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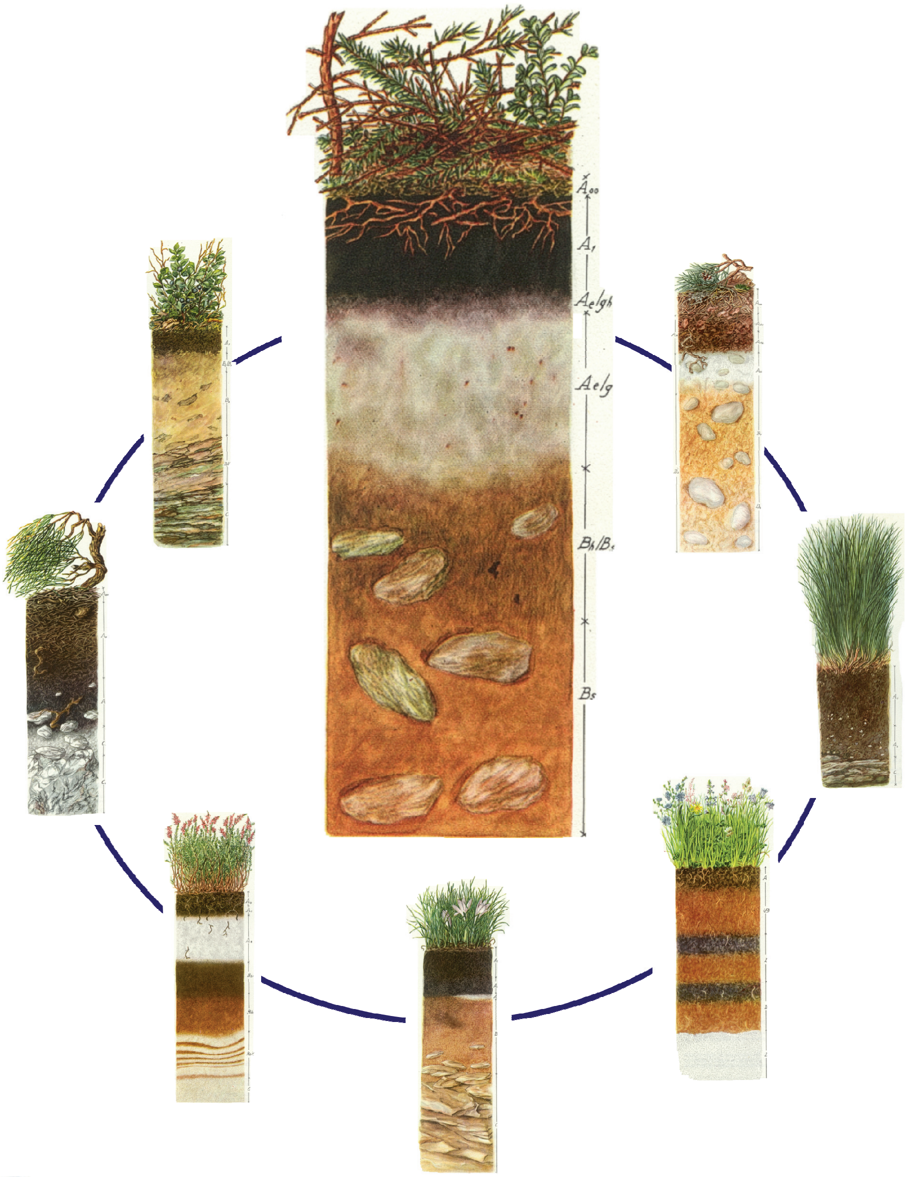
Environmental Assessment of Soil for Monitoring
Volume VI: Soil Monitoring System for Europe

M.G. Kibblewhite, R.J.A. Jones, L. Montanarella, R. Baritz, S. Huber, D. Arrouays, E. Micheli, M. Stephens (eds)



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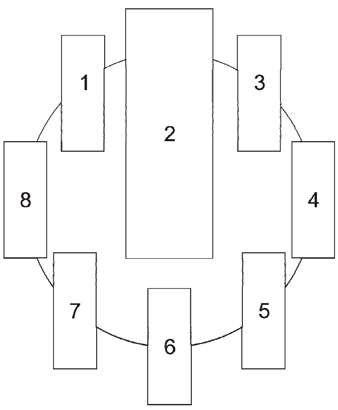

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Environmental Assessment of Soil for Monitoring
Volume VI: Soil Monitoring System for Europe

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Preface

The ENVironmental ASsessment of Soil for mOnitoring – ENVASSO – Project (Contract 022713) was funded, 2006-8, as Scientific Support to Policy (SSP) under the European Commission 6th Framework Programme of Research. The project's main objective was to define and document a soil monitoring system for implementation in support of a European Soil Framework Directive, aimed at protecting the continent's soils. The ENVASSO Consortium, comprising 37 partners drawn from 25 EU Member States, succeeded in reviewing soil indicators and criteria (Volume I) that are currently available upon which to base a soil monitoring system for Europe. Existing soil inventories and monitoring programmes in the Member States (Volume II) were also reviewed and a database system to capture, store and supply soil profile data was designed and programmed (Volume III). Procedures and protocols (Volume V), appropriate for inclusion in a European soil monitoring system were defined and fully documented by ENVASSO, and several of these procedures have been evaluated by pilot studies in the Member States (Volume IV). Finally, a European Soil Monitoring System (Volume VI) was described that comprises a network of geo-referenced sites at which a qualified sampling process is or could be conducted.

Volume VI summarises the results presented in preceding volumes and concludes with a proposed approach to monitoring soil conditions in Europe. A framework is proposed and the number of new monitoring sites needed to cover area, as yet not characterised, are estimated. The results of the ENVASSO Project (Volumes I-VI) provide a basis for implementing a soil monitoring programme in the near future but they are the scientific opinions of the ENVASSO Consortium, presented here without prejudice, and in no way represent the official position of the European Commission on soil monitoring in Europe.

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29 June 2008

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3. Inventory and Monitoring	Dominique Arrouays and Xavier Moran (INRA)
4. Database Design and Selection	Rainer Baritz and Einar Eberhardt (BGR)
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7. Proposed Soil Monitoring System for Europe	Mark Kibblewhite, Rainer Baritz, Sigbert Huber, Dominique Arrouays, Robert Jones and Erika Micheli
8. References	
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Executive Summary

The ENVASSO project addresses the need to monitor, at a continental scale, the condition of different types of soil that are subject to a range of threats. Its objective was to describe a common framework to enable a progressive harmonisation of current and future soil monitoring activities in EU Member States.

Eight threats to soil (erosion, organic matter decline, contamination, compaction, salinisation, decline in biodiversity, soil sealing, and landslides & flooding) are identified in the Thematic Strategy for Soil Protection in Europe. All of these have been addressed in ENVASSO except for flooding. In addition, desertification has been included as an additional 9th threat.

ENVASSO has developed further the European soil science community. It was led by 5 core partners supported by 32 additional ones drawn from all but two (Cyprus and Luxembourg) of the EU Member and Associated States. The human and social capital created within ENVASSO builds on that already existing within the European Soil Bureau Network and this capital should have an important and lasting influence on improved soil monitoring throughout the European Union. At least 150 European scientists have contributed materially to the ENVASSO work programme and during the course of the project, meetings were held with European stakeholders.

The outputs from ENVASSO are a series of technical reports documenting criteria and indicators for the characterisation of soil (Volume I), inventory and monitoring systems (Volume IIa & IIb), a database system suitable for data capture (Volume III), the procedures and protocols for inventory and monitoring (Volume V), and the results of evaluating prototype procedures and protocols in a number of pilot areas in Europe (Volume IVa & IVb). This Volume (VI) reports detailed recommendations for a future European Soil Monitoring System.

A large number of potential indicators have been identified that link to issues relating to the threats to soil. From these a set of 27 priority indicators have been selected, rigorously defined and evaluated. Baselines and threshold values for these selected indicators have been considered and recommendations made for their definition.

The current arrangements for soil monitoring in EU Member States have been reviewed. Design options have been assessed for a future European-wide network of soil monitoring sites: recommendations have been agreed within the ENVASSO community for a minimum density of sampling sites (one per 300 km^2), the sampling and testing protocols required for indicator estimation and the frequency of re-sampling (for example 10 year intervals). The recommended approach would allow existing soil monitoring networks in Member States to be substantially accommodated, so that past investment is not lost and can be exploited efficiently into the future.

The requirements have been described for the collation of soil information to support the operation of a future European soil monitoring initiative and for archiving and facilitating access to information by citizens, Member States and European institutions. A prototype database system has been constructed to meet these requirements. This provides web-based interoperability that is considered critical for the successful delivery of a comprehensive database holding up-to-date information and supporting access for the widest user community.

The outputs from the project have been synthesised and codified into a set of documented operating procedures and protocols, describing practical steps required for indicator estimations. Wherever possible established methods (for example those published by ISO) have been adopted but additional material has been assembled and agreed, which can form the basis for future standardisation. In addition to technical procedures, a glossary of key terms has been compiled that has relevance for soil management initiatives generally as well as specifically to soil monitoring.

An intensive collaboration has been completed to test the indicator selection, the procedures and protocols for their estimation and the prototype database. A total of 28 pilot studies, including several trans-national collaborations, have been completed involving a majority of Member States and covering the main geographical regions of Europe. The pilot studies tested 22 potential indicators relating to nine threats to soil. This intensive activity represents one of the largest practical collaborations between European soil scientists that has been achieved up to the present.

The outputs from the pilot trials indicated that 20 of the 27 indicators that have been selected are qualified for potential inclusion in an operational soil monitoring system. These cover the threats of soil erosion, decline in soil organic matter, soil contamination, soil sealing, soil compaction, decline in soil biodiversity, soil salinisation and desertification.

The performance of these indicators has been judged to be sufficient to support their early implementation within an operational monitoring system, although there remain some relatively minor gaps which could not be filled within the ENVASSO project. The indicators which could not be qualified include those for: wind and tillage erosion; peat stocks; landslides; re-use of previously developed land and progress in the management of contaminated land. Currently, the scientific base is inadequate or the statistical data is not available in many member states to support indicator estimation.

In conclusion, ENVASSO has developed a system to harmonise existing, mostly national soil monitoring networks and databases, to form a European-wide reference that can assess current and future soil status and support the sustainable management of soil resources.

1. Introduction

Soil is a vital non-renewable resource essential to human life and terrestrial ecosystems. It is a form of natural capital available to European Citizens. Increasingly, soil is recognised as a habitat in its own right as well as a foundation for others. Living soil systems deliver valuable ecosystem services (biodiversity, clean air and water, food security, cultural heritage and support for built environment). European policy is intended to accord soil protection an equivalent status to that already given to protecting air and water. Better scientific information will ensure that soil is managed well at local, regional and continental levels as part of sustainability goals. The impact of global change on soil resources, through climate, technology and socio-economics, makes this a priority.

There is good agreement over the functions that soil performs in the environment and the economy and the importance that should be given to its sustainable management (Blum, 1993). However, soil protection policies, and the monitoring of soil condition and status, have lagged behind policies to protect air and water. As a consequence, there are only a few examples of fully operational soil monitoring systems within Europe (Bullock *et al.*, 2005). Relatively few of these have more than one sampling point in time and most are, therefore, only inventories until sampling is repeated. In recent years, progress has been hampered by a lack of perception of the importance of soil, data ownership issues and data incompatibility resulting from the multiplicity of different sampling and analytical procedures (Van-Camp *et al.*, 2004e).

