total of 25 map sheets for Europe) partly with explanatory notes have been finished (Karrenberg and Deutloff 1973; Karrenberg *et al.* 1974). BGR and UNESCO, responsible for the cartography, printing and publication of the map sheets and explanatory notes, are closely coorperating with the respective national institutions and experts under the auspices of the International Association of Hydrogeologists (IAH), Commission on Hydrogeological Maps (COHYM). The project is supported by the Commission for the Geological Map of the World (CGMW).

The IHME map series is also intended to serve as a model for small-scale hydrogeological maps in other parts of the world. An International Legend for Hydrogeological Maps has been elaborated as the basis for the General Legend for the International Hydrogeological Map of Europe (1974) and the preparation of the first sheet C5 Bern (printed in 1970).

At the beginning of the project, quantitative attribute data were gathered: e.g. specific capacity, well yield, transmissivity and groundwater recharge. However, this has proved impracticable since knowledge about the hydrogeological parameters differed greatly among regions and countries. Later on, the definitions have become more descriptive. This information is provided in the explanatory notes which accompany most of the map sheets. Examples are climate, chemical composition of the groundwater, and geological features of significance to groundwater flow.

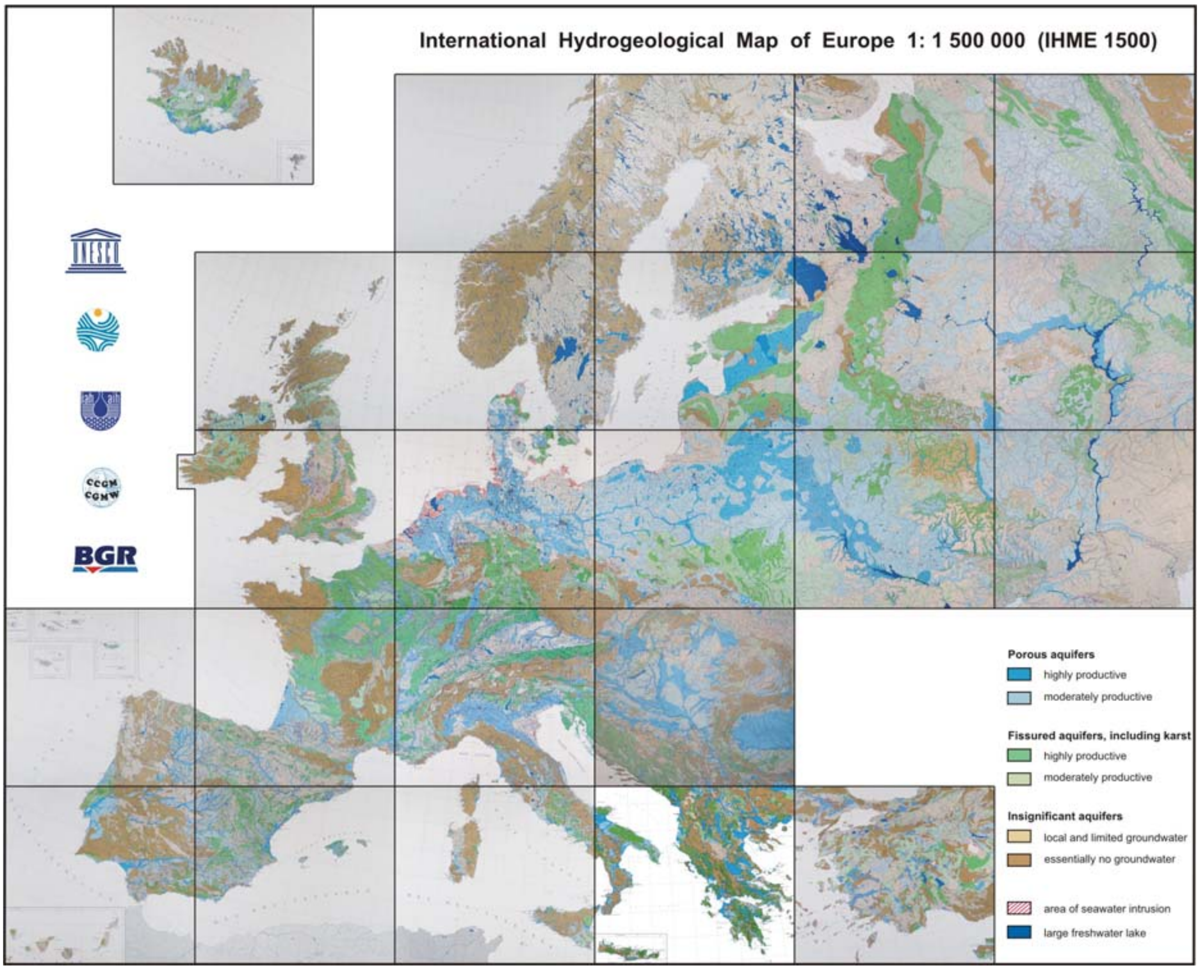

Figure 15: International Hydrogeological Map of Europe 1:1,500,000 (IHME 1500)

The single analogue sheets can be purchased via the following addresses:

- UNESCO Publishing, 7, Place de Fontenoy, F-75700 Paris
- GeoCenter Scientific Cartography, Schockenriedstrasse 44, D-70565 Stuttgart

The availability of digital data is currently under development.

Bibliography Section 8

Asch, K. (2003). The 1:5,000,000 International Geological Map of Europe and Adjacent Areas: Development and Implementation of a GIS-enabled Concept. Geologisches Jahrbuch SA3. Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover. 172pp.

Asch, K. (2005). The 1:5 Million International Geological Map of Europe and Adjacent Areas. Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR), Hannover. 1 map.

Finke, P.A., Hartwich, R., Dudal, R., Ibàñez, J.J., Jamagne, M., King, D., Montanarella, L. & Yassoglou, N. (1998): Georeferenced Soil Database for Europe, Manual of Procedures, Version 1.0. - European Soil Bureau Research report No. 5, EUR 18092 EN, 170pp. Office for Official Publications of the European Communities, Luxembourg

Hartwich, R., S. Thiele, R. Baritz, M. Fuchs and D. Krug (2005). The Soil Regions Map of the European Union Die Bodenregionenkarte der Europäischen Union and Adjacent Countries 1:5,000,000 (version 2.0). German text version: Arbeitshefte Boden (submitted), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover. English text version: European Soil Bureau Research Reports (submitted), Office for Official Publications of the European Communities, Luxenbourg.

Karrenberg H. and O. Deutloff (1973). Directions for the Construction of the International Hydrogeological Map of Europe 1 : 1,500,000. – IAH Bull. Inform., 15-16: 58 – 63; Paris.

Karrenberg H., O. Deutloff and C. v. Stempel (1974). General Legend for the International Hydrogeological Map of Europe 1 : 1, 500,000. – Hannover (Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR)/UNESCO).

9. Biogeographic Regions/Climate Regions

For meaningful regional ecological interpretations of soil inventory data, it is important to consider bio-geographic aspects of the landscape. Several classifications exist, partly harmonized, partly close in concept to each other with deviating delineation criteria and purposes. Thus, before any of these maps is used, more intensive investigations about the map concepts are necessary by each potential user. Hartwich *et al*. (2005) give an example of a comparison of different approaches. They also provide an example of how climatic regions can be used to stratify soil mapping data and soil plot inventory data to assess a soil carbon baseline inventory.

The general idea of biogeographic classifications is to identify 'homogenous' areas within the complex landscape pattern in Europe for ecological landscape stratification.

9.1 EEA

Two maps (and various intermediate products) have been presented by EEA and co-authors:

- *Biogeographical Regions of* Europe (EEA 1995-2002, cited in Roekerts 2002)
  [N = 11 mapping units; 1:10,000,000], in the following referred to as 'EEA map
- *Map of European Ecological Regions* [DMEER] (EEA/ETC BD 2000)
  [N = 68 classes; 1:2,500,000], in the following referred to as **'**DMEER map**'**

The main basis for both maps is the Map of the Natural Vegetation of Europe, Scale 1:2,500,000 (Bohn *et al*. 2003). Both the EEA and the DMEER maps provide a rough overview of the natural site conditions in Europe including climate. Figure 16 presents the DMEER map. The ecoregions are defined as geographical units, which are characterized by a specific climate and ecological properties, in combination with a specific flora and fauna. According to Metzger *et al*. (2003), climate and topography are the main factors driving ecological conditions of a landscape, with geology and soil at a succeeding level.

While the DMEER map combines numerical classification with expert knowledge, the approach presented by Metzger *et al*. (2003) is purely numerical, see also Mücher *et al*. (2003), which has resulted in:

- *Environmental Classification of Europe* [84 classes aggregated to N = 9, 1:30,000,000]

The latter approach has the advantage that the classes defined can be quantitatively described and repeated with higher resolution input data if available.