A new-generation of European information infrastructure is increasing the demand for new soil information as a key resource for fully integrated environmental assessment and management. Thus, there is a simultaneous correspondence between scientific opportunity and societal need that supports development of a set of well-founded principles and theory, processes and tools for establishing and maintaining common criteria and indicators for the characterisation of European soils. The achievement of these common criteria and indicators is a central part of the support required for soil protection, as set out in the official Communication from the European Commission 'Towards a Thematic Strategy for Soil Protection' (European Commission, 2002) that has been developed further in a second Communication (European Commission, 2006). The two directions inherent in this strategy, i.e. trans-national soil protection at the level offered to air and water, and the need for robust policy-relevant soil information in relation to major threats to soil, are the rationale for the ENVironmental ASsessment of Soil for MOnitoring (ENVASSO) project, which is reported here.

The main threats to soil identified in the Soil Thematic Strategy are Soil Erosion, Decline in Soil Organic Matter, Soil Contamination, Soil Sealing, Soil Compaction, Decline in Soil Biodiversity, Soil Salinisation, and Landslides. Flooding was also identified but is not covered within ENVASSO because it falls outside the anticipated scope of future policy measures specifically targeted at soil protection. However, the cross-cutting issue of Desertification is included as an additional threat to soil..

ENVASSO has designed and partly-tested a single, integrated, EU-wide and operational set of measurable criteria and indicators that provide a basis for a harmonised comprehensive European soil and land information system. The choice of criteria and indicators within ENVASSO has built on previous outputs, for example from the Soil Thematic Strategy (Van Camp *et al.*, 2004a-f). Formal procedures and protocols, and an operational database have been developed for collecting, collating and reporting of harmonised European-wide soil information.

1.1 Project structure

The ENVASSO project has five work packages (WPs) each with its own subset of objectives (Figure 1). Most members of the project team are drawn from the European Soil Bureau Network – ESBN – (Montanarella et al., 2005) and many also contributed to the Soil Thematic Strategy stakeholder consultation. The reports of the Technical Working Groups of the Soil Thematic Strategy (Van-Camp *et al*. 2004a-f) represent a comprehensive statement of current knowledge about threats to Europe's soil resources, but they lack sufficient structure and the detail necessary to implement comprehensive and cost-effective monitoring of Europe's soils.

ENVASSO provides a formalised structure for this monitoring, founded on previous work of the ESBN and its reports on the soil resources of Europe (Bullock *et al.*, 1999; Jones *et al.*, 2005b).

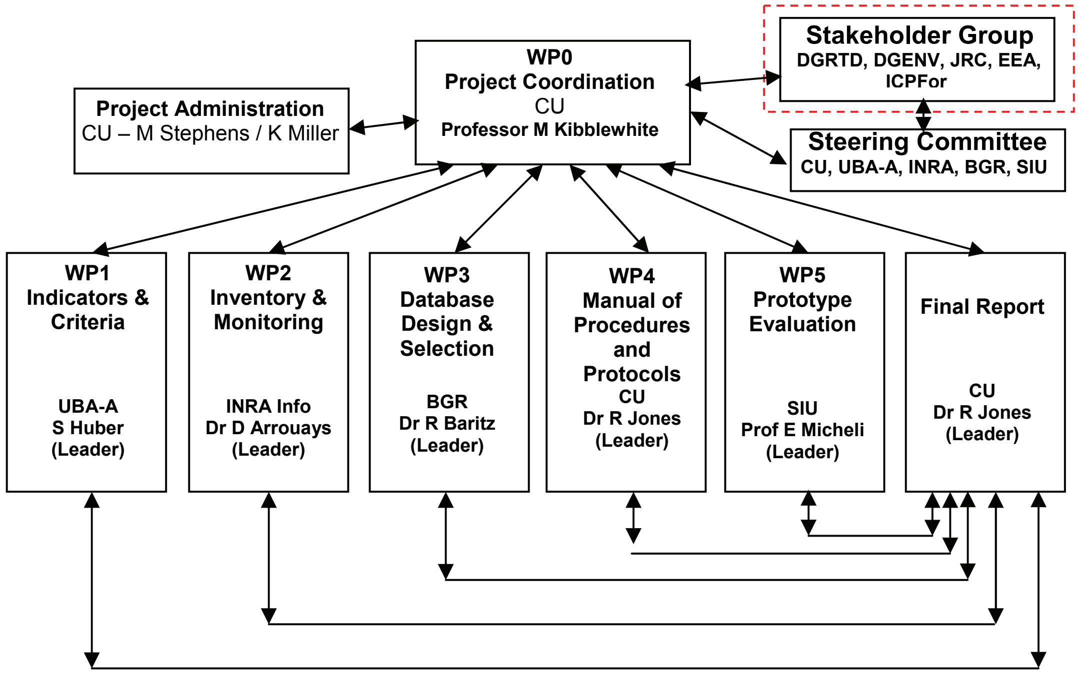

Figure 1: Project Structure and Organisation

ENVASSO Volume VI summarises the main findings and Volumes I-V describe the systems developed in more detail. The outputs have been assessed and further developed by a review process involving the steering committee, plenary project meetings, and acknowledged experts advising the project.

2. Criteria and Indicators

ENVASSO Volume I describes each threat to soil, the selection of key issues and indicators including supporting arguments, and guidelines on how baseline and threshold values have been identified or can be derived, accompanied by some examples. Specific data and user requirements are given for the proposed.indicators.

Desertification, originally perceived as a key issue for Soil Erosion, is a cross-cutting issue that is also associated with Decline in Soil Organic Matter, Soil Salinisation and Decline in Soil Biodiversity and, therefore, is treated as a 9th threat to soil. The indicators and their definitions are documented under each threat, and fact sheets for three priority indicators (TOP3) selected for each threat are presented in Annex I.to Volume I These fact sheets follow a format originally designed by the European Environment Agency and used for many years to provide information for the EEA environmental indicators, for example the 'State of the Environment' reports. The fact sheets attempt to show the situation at the European scale and give background information on policy relevance, scientific soundness, methodology for calculation of meta-information on data used and quality of output.

The objective of ENVASSO was to propose a well-defined set of indicators for each soil threat, based on sound science. Current knowledge and understanding of soil processes and properties has been reviewed to derive appropriate key issues that relate to each threat. Internationally or nationally developed indicators have been reviewed, building on the work of the Soil Thematic Strategy Technical Working Groups (Van-Camp *et al.,* 2004a-f). From an extended list of candidate indicators, a selection was made by ENVASSO using an expert consultation process, with formal internal guidelines based on an OECD approach (OECD, 2003).The main focus was on state, pressure and impact indicators, with less emphasis on driver and response indicators, reflecting the relatively early development stage of soil indicators for monitoring threats to soil.

2.1 Indicator selection

An extensive literature review on existing indicators was carried out to provide material for the selection process. In particular, account was taken of the reports of the Technical Working Groups on the Soil Thematic Strategy (see Van Camp *et al.,* 2004a-f). Furthermore, reports from organisations such as the European Commission, the European Environment Agency, the Joint Research Centre (Ispra), and Eurostat were consulted together with national and regional reports. The main scientific journals of relevance were also searched for appropriate material. In total, 290 potential indicators relating to 188 key issues for the threats to soil were compiled. As far as possible, relevant information for each indicator was collected according to the standard guidelines.

The selected key issues are linked directly to the threats to soil that are identified in the Soil Communication (European Commission, 2002); they are intended to fulfil the needs for soil information to support the Thematic Strategy for Soil Protection. The set of recommended indicators, for the environmental assessment of soils at the European scale, were selected in view of their thematic relevance, methodological soundness, measurability, policy relevance and data availability. The selection process was also based on common guidelines and some selected indicators were subject to re-adjustment and 'fine-tuning' following feedback from the pilot area testing reported in Volume IVa and IVb.

The work followed a hierarchical scheme for indicator selection:

- Thematic groups were established with each linked to one threat to soil,
- The indicators collected or proposed during the literature review were evaluated using guidelines, which defined criteria and corresponding classes,
- Based on expert judgement, 27 key issues and 60 candidate indicators were selected to cover all threats to soil (this process is fully documented in D2),

- The three priority (TOP3) indicators for each threat to soil were selected by expert judgement on the basis of the following criteria: relevance for assessing the soil threat, ease of application (focused on thresholds), linkage to policy aims and applicability in a pan-European context.

Because of the variety of soil types and the variability in environmental conditions and land use across Europe, baseline and threshold values may have to be set differently for different areas (e.g. by Member States), but definitions and methods for estimation and implementation of soil monitoring should be standardised. The following definitions are used (see Annex II):

Baseline: Minimum or starting point of an indicator value, for example measurement which serves as a basis to which all following measurements are compared; a characteristic value - such as the background value - for an element content in soil.

Threshold: An indicator value at which a critical soil status is reached, causing a deterioration or loss of one or more soil functions, for example a guideline value for heavy metal content, limits for crop production or soil remediation, etc. A threshold is a point or level that, when approached or exceeded, will initiate consideration of policy or other actions in order to alleviate adverse impacts either on the environment or human health (based on EEA, 2005).

For each of the selected indicators an analysis was made on the availability of baseline and threshold values. The possibility of their derivation was examined or, where these values were not available, consideration was given to natural factors such as the spatial variability of soils, landscapes and land use. The outcome is a set of proposals and recommendations for derivation of baseline and threshold values for most of the selected indicators. The objective was to define threshold values that indicate good soil status, i.e. where a reference value is not exceeded. Data requirements for calculating indicator values and deriving baseline and threshold values were identified.

The data needs for calculation of the selected indicators were compiled, using the information gathered during the literature review (see Volume I). These include input parameters as well as requirements for data quality and spatial resolution. A minimum detectable change for an indicator is proposed as the user requirement. It was decided to define a minimum list of data needs in relation to the implementation of the indicator set, as the Member States can improve this list step by step.

2.2 Selected priority indicators

Twenty seven priority indicators (TOP3 indicators) have been selected from the 60 candidate indicators, to cover the threats to soil. These TOP3 indicators are proposed as a minimum set should the proposed complete set of indicators be too extended. The selection of these priority indicators is the first step in the implementation of soil monitoring. The TOP3 indicators were selected for each threat without ranking them, taking account of the following aspects:

- priority for the assessment of the soil threat,
- applicability (with focus on threshold values),
- link to policy aims and
- the EU policy context.

2.2.1 Soil Erosion

Water erosion, which is the most prevalent form of erosion in Europe, takes place through rills, inter-rills, gullies and sheet wash as a result of excess surface runoff (Jones *et al.*, 2004). These types of water erosion, accelerated by human activity, are of most concern with respect to soil protection. Water erosion is most severe in Mediterranean environments where long dry periods are often followed by heavy bursts of rain, creating particularly erosive conditions on steep non-vegetated soils.

Wind is the dominant process causing soil erosion in some specific areas, particularly on the North European Plain and in the Mediterranean (Breshears *et al.*, 2003, De Ploey, 1989, Quine *et al.*, 2006, Warren, 2002). Soils in the eastern Netherlands, eastern England, northern Germany and the Mediterranean, under shrubland and forest, are also known to suffer from significant wind erosion (Chappell, 1999, Barring *et al.*, 2003).