The work on the map of Soil Regions in Europe by Hartwich *et al*. (2005) has shown, that biogeographic maps do not specifically address the relationship 'soil – climate'. Even though the maps mainly concentrate on the climate-induced development of vegetation regions, climate is not always the main descriptor to explain the borders of biogeographic regions. For example, some regions were found to match the borders of soil associations rather than climate areas, for example according to Walther and Lieth (1969/1967).

9.2 Climate areas in the Map of European Soil Regions 1:5,000,000

In order to stratify large soil mapping units, the map Climatic Areas of Europe 1:15,000,000 (Figure 17) has been developed (Hartwich *et al*. 2005). To date, no purely climatically defined regional stratification of Europe exists, which sufficiently reflects climatic parameters relevant for soil genesis. If large soil mapping units with similar regional soil associations that extend into different climatic regions are treated homogenously, ecological interpretations are not very reliable. The map was used to stratify soil regions in Europe. Even though soil associations may be similar in different landscapes, they are ecologically different if they are found in different climatic zones.

Figure 16: Map of European Ecological Regions (DMEER)

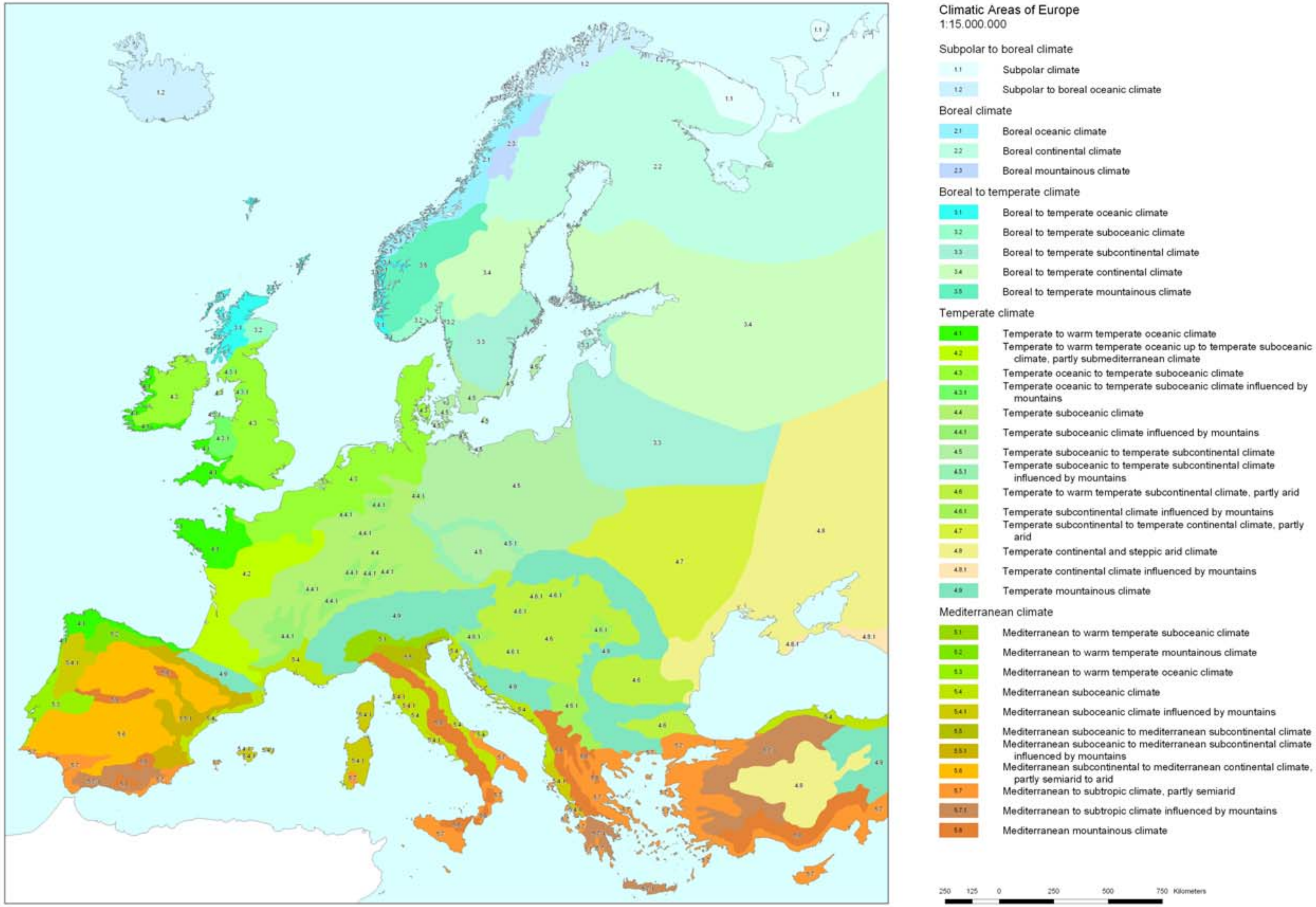

Figure 17: Climatic Areas of Europe (Hartwich et al. 2005)

Bibliography Section 9

Bohn, U., G. Gollup, C. Hettwer, Z. Neuhäuslova, H. Schlüter and H. Weber (eds) (2003). Map of the Natural Vegetation of Europe, Scale 1:2,500,000 – Explanatory Text with CD-Rom, 656 p. – Federal Agency for Nature Conservation, Bonn.

EEA/ETC BD (2000). Digital Map of European Ecological Regions (DMEER), Version 2000/05 – Environmental Protection Agency / European Topic Centre for Biological Diversity, Kopenhagen.

Hartwich, R., S. Thiele, R. Baritz, M. Fuchs and D. Krug (2005). The Soil Regions Map of the European Union Die Bodenregionenkarte der Europäischen Union and Adjacent Countries 1:5,000,000 (version 2.0). German text version: Arbeitshefte Boden (submitted), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover. English text version: European Soil Bureau Research Reports (submitted), Office for Official Publications of the European Communities, Luxenbourg.

Metzger, M., Bunce, B., Jongman, R., Mateus, V. and S. Mücher (2003). The environmental classification of Europe, a new tool for European landscape ecologists. Landscape 20 (5).

Mücher, C.A., Bunce, R.G.H., Jongman, R., Klijn, J.A., Metzger, M. and D.M. Wascher (2003). Indentification and characterization of Environments and Landscapes in Europe. ALTERRA Report 832. ALTERRA, Wageningen.