Tillage erosion has been recognised for decades, but the magnitude of this process in Europe has only been fully appreciated and documented during the last 10-15 years (Govers *et al.*, 1996; Quine *et al.*, 2006). In this report, tillage erosion includes both ‘tillage operations’ and soil removed by harvesting root crops such as potatoes and sugar beet.

Key issue	Key question	Candidate indicator	Unit	ID
Water erosion	What is the current status of water erosion in Europe?	Estimated soil loss by rill, inter-rill, and sheet erosion	t ha^{-1} yr^{-1}	ER01
Wind erosion	What is the current status of wind erosion in Europe?	Estimated soil loss by wind erosion	t ha^{-1} yr^{-1}	ER05
Tillage erosion	What is the current loss of soil by tillage practices, land levelling and crop harvest (root crops)?	Estimated soil loss by tillage erosion	t ha^{-1} yr^{-1}	ER07

ER01 was selected as a TOP3 indicator for soil erosion because soil loss by water in Europe is the most extensive form of erosion. Furthermore, it is possible to obtain estimates of soil erosion by water for the whole of Europe by modelling (although this is not yet feasible by direct measurement). ER02 is the support indicator for calibration and validation of model estimates.

ER05 was selected because wind erosion is a significant cause of soil loss in Europe, although less extensive than water erosion. It may be possible to model wind erosion at European scale in the near future and ER06 is the support indicator for validating the modelled estimates.

ER07 represents tillage erosion, a form of soil erosion in Europe that is of increasing concern. ER08 is the support indicator for validating any estimates produced by modelling.

Baselines and Thresholds

In areas of Europe that are not currently eroding, the baseline is 0 t $ha^{-1}yr^{-1}$. For the remaining areas the degree of soil erosion varies according to soil type, slope, land use and climatic conditions, which suggest the need for regional baselines. Depending on the availability of measured soil loss by erosion, regional baseline values for specific types of soil erosion should be defined.

There has been much discussion in the literature about thresholds above which soil erosion, whether by water, wind, tillage or other agents, should be regarded as a serious problem. This has given rise to the concept of 'tolerable' rates of soil erosion based on reliable estimates of natural rates of soil formation. However, soil formation processes and rates differ substantially throughout Europe. These are comprehensively reviewed in Volume I.

A precautionary approach to environmental protection should regard soil losses of more than 1 t $ha^{-1}yr^{-1}$ as unsustainable in the long term (Jones et al., 2004), because this rate of loss significantly exceeds the estimated average natural rate of erosion ~ 0.1 – 1.0 t $ha^{-1}yr^{-1}$ (Alexander, 1988; Nihlen *et al.*,1995; Pillans, 1997; Wakatsuki and Rasyidin, 1992; Wilkinson and McElroy, 2007).

2.2.2 Decline in Soil Organic Matter

Despite its ubiquitous measurement, a consensus definition of soil organic matter (SOM) is not apparent in the literature (Carter, 2001). Many different definitions have been reported (e.g. Sollins et al., 1996; Schnitzer, 1991; Oades, 1988). The main disparities between these definitions are:

i) inclusion/exclusion of living biomass;
ii) inclusion/exclusion of the litter, fragmentation and humification layers;
iii) ‘threshold degree’ of decomposition.

Soil organic matter decline is of particular concern in Mediterranean areas (Jones *et al.*, 2005a). The problem is, however, not restricted to Mediterranean regions and a recent study in the UK confirms that loss of soil organic matter can be relatively high even in temperate climates (Bellamy *et al.*, 2005). Mineralization of peat soils is a major cause of reduction of organic matter stocks in northern Europe.

Several factors are responsible for a decline in soil organic matter and many of them relate to human activity such as: conversion of grassland, forests and natural vegetation to arable land; deep ploughing of arable soils; intensive tillage operations; high application rates of nitrogen-containing fertilizers causing rapid mineralisation of organic matter; drainage, liming, fertilizer use and tillage of peat soils; crop rotations with reduced proportion of grasses; soil erosion; and wild fires (Kibblewhite *et al.*, 2005). Declining organic matter contents in soil are also associated with ongoing desertification (Kibblewhite *et al*., 2007).

Changes in soil organic matter content occur in response to changes in the factors controlling organic matter dynamics in soil. Some of them are inherent soil properties, for example clay content influences the capacity of soils to protect organic matter against mineralisation and, therefore, influences rates of change in organic matter content, others are external or human-induced factors (climate, land cover, land use, agricultural practices, etc.). The Technical Working Group on Monitoring of the Soil Thematic Strategy recommended that for general purpose monitoring the following parameters related to soil organic matter should be measured: total organic carbon content, total organic nitrogen content, C:N ratio and bulk density (Van-Camp *et al.*, 2004c).

Key issue	Key question	Candidate indicator	Unit	ID
Soil organic matter status	What are the present organic matter contents in topsoils of Europe?	Topsoil organic carbon content (measured)	%	OM01
Soil organic matter status	What are the present organic carbon stocks in soils of Europe?	Soil organic carbon stocks (measured)	t ha^{-1}	OM02
Soil organic matter status	What are the peat stocks in Europe?	Peat stocks (calculated or modelled)	Mt	OM03

OM01 was selected because topsoil organic carbon content is a relatively simple indicator that can be measured directly. Currently, it is the indicator for soil organic matter for which most data are available at the European scale. It is understandable to policy makers, who can interpret it to inform policies that can have a direct influence on soil conditions (e.g. conservation tillage, maintenance of grasslands, afforestation, etc.). It is also feasible to derive regional/local baselines using combinations of climatic, soil and land-use data although there is no consensus on thresholds.

OM02 was selected because soil organic carbon stocks are a key part of the global carbon cycle and changes in them are relevant to setting greenhouse gas budgets. Baselines could be estimated by statistical analysis of organic carbon stocks at a given date.

OM03 is a crucial indicator, because peat soils are much richer in organic matter than mineral soils and so any decline in the organic matter content in these soils will lead to a significant decline in overall soil carbon stocks. Moreover, peat soils often also support important above ground biodiversity. Thus there are strong arguments for protecting peat soils from degradation. There is also increasing interest in the re-establishment of wet lands in lowland areas where peat soils have been degraded to allow their re-establishment in the longer term. In these contexts, a baseline value could be the present status of peat stocks in Europe (Montanarella *et al.*, 2006), while threshold values could be set that target no further decrease in peat stocks.

Baselines and Thresholds

Baselines could be defined as the present values of the indicators, but the concept of a universal baseline is questionable, as it is often not in equilibrium and so current levels will not remain constant regardless of any direct human-induced pressures. Regional baselines values should be established using data within inventories, with different baseline ranges depending on land use, clay content, and climate.

A significant area of the more intensively cultivated soils of Europe have already reached low soil organic carbon contents (Loveland and Webb, 2003; Arrouays *et al.*, 2001, 2006). Although a lower threshold of 2% soil organic carbon has been used widely to indicate potential degradation (Kemper and Koch, 1966; Greenland *et al.*, 1975), even where the majority of soils have less than 2% soil organic carbon such as for some of the sandy soils in the relatively dry parts of England, there is no conclusive evidence of significant effects on other soil properties and crop yields (Verheijen, 2005). However, there is some suggestion that below a threshold of ca. 1% soil organic carbon, and without addition of exogenous soil organic matter and fertilizers, a dis-equilibrium in N-supply to plants might occur, leading to a decrease of both soil organic matter and biomass production (Körschens *et al.*, 1998).

Whatever threshold is chosen, the depth of sampling is a major issue because soil organic matter content varies strongly with depth, and as the depth of interest might be the upper few centimetres (e.g. risk of erosion linked to aggregate stability) or the whole arable layer (e.g. nutrient availability) or the depth of the whole soil profile (e.g. available water capacity). The thresholds, if any, should depend on the properties and functions of soil that soil organic matter influences, for example crop production and nutrient availability, available water capacity, aggregate stability, cation exchange capacity, porosity, etc.

One theoretically straightforward approach would be to set thresholds for total organic carbon and peat stocks that protect against a net loss over a given area. However, practical difficulties would be encountered when implementing these thresholds, including the requirement to include organic carbon present throughout the soil profile and to obtain data on the spatial variability of its depth, the need for extensive bulk density measurements and the high degree of spatial and temporal variability of organic carbon contents in soil.

2.2.3 Soil Contamination

It is important to distinguish clearly between diffuse and local soil contamination. Diffuse soil contamination arises from dispersed sources, and occurs where emission, transformation and dilution of contaminants in other media has occurred prior to their transfer to soil. As a result, the relationship between the contaminant source and the level and spatial extent of soil contamination is indistinct. This contamination is generally associated with atmospheric deposition, certain farming practices and inadequate waste and wastewater recycling and treatment. Atmospheric deposition of anthropogenic contaminants (including nutrients and acid deposition) are due in the main to emissions from industry, transport, households and agriculture.

Local soil contamination occurs where intensive industrial activities, inadequate waste disposal, mining, military activities or accidents introduce excessive amounts of contaminants. If the natural soil functions of buffering, filtering and transforming are overexploited, a variety of negative environmental impacts arise, the most problematic of which are pollution of water, acute or chronic toxicity, uptake of contaminants by plants and explosion of landfill gases (EEA, 1999).

No European consensus has yet been reached on common definitions for a ‘contaminated site’ and ‘potentially contaminated site’ (Volume I). The definitions published by the technical Working Groups of the Soil Thematic Strategy are the most recent that have broad recognition. ISO 11074:2005 distinguishes between a ‘contaminated site’ being hazardous to soil and soil functions and a ‘hazardous site’ being hazardous to human health or safety, or to the environment.

Key issue	Key question	Candidate indicator	Unit	ID
Diffuse contamination by inorganic contaminants	Which areas show heavy metal contents exceeding national thresholds?	Heavy metal contents in soils	%	CO01
Diffuse contamination by soil acidifying substances	Are we protecting the environment effectively against acidification?	Critical load exceedance by sulphur and nitrogen	%	CO07
Local soil contamination	Is the management of contaminated sites progressing?	Progress in management of contaminated sites	%	CO08

CO01 was selected because diffuse contamination by inorganic contaminants is an important key issue and data availability is generally good. Diffuse contamination by nutrients and pesticides is strongly related to the impacts of agriculture which makes it less valuable when evaluating diffuse contamination in general. Data availability is poor for persistent organic pollutants.

CO07 was selected because soil acidification is a widespread problem, especially in northern Europe.

CO08 ‘Progress in management of contaminated sites’ was selected as an indicator related to local soil contamination. The indicator CO09 ‘New settlement area established on previously developed land’ was judged to be less directly related to the key issue, although it was selected as an indicator for soil sealing (see SE05). Indicator CO10 ‘Status of site identification’ cannot be related to an objective target and is only useful for assessing trends.

Baselines and Thresholds

Background values of contaminants in soils are often used to define baselines. A brief description of background values can be found in ISO 19258 (i.e. percentiles of sample distributions). Reference values specified for different land uses can be derived from soil data referring to a systematic grid, for example calculation of the 85th or 90th percentile of a harmonised data set (Umweltbundesamt, 2004a). Depending on the objective, other stratification criteria are possible.

Heavy metal content thresholds should be defined at national or larger regional scales, to allow for varying natural conditions. Threshold values have been defined in the context of regulations for sewage sludge application and food production, but these do not take account of the wider multifunctional use of soils; impacts on soil biology and environmental services (e.g. aquifer protection) should be considered as well. This suggests that most national limits, at least, need reviewing and may inadequately cover impacts on the full range of soil functions.

Further research on the impacts of heavy metal contamination on soil biota, and studies on heavy metal leaching into water supplies, are needed to inform threshold value determinations. Some examples of existing threshold values at European and Member State scales are given in Volume I. A comprehensive compilation of limit values for soils, in the context of sewage sludge applications, is given by Marmo (2001).

According to the definition of critical loads and their exceedance, a baseline for indicator CO07 could be the exceedance in first year of monitoring, whereas the threshold must be the critical load itself. As critical loads for acidification are calculated in relation to land use, thresholds should be differentiated accordingly.

A baseline for management of contaminated sites (indicator CO08) would ideally correspond to the indicator value in a reference year, typically the year when monitoring started. The choice of a threshold value for this indicator is a policy, not a scientific, decision.

2.2.4 Soil Sealing

Soil is sealed when agricultural or other rural land is incorporated into the built environment (land consumption). It is also a continuing process within existing urban areas, especially where the urban population and the density of built structures are increasing and residual green space is reducing. Soil sealing occurs as a result of the development of housing, industry, transport and other physical infrastructure, including utilities (e.g. waste disposal and water distribution) and military installations. Sealing of the soil and land consumption are closely interrelated; when natural, semi-natural and cultivated land is covered by built surfaces and structures, this degrades soil functions or causes their loss.

Urbanisation, suburbanisation, and urban sprawl are the most important drivers of soil loss due to soil sealing. These processes are in turn driven by complex socio-economic factors. Their impact on soil in urban and metropolitan areas is greater where a high proportion of the surface area is sealed by buildings and infrastructure. Over the past 20 years the extent of built-up areas in European countries has increased by 20% while the population has increased by only 6%. At present 75% of Europe’s population live in urban areas and this is expected to increase to 80% on average by 2020, but to 90+% in several Member States (EEA, 2006).

Soil loss due to land consumption and sealing causes many pressures on soil ecosystems as well as other environmental impacts. By interrupting the contact between the soil system (pedosphere) and other ecological compartments, including the biosphere, hydrosphere, and atmosphere, sealing affects natural processes including the water cycle (infiltration, filtering of rainwater, groundwater renewal, and evapo-transpiration), geochemical cycles and energy transfers. Furthermore, it affects the climate at micro- and meso- scales by altering the albedo, evaporation and local air temperatures. Soil sealing increases surface water runoff, which leads to additional flood risk and in some cases catastrophic floods (Burghardt et al., 2004). It also alters and generally reduces the options for biodiversity conservation and restoration.

In some Member States, soil sealing, land consumption and certain response measures (brownfield redevelopment, de-sealing) are monitored in a quantitative way by applying statistical methods or aerial photograph interpretation. There is, however, a lack of European-wide information and much of the available data is not comparable due to the use of different estimation methodologies. At the European scale, land consumption is currently assessed by calculating the extent and growth in built-up areas from the CORINE land cover database (1990 and 2000) on the basis of satellite images (EEA, 2005). In addition, the MOLAND (Monitoring Land Use Dynamics) database supports the estimation of rates of change in built-up areas at regional and local level for a limited number of urban areas (EEA, 2006). All these approaches use the extent of the built-up area as a proxy indicator to estimate the increase of sealing as land is consumed.

Key issue	Key question	Candidate indicator	Unit	ID
Soil sealing	What is the share and growth rate of actually sealed area in the total land consumed by settlements and transport infrastructure?	Sealed area	ha or % of consumed land; ha yr^{-1} ha d^{-1}	SE01
Land consumption	How much bio-productive, semi-natural, or natural, land has been converted to urban or other artificial land cover in the last 3-5 years	Land take (CLC)	% of initial status or ha	SE04
Brownfield re-development	How much previously developed land, which was abandoned (brownfield), has been re-used for settlement purposes in order to reduce new land consumption on greenfield sites?	New settlement area established on previously developed land	%	SE05

SE01 was selected as sealed area because it is the most direct and straightforward indicator for soil sealing. To some extent sealing can also be regarded as a proxy indicator for the broader process of land consumption.

SE04 was selected because land consumption, for example by housing, utilities, transport, industrial and commercial development and recreational facilities relates directly to the threat of soil sealing.

SE05 was selected because recycling of previously developed land contributes to the reduction of new land consumption and soil sealing. In principle, the methodology is well developed and its applicability has been proven, at least in the United Kingdom.

Baselines and thresholds

The general ENVASSO definition of baselines has been followed, but the concept of thresholds had to be adapted and developed when applied to soil sealing. Numerical threshold values for indicators relating to soil sealing cannot be determined by science alone. Societal choices determine how much land consumption and soil sealing are recognised as being sustainable, and the extent to which response measures are justifiable. Although the definition of policy target values for soil sealing is beyond the scope of this research project, some existing or suggested national target values are provided in Volume I.

2.2.5 Soil Compaction

Soil compaction is a form of physical degradation which reduces biological activity and agricultural and forest productivity; it also reduces surface infiltration of water, thereby increasing surface water run-off and, thus, the risk of erosion. The compaction process can be initiated by wheels, tracks or rollers of agricultural or construction machinery, grazing animals and pedestrian traffic.

The decrease in pore volume that accompanies compaction is largely due to a reduction in macropores, which provide connectivity for water and gas movements through the soil profile. Some consequences of compaction include restricted root extension through physical impedance and increased anaerobic conditions, loss of drainage leading to surface water accumulation on flat areas and run-off on slopes.

Natural loosening processes are much more active and stronger in topsoil than in subsoil, which makes topsoil more resilient to compaction because of its inherent capacity to recover. Compaction in topsoil can also be broken down by regular cultivation, but tends to persist and accumulate in subsoil. The latter is a largely hidden problem in agricultural soils, although the degree and extent of subsoil compaction is increasing (Van den Akker *et al.*, 2003).

Key issue	Key question	Candidate indicator	Unit	ID
Compaction and structural degradation	What is the state of soil compaction and structural degradation in Europe?	Density (bulk density, packing density, total porosity)	g cm^{-3} or t m^{-3}; %	CP01
Compaction and structural degradation	What is the state of soil compaction and structural degradation in Europe?	Air-filled pore volume at a specified suction	%	CP02
Causes of soil compaction	What are the causes and circumstances that result in persistent compaction?	Vulnerability to compaction (estimated)	Classes	CP06

CP01 was selected because it gives information on the status of soil compaction and can be used to identify where compaction occurs or is likely to occur. The main problem is that bulk density is not well related to soil structure and structural degradation; this can be partly overcome by using packing density, which better reflects the apparent compactness of soil and is more closely related to porosity (see Indicator Fact Sheet for CP01 Density in Volume I). Bulk density is already measured in some monitoring and soil survey programmes across Europe.

CP02 was selected as a quantitative measurement of soil structure that is relatively easy to measure when combined with the determination of the bulk density. It is linked to important soil properties, such as oxygen diffusion, hydraulic conductivity and root extension. However, air-filled porosity has not been included in most national soil databases, and therefore implementation of this indicator will require new investment in data collection.

CP06 was selected because the vulnerability of soils to compaction provides information about the need for risk management for compaction at the European scale, by categorising the inherent susceptibility to compaction according to soil texture (taking soil organic matter content into account) and soil density. This susceptibility is then converted into an estimate of vulnerability that expresses the likelihood of the soil compacting under different soil moisture and climatic conditions.

Baselines and Thresholds

A possible baseline value for soil compaction is an estimate of its extent or absence prior to the introduction of compaction hazards, such as heavy machines, by inspection of historical data or by making measurements in fields, with similar environmental conditions, that have never been trafficked by heavy farm machinery (e.g. paired-field comparison). Håkansson *et al.* (1996) measured penetration resistances that were 40% higher in fields trafficked by heavy slurry manure tankers, in intensive potato and sugar beet production systems, than in fields not trafficked by such farm machinery.

Threshold values are presented in Volume I for five indicators: CP01 Density (packing density, dry bulk density), CP02 Air capacity (air-filled pore volume), CP03 Permeability (saturated hydraulic conductivity), CP04 Mechanical resistance (penetrometer resistance) and CP08 Soil strength. Soils with high packing density (1.75 g cm^{-3}) can be regarded as compact and almost always have an air capacity (air-filled pores at 5kPa) of less than 10%, and often less than 5%. Most plant roots are impeded where the total pore volume is less than 40% (Hidding and van den Berg, 1961) and under these conditions the oxygen supply to roots is insufficient (Bakker et al., 1987; Tacket and Pearson, 1964). For soils low in organic matter content, for example sands and sandy loams, a pore volume of 40% is equivalent to a bulk density value of about 1.6 g cm^{-3}.

According to Grable and Siemer (1968) an air capacity value of at least 10% (air-filled pore volume at a specified suction) is required for satisfactory plant growth. Therefore, ENVASSO proposes a threshold value of 10% for air capacity (air-filled pores) at a soil water suction of 5 kPa.

Vulnerability to compaction addresses the likelihood of soils to become compact, and the causes and circumstances that result in persistent compaction and structural degradation of the topsoil and/or subsoil. 'Persistent' is a key word because a temporary degradation in soil quality and functioning may be acceptable, and degradation may be short-lived if natural and/or artificial loosening is effective.

2.2.6 Decline in Soil Biodiversity

Soil biodiversity is generally defined as the variability of living organisms in soil and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (UNEP, 1992). Decline in Soil Biodiversity is generally considered as the reduction of forms of life living in soils, both in terms of quantity and variety (Jones *et al.*, 2004). Within ENVASSO, the term 'biodiversity' was expanded to include the biological functions of soil. The following definition is proposed for this threat: "reduction of forms of life living in soils (both in terms of quantity and variety) and of related functions" (Volume V, Appendix 2 ENVASSO Glossary of Key Terms).

Little is known about how soil life reacts to human activities, but there is evidence that soil organisms are affected by the:

- soil organic matter content,
- chemical properties of soils (e.g. amount of soil contaminants or salts),
- physical properties of soils such as porosity (affected by compaction or sealing).

Biological organisms and related activities are central to most soil functions and, therefore, many of the threats to soil will affect its biodiversity, making monitoring crucial.

Key issue	Key question	Candidate indicator	Unit	ID
Species diversity	What is the state of the diversity of soil macrofauna in Europe?	Earthworms diversity and fresh biomass	Number m^{-2}, g fresh weight m^{-2}	BI01
Species diversity	What is the state of the diversity of soil mesofauna in Europe?	Collembola diversity (Enchytraeids diversity if no earthworms)	Number m^{-2}, g fresh weight m^{-2}	BI02
Biological functions	What is the state of biological soil functioning in Europe?	Microbial respiration	g CO_2 kg^{-1} soil (DM)	BI03

BI01 was selected because earthworms are the main natural tillage agents. Changes in their abundance and community structure cause changes to many soil properties, such as porosity and density, thereby affecting soil functions, for example recycling and distribution of organic matter. Earthworm sampling is resource intensive, but is already standardized and included in many soil studies.

BI02 was selected for estimating species diversity in soils because Collembola are primary agents for soil organic matter decomposition. Changes in their abundance and community structure modify the kinetics of organic matter degradation. Collembola sampling is resource intensive, but is already standardized and included in many soil studies.