Walther H. and H. Lieth (1969/1967). Klimadiagramm Weltatlas. – Gustav Fischer Verlag, Jena.

10. River basins/watershed in Europe

Statistics aggregated in administrative zones are often not ecologically effective. For example, pollution does not follow adminstrative boundaries, rather water courses, such as drainage basins (Vidal *et al.* 2001).

Under FP6, Joint Research Centre (JRC) has developed a first version of a European-wide river and catchment database for future use in environmental modelling activities (Vogt *et al.* 2003). The objective was to allow evaluations in river catchments, the monitoring of quality and quantity status and trend of water resources, and the integrated analysis of environmental pressures and impacts – while building on a fully connected river network with associated catchments, including lakes, transitional waters, coastal waters.

The database corresponds to a mapping scale of roughly 1:250,000 to 1:500,000, depending on the region. The data have been processed in raster format with a 250 meter grid-cell size (scale equivalent: 1:250,000 to 1:500,000). It includes a hierarchical set of river segments and catchments. The inland lakes and rivers (River Network 1:3,000,000) were derived from the GISCO reference database see Section 5.2).
(http://eurolandscape.jrc.it; http://agrienv.jrc.it/activities/catchments/ccm.html)

10.1 Catchment Information System

The processes to be observed and the parameters to be assessed to answer agri-environmental questions are mainly related to the hydrologic cycle. Also, the results should be quantitative and should be based on physical parameters, such as soil, topography and climate. Processes related to the hydrological cycle do in general not coincide with geometrically regular sample areas, as used for crop monitoring, nor with administrative units, as used for statistical purposes. Therefore, the drainage basin or *catchment* is the logical entity to perform agri-environmental studies.

Recognizing those needs DG JRC initiated in 1998 an activity with the aim of installing a Catchment-based Information System (CIS). The CIS was created as a system to address agri-environmental issues. In particular the following specific areas were to be served:

- Assessing the impact of European Union policy on agriculture and environment.
- Monitoring environmental changes.
- Evaluating detrimental effects to the environment.
- Supporting environmental protection.

The aim of the CIS was not to produce catchment boundaries, but to provide information. However, because no suitable catchment boundaries existed they had to be created. This task alone took 2 years of development.