BI03 was selected for estimating the biological functioning of soils because the microflora is involved in all catabolic reactions in soils. Microbial respiration is a core process in the soil ecosystem, which correlates with degradable organic matter and soil microbial biomass. Microbial respiration is relatively easy to measure and standard protocols are already available.

This minimum set of indicators represents the two priority key issues (species diversity and biological functions) and includes organisms with different:

- sizes (macro and mesofauna, microflora),
- habitats (e.g. soil micro/macro-porosity, soil litter, burrows, rhizosphere)
- feeding habits,
- functions in soils, for example soil engineering, primary degradation of organic matter, mineralization of organic matter.

Baselines and Thresholds

It is not possible to define a single baseline for all soils within all land uses because the diversity and activity of soil organisms are strongly dependant on climate, land use, soil type and management practices. It is possible, however, to adopt a common approach to the derivation of baseline and threshold values.

A baseline for temporal comparisons might simply be defined by reference to measurements made at a point in time at existing or historical monitoring sites. This approach needs to be adopted with care as different soil conditions as well as a lack of harmonised measurements can lead to misleading estimates of temporal change.

The simplest threshold value of earthworm or collembola diversity would be nil, meaning that no organisms belonging to the target group are found at specific sites (it should be noted that in some cases, depending on the soil characteristics, this is the normal situation, for example earthworms are absent in very acidic soils). Another approach could be to define a threshold as an unacceptable deviation from the baseline value or from an initial measurement, although in both cases care is needed due to the potentially large variations occurring between seasons and years. Furthermore, each indicator may react differently to altered soil conditions, such as compaction, contamination and organic matter content.

Due to lack of standardisation and investment, soil biodiversity is poorly explored considering its importance to soil functions. The consequent lack of data means that it has not been possible to propose baseline and threshold values at the European scale for the priority indicators

2.2.7 Soil Salinisation

Soil salinisation is a process that leads to an excessive increase of water soluble salts in soil. The salts which accumulate include chlorides, sulphates, carbonates and bicarbonates of sodium, potassium, magnesium and calcium. A distinction can be made between primary and secondary salinisation processes. Primary salinisation involves accumulation of salts through natural processes such as physical or chemical weathering and transport from saline geological deposits or groundwater. Secondary salinisation is caused by human interventions such as use of salt-rich irrigation water or other inappropriate irrigation practices, and/or poor drainage conditions.

Soil sodification is a process that leads to an accumulation of Na^+ in the solid and/or liquid phases of the soil as crystallised $NaHCO_3$ or Na_2CO_3 salts (salt 'efflorescence'), in highly alkaline soil solution (alkalisation), or as exchangeable Na^+ ion in the soil absorption complex.

Salt-affected soils in Europe occur south of a line from Portugal to the Upper Volga including parts of the Iberian Peninsula, the Carpathian Basin, the Ukraine, and the Caspian Lowland, and can be classified in terms of the dominant management problem as:

- High salt content (saline soils),
- High sodium content (sodic soils),
- Specific characteristics linked to certain environmental conditions (acid sulphate soils, etc.)

Soil salinisation causes harm to plant life (soil fertility, agricultural productivity, cultivated crops and their biomass yield); natural vegetation (ecosystems); life and function of soil biota (biodiversity); soil functions (increased soil erosion potential, desertification, soil structure, aggregate failure, compaction); the hydrological cycle (moisture regime, increasing hazard in terms of frequency, duration, and severity of extreme moisture events such as flood, water-logging, and drought); and biogeochemical cycles (plant nutrients, pollutants, potentially harmful elements and compounds).

Key issue	Key question	Candidate indicator	Unit	ID
Soil Salinisation	What is the vertical distribution of water soluble salts in the profiles of salt-affected soils in Europe?	Salt profile	total salt content: %; electrical conductivity : dS m^{-1}	SL01
Sodification	What is the pH and exchangeable sodium percentage (ESP) in the soil profile: the depth of the sodium accumulation horizon?	Exchangeable sodium percentage (ESP)	pH unit ESP: %	SL02
Potential soil salinisation/ sodification	What are the main sources of salts that can accumulate in the upper soil horizons?	Potential salt sources (groundwater or irrigation water) and vulnerability of soils to salinisation/sodification	Salt content: mg l^{-1}; SAR: calculated ratio	SL03

SL01 was selected because it provides a complete picture of the salinity/sodicity state of the soil, or, more exactly, the salt-affected extent. It describes the horizontal and varying vertical extent of salinisation. Salt can be measured either as the total concentration of salts, or electrical conductivity (EC) of a saturated paste or saturation extract.

SL02 (Exchangeable Sodium Percentage and Sodium Absorption Ratio) are diagnostics of increasing sodicity (solonetz formation). The most important indicative parameters are pH and ESP or SAR in a saturated soil extract.

SL03 was selected because of its critical importance to protecting soil from salinisation. Secondary salinisation may be caused where a rising water table has a high salt content and an unfavourable ion composition. This may be due to natural fluctuation in groundwater levels or to improper irrigation practice (uneven water distribution, seepage from reservoirs, irrigation canals and irrigated fields) without proper drainage. Even good quality groundwater can transport salts from deeper horizons to the root zone. Human-induced secondary salt accumulation from poor-quality irrigation water may take place where: i) the water source (rivers, lakes, reservoirs, groundwater) has a high salt content and an unfavourable ion composition; or ii) the irrigation water collects salts while flowing in unlined earth canals. The most important indicative parameters for water are total salt content, electrical conductivity (EC), SAR and pH; and for soils are total salt content or electrical conductivity (EC) of the saturated paste or saturation extract; together with pH and exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) in the saturated soil extract.

Baselines and Thresholds

The characteristics of a 'normal' soil that lacks any specific influence of salts and sodium can be considered as a 'general baseline'. These soils do contain some salts in the 0–150 cm layer as a result of weathering processes and land use practices. In such cases the total amount of soluble salts is less than 0.05% or the electrical conductivity (EC) is < 2 dS m^{-1} in the saturated soil paste. The baseline for exchangeable sodium percentage (ESP) is 5%; the sodium adsorption ratio (SAR) in the saturation extract is < 4; and pH is in a range of 5 to 8.

Threshold values are highly specific for various salts, because their impacts are different and depend on various land use practices and cropping patterns. The threshold values are determined by the following factors:

- salinity status: quantity of salts, their vertical distribution (salt profile), salt composition (concentration, cation and anion composition) and their changes over time;
- soil reaction (pH and carbonate status);
- exchangeable sodium;
- land use practices: land use pattern, cropping pattern, salt tolerance of crops.

Specific thresholds are defined as:

- 0.10% total salt content or 4 dS m^{-1} EC in the 0–30/50 cm soil layer;
- an equivalent sodium percentage (ESP) > 15;
- sodium absorption ratio (SAR) >10;
- pH>8.5 in the accumulation horizon;
- < 500 mg l^{-1} salt content or 0.5 dS m^{-1} EC, < 4 SAR for irrigation waters.

2.2.8 Landslides

A landslide is the movement of a mass of rock, debris, artificial fill or earth down a slope, under the force of gravity (Cruden and Varnes, 1996). This '*en masse*' movement (or slope failure) may be induced by physical processes such as excess rainfall, snow melt or seismic activity, or it may be a consequence of human interference with slope morphology (e.g. constructing over-steepened slopes) that affects slope stability. Landslides will occur when the inherent resistance of the slope is exceeded by the forces acting on the slope. This is expressed as the 'Factor of Safety' (F) of a slope, which is defined as the ratio of the available shear strength of the soil to that required to keep the slope stable.

A landslide as a 'threat to soil' can be defined as: 'the movement of a mass of rock, debris, artificial fill or earth down a slope, under the force of gravity, causing a deterioration or loss of one or more soil functions' (see Volume V, Appendix 2). Clearly, landslides sometimes form more dramatic hazards in populated areas, threatening human lives and properties, but in the context of ENVASSO the focus is on the threat to the soil itself. Landslides threaten soil functioning in two ways: i) removal of soil from its *in situ* position, and ii) deposition of colluvium on *in situ* soil downslope from the area where the soil mass 'failed'.

Where a landslide removes all soil material, all soil functions will be lost and weathering processes of the hard rock, or sediment, now exposed at the surface, need to operate for thousands of years to produce enough soil material for soil functioning to resume. When only a part of the soil profile (e.g. the A horizon) is removed by a landslide, no soil function may be lost entirely, although most functions are likely to be impaired. The 'engineering' soil function may not suffer to any great extent, and in some cases may even benefit, from topsoil removal by landsliding. A similar rationale can be used for the deposition area. When the soil is covered by a thick layer of colluvium (e.g. > 30-50 cm) the 'production', 'habitat' and 'engineering' soil functions (see Volume I, Appendix 2) are lost. However, when the colluvium layer is thin (e.g. < 10 cm), mixing of the colluvium into the A horizon may be beneficial to those same functions.

There are many different types of landslide, making classifications complex and sometimes contradictory. However, there is a general consensus that mass movements can be classified according to their mode of failure and the different types of failure are summarised by Cruden and Varnes (1996) and presented in Volume I.

Key issue	Key question	Candidate Indicator	Unit	ID
Landslide activity	What is the status of landslide activity in Europe?	Occurrence of landslide activity	ha (or km^2) affected per ha (or km^2)	LS01
Landslide activity	What is the status of displaced material by landslide activity?	Volume/weight of displaced material	m^3 (or km^3) (or tonnes) of displaced material	LS02
Vulnerability to landsliding	What is the susceptibility of slope materials to landslide processes?	Landslide hazard assessment	Variable	LS03

LS01 (the historic occurrence of landslides) highlights the areas where the threat to soil resources by slope instability is greatest and also identifies areas potentially at greatest risk of further slope failure in the future. This indicator was selected because data on past landslides are available in some parts of Europe and the techniques exist to extend this kind of information across Europe.

LS02 was selected because it estimates the amount of slope forming material which is displaced by landslide activity, which is a fundamental measure of the degree of landscape degradation caused. Increasingly accurate methods based on GIS technology either currently existing for some parts of Europe, or at the advanced stage of development.

LS03 was selected because of the need to include a predictive indicator. Assessing the likelihood of landsliding depends on a number of quantifiable factors, and any evidence of previous landslide activity is valuable for refining hazard assessments.

Baselines and Thresholds

In areas of Europe where no landslide activity is present, the baseline is zero unit area affected per unit area. In other areas affected by landslides, a detailed inventory is required to define a baseline.

It may be considered that any landslide activity exceeds an acceptable threshold, as any disruption to the soil profile may affect soil functions, both at the origin of the landslide and at the destination of the failed material. The degree of soil profile disruption will depend on the deformation of the slope materials during failure. For example, translational slides will undergo less soil deformation than mud flows.

2.2.9 Desertification

Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD, Article 1, 1994). In the broadest terms, desertification includes the degradation of land, water, vegetation and other resources (Martinez-Fernandez and Esteve, 2005). Because of its importance worldwide, the United Nations has formulated the Convention to Combat Desertification (UNCCD), to which the European Union is a signatory. In ENVASSO, desertification was considered initially as a key issue within the threat Soil Erosion but then considered separately as a cross-cutting threat to soil – the 9th threat.

Desertification is a consequence of a set of important processes that are most active in arid and semi-arid environments, i.e. where water availability is the main limiting factor in ecosystems (Kirkby and Kosmas, 1999), but also operate in the dry sub-humid zone. A number of factors control the process of desertification and Kirkby *et al.* (1996) have defined the different feedback mechanisms that control this process. When climatic conditions become more arid, the vegetation cover reduces in area, resulting in less organic matter addition to the soil, causing a decrease in water retention capacity, and an increase in runoff and sediment yield (Boix-Fayos *et al.,* 2005). Thereafter, soil structure controls the erosion process.

Indicators of desertification may demonstrate that desertification has already proceeded to its end point of irreversibly infertile soils, for example as rocky deserts or highly sodic soils. The most useful indicators, however, are those which indicate the potential risk of desertification while there is still time and scope for remedial action (Kibblewhite *et al.*, 2007). In Spain, desertification has been – and still is – mainly associated with soil erosion, particularly under natural or semi-natural vegetation (Martinez-Fernandez and Esteve, 2005).

However, at the European scale desertification is also closely associated with other degradation processes (Brandt and Thornes, 1996) including decline in soil organic matter, soil salinisation, loss of biodiversity, over-exploitation of groundwater, forest fires, soil contamination and even uncontrolled urban expansion (Sommer *et al.,* 1998). As such, desertification is a cross-cutting issue and the countries in Europe that are most affected are Spain, Portugal, southern France, Malta, Greece, Cyprus and southern Italy. Some small parts of other countries may meet the criteria of desertification largely through *aridification*, where the ground water level has been lowered by over-exploitation, or intensive drainage has dried out the land and there are prolonged periods without rainfall.

Key issue	Key question	Candidate indicator	Unit	ID
Desertification	What is the extent of Desertification in Europe?	Land area at risk of Desertification	km^2	DE01
Desertification	What is the current status of soil loss as a result of wild fires in Europe?	Land area (forest and other non-agricultural land use) burnt by wildfires	$km^2\ yr^{-1}$	DE02
Desertification	What is the current status of soil organic matter decline as a result of Desertification in Europe?	Soil organic carbon content in desertified land	%, $g\ kg^{-1}$	DE04

DE01 (land area vulnerable to or at risk of desertification) was selected because of the potential it holds for mitigation by policy implementation and subsequent changes to land management.

DE02 was selected because of the destructive capacity of wild fires, and the significant increase in their occurrence in recent years, which may be linked to climate change.

DE04 was selected because conservation of soil organic matter (SOM) is important to maintaining soil functions in desertified land systems. It is synonymous with indicator OM01, soil organic carbon content. However, it is anticipated that the third priority indicator for desertification should be redefined as a 'soil degradation index' combining soil organic carbon content (measured by OM1), total salt content (SL01) and some measure of soil biodiversity (for example BI03). However, more scientific and technical progress will be needed to develop such a soil degradation indicator for desertification.

Baselines and Thresholds

There are several approaches to assessing whether an area is desertified. Banco íblico de indicadores ambientales del Ministerio de Medio Ambiente (Spain) used the excess of potential evapotranspiration over precipitation as an aridity index whereas the Medalus Project (Kosmas *et al.,* 1999a) calculated aridity using annual precipitation and air temperature regimes. There seems to be little basis upon which to establish an overall baseline for desertification. Defining areas vulnerable to desertification relies on average climatic data providing the index of aridity. Thus, a baseline value could be an average amount of annual precipitation in relation to average annual evapotranspiration or mean annual temperature. Thresholds values are more difficult to define. One approach is to set a certain aridity index or to estimate a certain percentage above the baseline value, or a change in a certain period of time.

2.3 Conclusions and recommendations

2.3.1 Coverage of threats by priority indicators

Before the selection of indicators, 44 key issues relating to the different soil threats were identified. A detailed analysis and filtering process reduced this number of key issues to 27 for which 60 candidate indicators were proposed in total. Further assessment by expert judgement led to the selection of three priority (TOP3) indicators for each of the threats, covering 20 key issues.

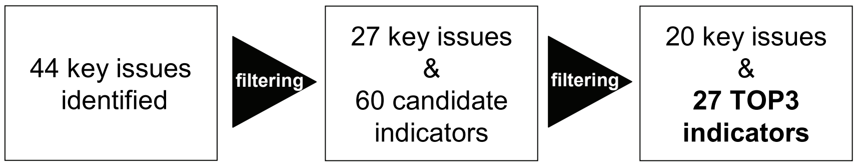

Figure 2: Defining the most important indicators for nine threats to soil

The TOP3 indicators proposed do not cover all of the key issues that were proposed initially: some of these were considered redundant while others were combined or integrated into the remaining ones (including ‘peat lands’ in ‘status of soil organic matter’ and five key issues related to compaction that were merged in to a single key issue). In conclusion, a good coverage of key issues was achieved; for the few key issues not covered by TOP3 indicators at least three are covered to some extent by other candidate indicators (see Volume I, Chapter 13).

Table 1: Key issues not covered by the TOP3 and candidate indicators

Key issue	Covered b by TOP3 indicators	Covered by candidate indicators
Erosion control	N	N
Dissolution erosion	N	N
Coastal erosion	N	N
Natural causes of soil organic matter change	N	N
Diffuse contamination by nutrients and pesticides	N	Y
Diffuse contamination by persistent organic pollutants	N	Y
Fragmentation (by soil sealing)	N	Y
Impact of salinisation / sodification	N	N
Mechanisms causing landslides	N	N
Assessing the impacts of landslides	N	N

2.3.2 Indicator coverage of the DPSIR cycle

The majority of the TOP3 indicators describe the state of the corresponding soil threat and those selected for the threats Soil Erosion, Decline in Soil Organic Matter, Soil Compaction, Land Slides, and Desertification are exclusively ‘state’ indicators. For the other threats to soil, the TOP3 indicators describe a mixture of ‘State’ (S), ‘Impact’ (I), ‘Response’, (R) and ‘Pressure’ (P) categories. Although not selected as TOP3 indicators, the other candidate indicators could be developed and these would then provide information on the other indicator categories (see Table 2) for many of the threats to soil.

Table 2 DPSIR elements covered by TOP3 and candidate indicators

Threatl	TOP3 indicators	Candidate indicators
Soil Erosion	S	S
Decline in Soil Organic Matter	S	S, P, I, R
Soil Contamination	S, P, R	S, P, R
Soil Sealing	P, R	P, I, R
Soil Compaction	S	S, P
Decline in Soil Biodiversity	I	I
Soil Salinisation	S, P	S, P
Landslides	S	S, R
Desertification	S	S

2.3.3 Difficulty of implementing indicators

Implementation of 70% of the TOP3 indicators requires sample collection and testing at representative sites. Predictive modelling using available data (e.g. land cover information, soil inventories) can be applied to the remaining 30%. The scales and resolution required are very variable depending on the indicators. For point measurements the range mainly from 1 km x 1 km up to 16 km x 16 km, for spatial data from 1:25,000 up to 1:100,000 (for further details see chapters on data and user requirements in Volume I).

Regarding current data availability to support implementation of the TOP3 indicators, this is judged to be high for about a half, medium for about a third and low for about a fifth of the indicators selected.

Considering the methodological approaches, data sources and data availability, it is expected that about 80% of the TOP3 indicators could be implemented in the short term (i.e. within 3 to 5 years) although this will vary between European regions depending on current data availability and monitoring activities.

2.3.4 Recommendations

ENVASSO has proposed a core set of indicators that can be recognised as authoritative because they have been selected collaboratively by a comprehensive group of European soil scientists from almost all Member States of the European Union. A stepwise implementation is recommended, with the TOP3 indicators (which support minimum requirements) followed by later extension using other ENVASSO candidate indicators to achieve comprehensive soil monitoring.

3. Inventory and Monitoring

A short definition of soil monitoring is "the systematic determination of soil variables so as to record their temporal and spatial changes" (FAO/ECE, 1994). Monitoring is widely recognised as an essential part of effective natural resource protection and management. This is as true for soil as it is for water and for air. Monitoring should allow the early detection of changes in soil condition, which indicate functional degradation and allow timely application of corrective measures. Equally it may be used to assess the effectiveness of existing soil resource protection, including as an input to estimation of the economic benefits of regulatory protection.

A soil monitoring network (SMN) is a spatial arrangement of soil monitoring sites, designed to be representative of soil type, land use and climatic zones. The use of a harmonised methodology is essential to provide comparable data between sites and Member States.

The objectives of the ENVASSO Project were to

1. Describe and review existing SMNs and their associated databases
2. Document coverage (over space and in time)
3. List indicators being estimated and identify supporting parameter measurements
4. Describe current soil sampling procedures and testing protocols.

Official networks for soil monitoring exist in most EU Member States, but the methodology used is not harmonised and coverage is far from uniform even within some Member States. While recognising the need to produce data that are consistent and comparable within the EU, the starting point for achieving this objective is a recognition that differences exist between the various soil monitoring systems. Therefore, a further aim of ENVASSO was to recommend improvements to current systems and ways to implement these improvements.

Soil monitoring practices were surveyed using questionnaires designed by the French Institut National de la Recherche Agronomique (INRA), in collaboration with ENVASSO partners and distributed electronically to partners in all EU Member States and Norway.

A significant success was the documenting within ENVASSO (for the purpose of the project only) of geo-referenced information about soil monitoring sites in all the Member States (except Cyprus and Luxembourg) and Norway. This allowed a detailed analysis of the existing density, scope of measurement and practices for soil monitoring within Europe, although it was not possible to identify all monitoring initiatives in all Member States. However, the overall data set was sufficiently comprehensive, with good enough geographical coverage (Figure 3), for sound conclusions to be drawn, for the first time, about the current soil monitoring infrastructure in Europe.

Greater soil variability within monitoring sites may increase the number of samples that need to be collected at these sites to detect a given amount of change. This has consequences for monitoring costs, the reliability of observed changes, and the minimum time step necessary to detect a given change. Therefore, we conducted a meta-analysis on soil variability within monitoring sites in order to assess the consequences of this variability on confidence intervals for the mean values of parameters monitored and on the minimum changes detectable for a given site density.

The description of the questionnaires and the methodology for data collection, harmonisation and analysis are given in ENVASSO Volume IIa & IIb, in which the geographical coverage of sites and indicators being measured by national and European SMNs is also described. Representativity was assessed by analysing the number and sufficiency of sites with combinations of particular soil (Figure 4), land use and main state, pressure or impact indicators

ENVASSO Volume IIa reviews sampling and testing protocols used in soil monitoring networks and Volume IIb summarises the SMNs in each country in standard fact-sheets. The main findings of a meta-analysis of the in-site variability and its consequences for minimum detectable changes and recommended time intervals between sampling campaigns are summarised together with an exhaustive list of testing protocols.

3.1 Site selection and geographical coverage

There are large differences in methodology and coverage between existing networks, whereas geographical coverage (Figure 1) is very heterogeneous between and within Member States. Soil Monitoring Networks are much denser in northern and eastern than in southern parts of Europe.