The 1:1,000,000 scale Pan-European catchment layer contains data relating to the major drainage basins of Europe (Figure 18). The catchments were derived from a hierarchical river network of scale 1:1,000,000, which was combined with a DEM of 1km grid size.

Catchments are separated into those draining into the sea, referred to as ‘primary’ catchments, and those, which constitute partitions of primary catchments, referred to as ‘sub-catchments’. To achieve complete coverage, areas below the limit and those, which could not be positively identified by the algorithm, were aggregated into coastal catchment areas. Those areas differ from primary catchments in that they do not have an identifiable single outlet.

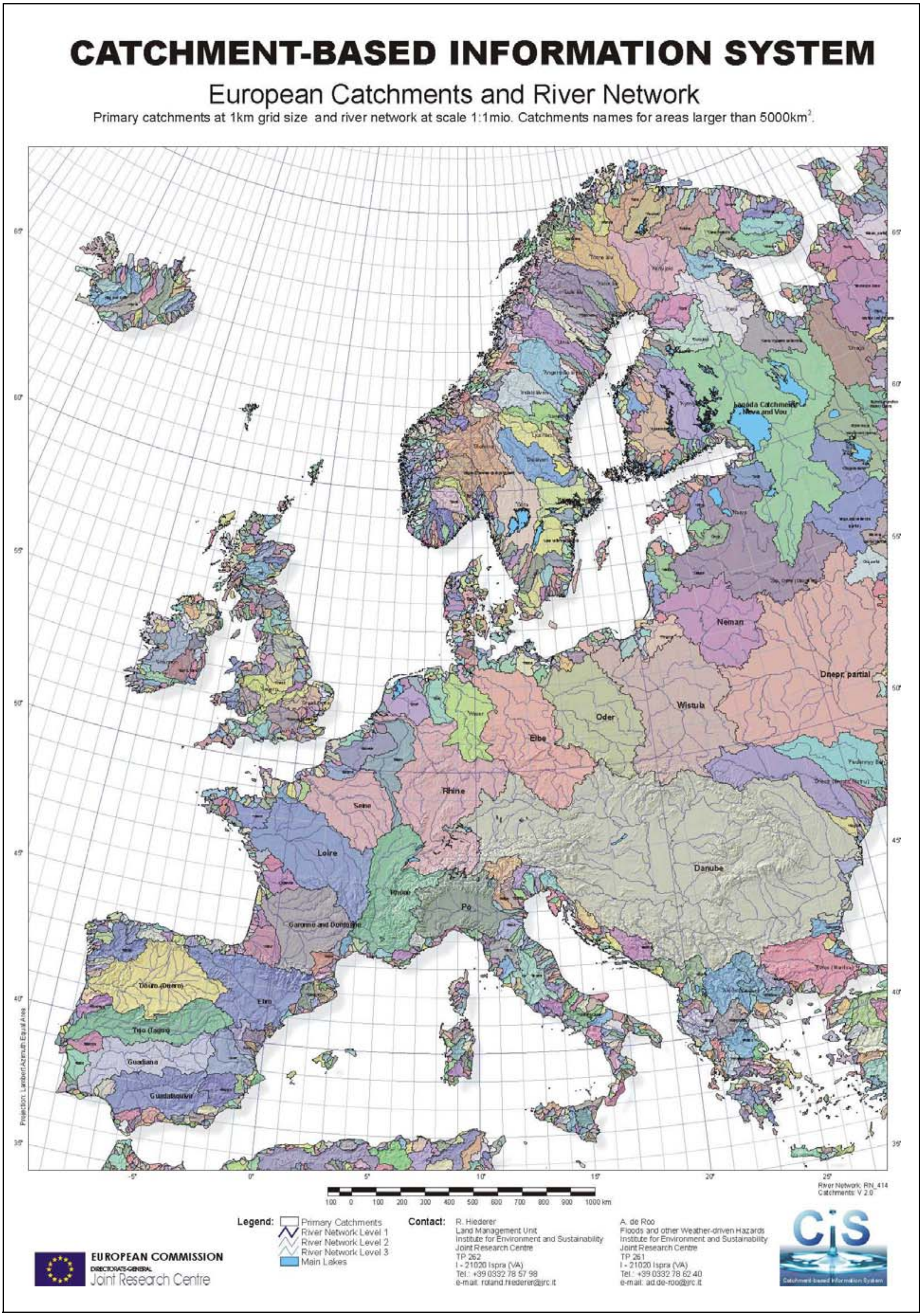

Figure 18: European Catchments at scale 1:1,000,000 Catchment-Based Information System

The highest level in the catchment hierarchy consists of primary catchments. The procedure applied allows for one and only one outlet of a primary catchment. This outlet comprises of the culminating point of all upstream surface flow. Regions of river deltas are created by linking adjacent primary catchments to the main catchment unit.