Table 3: New sites needed to reach a minimum density of 1 site per 300 km² in Member States, according to some specific parameters

Country	Total	Peat area	Compaction risk	High Population density	Desertification risk	High cattle density	high pig density
Austria	0	-	0	0	0	0	0
Belgium	0	-	1	0	-	1	1
Bulgaria	12	-	2	-	2	-	-
Czech Republic	0	-	1	-	0	-	-
Denmark	2	-	0	0	-	0	0
England & Wales	2	0	1	0	-	0	0
Estonia	21	2	8	-	-	-	-
Finland	209	81	203	0	-	-	-
France	452	-	124	30	1	61	29
Germany	205	0	51	61	-	63	86
Greece	330	-	16	9	34	-	-
Hungary	0	-	0	-	0	-	0
Ireland	0	0	0	0	-	0	-
Italy	656	-	115	213	163	52	91
Latvia	89	2	29	-	-	-	-
Lithuania	79	-	63	-	-	-	-
Luxembourg	0	-	-	0	-	2	-
Malta	0	-	-	-	-	-	-
Netherlands	2	0	0	2	-	1	1
Northern Ireland	0	-	0	0	-	0	-
Norway	417	4	313	-	-	-	-
Poland	247	3	97	-	-	-	72
Portugal	38	-	23	5	9	-	-
Romania	14	-	3	-	14	-	-
Scotland	4	0	0	-	-	-	-
Slovakia	0	-	0	-	0	-	-
Slovenia	0	-	-	-	-	-	-
Spain	914	-	109	67	566	4	118
Sweden	407	24	2	14	-	-	-
TOTAL	4100	116	1161	401	789	184	398

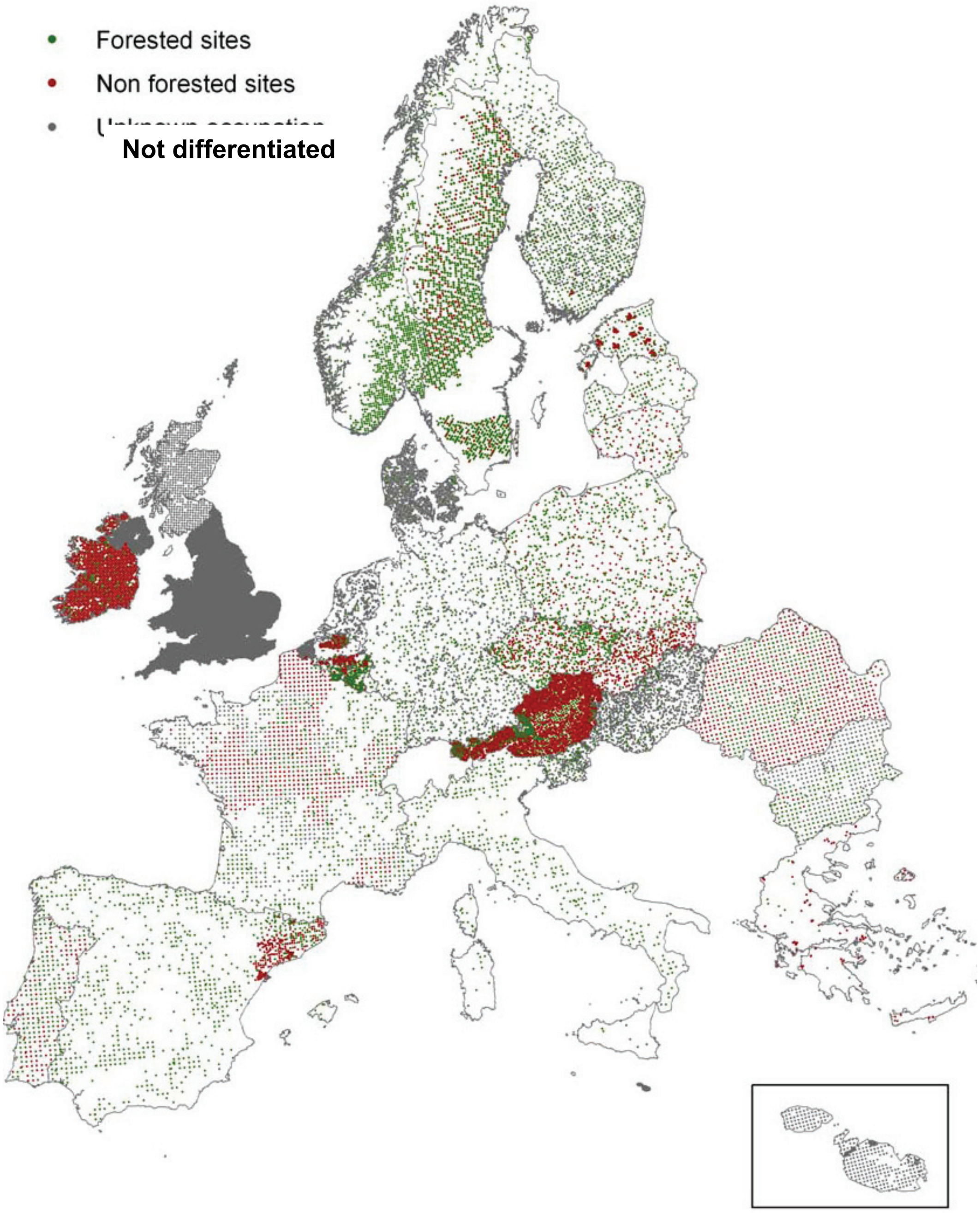

Figure 3: Distribution of soil monitoring sites in Europe

Different criteria may be used to select the locations of sampling sites. One approach is to apply a grid and to locate sampling sites at its nodes. Alternatively, a classical population sampling approach may be taken that aims to achieve representative sampling of particular topographies, soil types, land uses, crop types, natural vegetation classes or other categories. Otherwise, it may be decided to select existing monitoring sites (for soil or other environmental assessment) for reasons of efficiency and to allow comparison to relevant historic data.

At least one monitoring site exists for each of the major soil mapping units delineated on the Soil Map of Europe (CEC, 1985) and each of the different CORINE land use classes. However, the parameters, for which data were provided by Member States, were inconsistent. The density of sites in soil mapping units was also highly variable and for about 10 % of these no monitoring site was reported. For land use classes, the greatest site density was reported for grasslands, whereas arable lands and forests had a lesser, although comparable, site density. Permanent-crop lands (e.g. vineyards, orchards) and open spaces, with little or no vegetation, were under-sampled in comparison to other land uses.

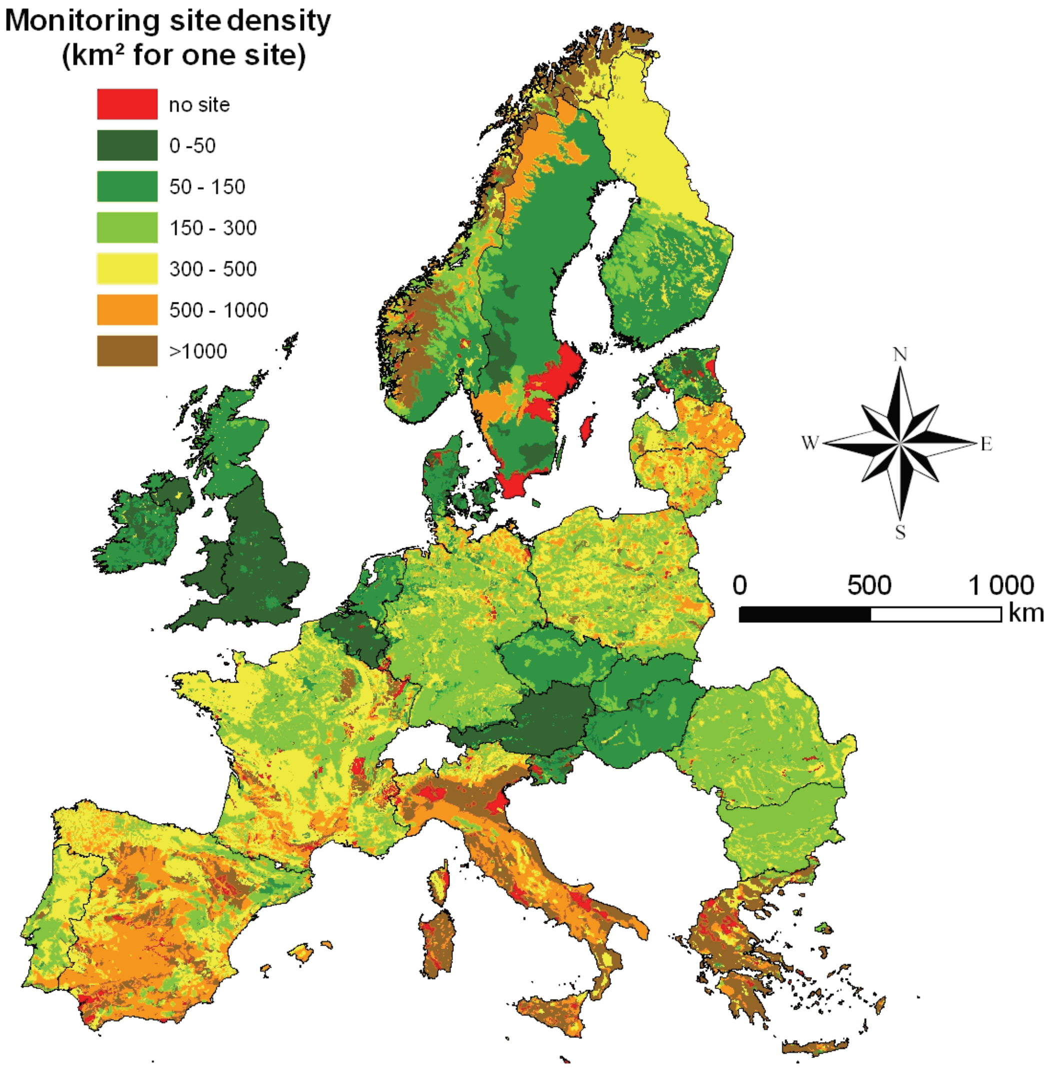

Figure 4: Density of sites in soil mapping units of Europe

The median density of sites, analysed in 50 km x 50 km cells covering Europe, is 1 site per 300 km², which is close to the density of the ICP Forest grid (UN/ECE ICP Forests, 1994). This median density is already reached for over half the combined area of the European Union and Norway. However, a large variability in site densities is reported when considering various indicators, as the minimum set of parameters measured differs between Member States. Converted into a systematic grid, the median density of one site per 300 km^2 would be equivalent to a 17 km x 17 km grid. As an existing 16 km x 16 km SMN grid already covers the forested areas in Europe, reaching at least this common median density would require new sites specifically on non-forested soils.

Considering the existing sites and their uneven distribution between Member States, achieving the median density in all 50 km x 50 km cells would require 4,100 new sites, mainly located in southern countries (Italy, Spain, Greece), and parts of Poland, Germany, the Baltic States, Norway, Finland and France. However, this number is thought to be a slight overestimate, because some metadata were not accessible for Italy, Spain and Sweden, and, in addition, some SMNs are currently being implemented (France). Nevertheless, it is clear that significant resources would be needed to reach a common level of 1 site per 300 km², across all Member States.

ENVASSO recommends that a minimum density of sites is achieved over the whole of Europe and we propose that the present median density of 1 site per 300 km² should be a starting point and an absolute minimum for soil protection in Europe. Table 3 gives the number of new sites needed to reach this minimum density in each Member State, and the number of new sites needed to address some specific threats to soil.

3.2 Site area and sampling strategy

Apart from a few watersheds (catchments), within which soil erosion is monitored, all the reported sites have sampling areas ranging from 10 m^2 to a few ha and are homogeneous with regard to soil profile development. In most cases, soil sampling for testing is based upon several sub-samples (from 4 to 100) taken within this area. Apart from watershed monitoring, ENVASSO recommends selecting a small area for sampling, ranging from 100 m^2 to 1 ha that has homogeneous soil profile development. Within the site area a set of sub-samples should be taken and retained for laboratory testing and subsequent archiving; a minimum of 4 sub-samples for every 100 m^2 of sampling area should be taken depending on the size of the site and the extent of soil profile variation. The exact location of cores within the sampling plot should be carefully recorded so that these can be avoided in future sampling campaigns.

The main sampling strategy should be based on core sampling to fixed-depth increments rather than sampling of identified pedogenic horizons. Fixed depth sampling ensures standardisation between sites and is effective for agricultural and other sites where surface horizons have been mixed by tillage and other interventions. It is also the most relevant approach for assessing some anthropogenic characteristics (e.g. anthropogenic heavy metals, radionuclides, pesticides and other organic trace contaminants), and for parameters showing a strong gradient near the surface. Pedogenic horizon samples may be collected in soil pits, outside but near to the monitoring area. This method of sampling is relevant for some parameters (e.g. particle-size distribution, water retention properties, mineralogy) which are required for soil inventories and as site parameters required in combination with monitored parameters for indicator estimation, or to link SMN observations to soil map data in geographical soil information systems.

It is not possible to make a single, European-wide, recommendation for sampling depth. Indeed, enforcing a change of depth on an existing national SMN would make it very difficult to use data from previous campaigns for the assessment of change. One way to harmonise reporting at the European scale could be to report the results on the basis of an equivalent mineral mass. We recommend sampling is done so that topsoil concentrations or stocks of elements can be calculated for depths ranging from 0-15 to 0-30 cm. When monitoring soil organic carbon stocks, additional steps are required: a second sample should be taken from the maximum depth of the first sample to a depth of 50 cm (possibly deeper for those soils with deep organic-rich horizons; volumetric stone content should be estimated and subtracted from the total soil volume.

3.3 Parameters monitored

In general within all SMNs, there is a minimum set of mandatory parameters which are measured systematically (at least once) or monitored (with different frequencies). This minimum set differs between Member State SMNs.

The density of area coverage is very heterogeneous for the indicators selected by ENVASSO. Soil organic carbon and pH are measured in most SMNs but most other parameters for indicator estimation are not included. In particular, soil biodiversity and erosion measurements are included only rarely.

Some trace elements are measured in almost all Member State SMNs (e.g. lead), whereas others are not (e.g. mercury). Parameters for soil compaction estimation such as bulk density or packing density are only measured in about half of the Member State SMNs. Many peri-urban areas are not monitored for contaminants, especially in southern Europe. Those areas identified as having the highest heavy metal deposition rates do not appear to be sampled with sufficient density, especially for mercury. Areas with heavy livestock pressures are unevenly covered by appropriate indicator measurements.

Existing international standards for soil testing are not used in most Member State SMNs. Future harmonisation of testing procedures is complicated by the wide variety of established practices, even for apparently less complex parameters such as organic carbon. Comparative evaluation of the more widely used procedures, on a set of samples representing the major soil mapping units and a range of target parameters values would be the best option to ensure data comparability over time and between countries and to arrive at an objective selection of the best methods to be adopted in future, while allowing future meaningful comparisons with data from past sampling campaigns. It may also be possible to establish multiple-regression functions linking the results obtained using different methods while taking account of soil properties. It should be noted that the main cost in soil monitoring is incurred by field sampling, so the inclusion of additional testing procedures would not necessarily increase costs disproportionately.

Most Member State SMNs use laboratories that have a quality control system covering the use of statistical processes, reference materials and proficiency testing. Except for analyses within the on-going project 'Forest Focus Biosoil' (UN/ECE ICP, 2006), there is no reference laboratory and the introduction of one for soil testing as part of a pan-European SMN would be advantageous. Overall, the absence is notable within the soil monitoring community of established inter-laboratory comparability exercises, organised cooperation on method development and harmonisation, and both the availability and use of shared reference materials, including certified reference samples. This situation compares unfavourably with the advances made in other areas of environmental measurement over the past few decades, including within programmes of the European Bureau of Community Reference. Investment to fill this gap in harmonisation is needed at both European and Member State scales.

3.4 Time interval for re-sampling and minimum detectable changes

Although the time intervals between sampling campaigns in different Member State SMNs, are variable, at least for the limited number that have already been re-sampled, most have adopted re-sampling intervals of 10 years or less. More frequent sampling has been adopted for some SMNs during the early years of their establishment, which has subsequently been reduced (to longer intervals) after observing rates of change in the parameters being tested. We recommend an overall re-sampling interval of 10 years as this would allow nearly all the SMNs to be incorporated into a common framework; reducing the re-sampling interval to less than 10 years will not deliver much better estimation of rates of change in soil parameters.

Our results suggest that the minimum detectable change differs considerably between both SMNs and indicators. In some Member States, irrespective of the indicator, considerable effort is needed to reach an acceptable density of sites to deliver a satisfactory minimum detectable change. For some indicators such as the topsoil organic carbon content, an interval of about 10 years would enable the detection of large changes. For other indicators, such as heavy metals, detecting changes at regional and continental scales occurring over such a relatively short time interval is impossible except in the case of ongoing and intense new contamination, notwithstanding that changes may be measurable within local areas and at field scale.

3.5 Archiving samples

Archiving of samples is essential to allow re-testing of samples from previous campaigns to allow control of bias arising from altered testing methods and / or performance; to provide the opportunity for estimating new indicators at later dates; to provide a source of samples for research and for inter-laboratory proficiency testing.

3.6 Conclusions and Recommendations

The ENVASSO results provide the most exhaustive review of European SMNs to date. Harmonisation and coordination are essential in view of the present heterogeneity of SMNs in Europe. Where existing Member State SMNs achieve the minimum density of 1 site per 300 km², the requirement is to include additional parameters to allow a full set of indicator estimations. For many Member State SMNs, however, new sites are also required. Indeed, considerable efforts are still needed to reach a common and acceptable standard of soil monitoring in Europe, based on framework supporting harmonisation that allows data interpretation linked to geographical databases.

4. Database Design and Selection

Soil monitoring requires representative information from repeated assessments, with present conditions being represented by data from the most recent sampling campaign. Member State (or regional) sampling, analytical and database design strategies often follow national criteria, which are sufficiently diverse to render data that are not comparable across Europe. For example, different nomenclatures are used in Europe; sometimes these are international standards or derivatives of them, but often these are national. These conditions lead to heterogeneous data, both in terms of content and structure.

The density of validated information (e.g. soil profile descriptions) in Europe is still extremely limited (Van Ranst *et al.* 2004). In the WISE database maintained by the ISRIC World Soil Information (Batjes *et al.*, 1997), 492 soil profiles are stored. From that data source, only 7 soil profiles were used for the Global Pedon Database after applying some quality control procedures (internal consistency, completeness such as geo-referencing, meta-data on methods). Even though not complete, and focusing on chemical properties, harmonised information on typical soil profiles for the soil map of Europe were gathered by the European Soil Bureau Network (Madsen and Jones, 1995) and subsequently anaysed by Hiederer *et al.* (2006).

Both of these data examples are far from being representative, compared to the very large number of soil profiles that have been described and analysed in Europe so far (Baritz 2005). From the development of European databases, including recent experiences (Hollis *et al.* 2006), it is known that data requests and data exchange is greatly limited when very prescriptive transfer rules and formats are imposed. This means that if databases are to be further enlarged, or representative datasets are to be compiled and data are to be exchanged (for example in order to produce comparable cross-border soil quality assessments), a database system should ideally be able to accommodate heterogeneous data sources and data formats.

Rather than asking data producers to export (new, existing, or historic) data following very prescriptive formatting and content rules, as much meta data as possible should accompany transferred datasets so that effective harmonisation efforts can be applied to original data by the coordinating centre to optimise comparability. In fact, Van Ranst *et al.* (2004) concluded that a particular problem with the existing (international) soil profile databases is that no accepted standard for the storage of these data exists.

In ENVASSO's prototype evaluation, it was observed that some partners have developed their own databases, while others used simple spreadsheets. The primary objective of the Database Design and Selection module was to develop support tools able to facilitate management of soil monitoring data. The intention was to provide for both local data management, and the requirement to process data from different sources, particularly to facilitate the cross-border evaluations within several ENVASSO pilot areas. Solutions were sought which would enable data producers to exchange data in a way that allows their data to be read and applied by others (partners, data centres, etc.). An increasing number of web-based data processing and evaluation services will become available to future soil information system developments. For example, a Member State might establish a soil portal supporting methods to calculate soil threat risk information but following international soil profile specifications, such as are currently under development (ISO work item N 12). Any user could then use such a service with locally sources data provided that the data are defined and coded according to standard specifications.

Considering the above requirements for data management and communication, and the objective to bring together up-to-date data from various institutions to produce 'on-the-fly' data evaluations, it can be concluded that enhanced approaches to information storage, processing and transfer are needed. The ENVASSO network offered a unique opportunity for testing concepts for this development throughout Europe.

4.1 Analysis of existing soil databases

The design of a support tool for data management is foundational to integrating existing soil monitoring information systems. Moreover, this can provide an efficient and effective contribution where a new local database is needed. Thus, the data or table structures, of several soil profile, analytical and map databases used in Europe, were accurately analysed with the aim of understanding how the various designs

- are capable of storing data of re-descriptions, repeated analyses and meta-data (in the wide sense as data on data, including method information for sampling and analysis)
- link profile and analytical data with soil mapping units
- could manage a great variety of parameters coded according to various soil survey or mapping guidelines, classifications, etc.
  and
- if they are connected to GIS or automated data evaluation
- on which technical platforms the designs are implemented.

Nine databases from seven countries were tested and described. The following list presents the most important conclusions. Almost all analysed soil database designs are similar in that they use spreadsheet designs (Figure 5) for data tables.

- To avoid a large number of empty fields (e.g. if analytical data are only available for certain horizons), databases often contain various data tables for the storage of analytical results (e.g. soil chemical and soil physical parameters), or even store data according to completed or ongoing projects.
- Storing monitoring data seems to be a challenge for many of the systems designed in the past; even some recent designs do not facilitate efficient storage of monitoring data. Those systems that were not designed to store (or do not allow storage of) re-analyses or re-determinations of the soil properties (or only with laborious re-work) can be referred to as static, and this in fact applies to the majority of database designs reported to ENVASSO.
- Direct relations between map and profile/analytical databases do not exist within the databases evaluated. A link is usually achieved by creating a separate map database, based on expert evaluation of the soil profile and analytical data. This step is required to de-couple soil profile data (in the map database) from the profile database.
- At the European scale, the soil databases analysed are static map databases which have been populated with mostly analytical data prior to when soil information systems were in their infancy, and disconnection of the data from its source database was unavoidable. An important consequence is that the data which are held become outdated or even redundant as the source database is updated, unless some protocol is in place to provide a new data transfer, which is most unusual.
- Moreover, it has been normal practice either for the provider to ‘harmonise’ data prior to its transfer or for the user to apply a common procedure to harmonise all the data received from different sources. Both approaches have severe disadvantages. In the former the harmonisation standards may be interpreted differently by different providers. In the latter, where data are delivered from different sources and harmonised centrally, it may be mistakenly categorised and commonly information is lost as a consequence of data elimination. Furthermore, harmonisation needs and procedures may change over time, for example, after new standards, classification or survey guidelines become effective. Thus, the best harmonisation results can only be expected if original data are used and this requires a continuing connectivity between provider and user databases.

Spreadsheet design

Horizon	