Lower layers of the hierarchical system are generated by sub-dividing primary catchments. The level of detail in the base data sets limits to the minimum size of catchments, which can be delineated. In the CIS the lower limit was set to 250km^2. The value was found to be an acceptable compromise between the details of representing catchment boundaries and the relative uncertainty in delineating the area.

The output of the procedure consists of 10 layers of the primary catchments and sub-catchments. To avoid redundancy each layer contains only the units defined at that level. Layers with complete cover can be generated by sequentially overlaying the reference layers.

The CIS catchment layers are now in Version 3.0 und distributed as part of the GISCO dataset. Other data layers of the CIS use the same geographic properties as the catchment layers, i.e. a 1km grid size, GISCO Lambert Azimuthal Equal Area projection of identical extent and a common land/sea mask. The thematic areas integrated into the CIS include administrative boundaries, European land cover, elevation data, soil properties from the European Soil Database v.1.0 and historic meteorological data.

Bibliography Section 10

EEA/ETC BD (2000). Digital Map of European Ecological Regins (DMEER), Version 2000/05 – Environmental Protection Agency / European Topic Centre for Biological Diversity, Kopenhagen.

Hiederer, R. & de Roo, A. 2003. A European Flow Network and Catchment Data Set. EUR 20703 EN, 40pp. European Commission Joint Research Centre, Ispra, Italy.

Vogt, J.V. *et al.* (2003). CCM River and Catchment Database for Europe, Version 1.0. EC-JRC, EUR 20756 EN.

Vidal, C., J. Gallego and M. Kayadjanian (2001). Geographical use of statistical data. In: EEA (2001). Towards Agri-Environmental Indicators – Integrating Statistical and Administrative Data with Land Cover Information. Topic Report 6. Office for Official Publications of the European Communities, Luxembourg, 2001, pp. 133. (http://europa.eu.int).

EUROPEAN SOIL BUREAU RESEARCH REPORTS

No.1 European Land Information Systems for Agro-environmental Monitoring. D. King, R.J.A. Jones and A.J. Thomasson (eds). EUR 16232 EN, 284 pp. (1995). Office for the Official Publications of the European Communities, Luxembourg.

No.2 Soil Databases to support sustainable development. C. Le Bas and M. Jamagne (eds). EUR 16371 EN, 149 pp. (1996). Office for Official Publications of the European Communities, Luxembourg.

No.3 The use of pedotransfer in soil hydrology research in Europe. A. Bruand, O. Duval, H.Wösten and A. Lilly (eds). EUR 17307 EN, 211 pp. (1997). Office for Official Publications of the European Communities, Luxembourg.

No.4 Land Information Systems: Developments for planning the sustainable use of land resources. H.J. Heineke, W. Eckelmann, A.J. Thomasson, R.J.A. Jones, L. Montanarella and B. Buckley (eds). EUR 17729 EN, 546 pp. (1998). Office for Official Publications of the European Communities, Luxembourg.

No.5 Georeferenced Soil Database for Europe: Manual of Procedures Version 1.0. European Soil Bureau, Scientific Committee. EUR 18092 EN, 184 pp. (1998). Office for Official Publications of the European Communities, Luxembourg.

No.6 Soil Resources of Europe. P. Bullock, R.J.A. Jones and L. Montanarella (eds). EUR 18991 EN, 202 pp. (1999). Office for Official Publications of the European Communities, Luxembourg.

No.7 Soil Classification 2001. Erika Micheli, Freddy O. Nachtergaele, Robert J.A. Jones & Luca Montanarella. EUR 20398 EN, 248 pp. (2002). Office for Official Publications of the European Communities, Luxembourg.

No.8 Soil Geographical Database for Eurasia & The Mediterranean: Instructions Guide for Elaboration at scale 1:1,000,000. Version 4.0. J.J. Lambert, J. Daroussin, M. Eimberck, C. Le Bas, M. Jamagne, D. King & L. Montanarella. EUR 20422 EN, 64 pp. (2003). Office for Official Publications of the European Communities, Luxembourg.

No.9 Soil Resources of Europe: Second Edition. R.J.A. Jones, B. Houskova, P. Bullock and L. Montanarella (eds). EUR 20559 EN, 420pp. (2005). Office for Official Publications of the European Communities, Luxembourg.

No.10 Land Degradation. Robert J.A. Jones and Luca Montanarella (eds). EUR 20688 EN, 324 pp. (2003). Office for Official Publications of the European Communities, Luxembourg.

No.11 Soil erosion risk in Italy: a revised USLE approach. M. Grimm, R.J.A. Jones, E. Rusco & L. Montanarella. EUR 20677 EN, 25 pp. (2003). Office for Official Publications of the European Communities, Luxembourg.

No.12 Validation of soil erosion risk assessements in Italy. A.J.J. Van Rompaey, P. Bazzoffi, R.J.A. Jones, L. Montanarella & G. Govers. EUR 20676 EN, 24 pp. (2003). Office for Official Publications of the European Communities, Luxembourg.

No.13 Validation of soil erosion estimates at European scale. A.J.J. Van Rompaey, V. Vieillefont, R.J.A. Jones, L. Montanarella, G. Verstraeten, P. Bazzoffi, T. Dostal, J. Krasa, J. Devente and J. Poesen. EUR 20827 EN, 26 pp. (2003). Office for Official Publications of the European Communities, Luxembourg.

No.14 Field Guide to the Soil-landscapes of the Piemonte eastern plain. F. Petrella, M. Piazz , Martalò, P. Roberto, F. Giannetti, N. Alliani, V. Ancarani, G. Nicoli, R. Salandin, & N. Filippi. EUR 20829 EN, 33 pp. (2003). Office for Official Publications of the European Communities, Luxembourg.

No.15 Organic Matter in the Soils of Southern Europe. Pandi Zdruli, Robert J.A. Jones and Luca Montanarella EUR 21083 EN, 16 pp. (2004). Office for Official Publications of the European Communities, Luxembourg.

No.16 Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). M.J. Kirkby, R.J.A. Jones, B., Irvine, A. Gobin, G. Govers, O. Cerdan, A.J.J. Van Rompaey, Y. Le Bissonnais, J. Daroussin, D. King, L. Montanarella, M. Grimm, V. Vieillefont, J. Puigdefabregas, M. Boer, C. Kosmas, N. Yassoglou, M. Tsara, S. Mantel, G.J. Van Lynden and J Huting. EUR 21176 EN, 20 pp. and 1 map in ISO B1 format. (2004). Office for Official Publications of the European Communities, Luxembourg.

No.17 The map of organic carbon in topsoils in Europe, Version 1.2 September 2003: Explanation of Special Publication Ispra 2004 No.72 (S.P.I.04.72). R.J.A. Jones, R. Hiederer, E. Rusco, P.J. Loveland, and L. Montanarella. EUR 21209 EN, 26 pp. and 1 map in ISO B1 format. (2004). Office for Official Publications of the European Communities, Luxembourg.

No.18 Computer program on DRIS, MDRIS and CND - bivariate and multivariate analyses tools for monitoring the soil and plant nutrient imbalances. Senthil-Kumar Selvaradjou, Luca Montanarella & Aruna-Geetha. EUR 21505 EN, 49 pp. (2005). Office for Official Publications of the European Communities, Luxembourg.

No.19 SPADE-2: The Soil Profile Analytical Database for Europe, Version 1.0. John M. Hollis, Robert J.A. Jones, Charles. J. Marshall, Ann Holden, Jan Renger Van de Veen & Luca Montanarella. EUR 22127 EN, 38 pp. (2006). Office for Official Publications of the European Communities, Luxembourg.

No.20 (2006). Common Criteria for Risk Area Identification according to Soil Threats. Wolf Eckelmann, Rainer Baritz, Pavel Bielek, Stanislav Bialousz, Florence Carre, Beata Houšková, Robert J A. Jones, Mark. Kibblewhite, Josef Kozak, Christine Le Bas, Gergely Tóth, Tibor Tóth, György Várallyay, Markku Yli Halla, & Marco Zupan. EUR 22185 EN, 94 pp. (2006). Office for Official Publications of the European Communities, Luxembourg.

▪

MISSION OF THE JRC

The mission of the JRC is to provide scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre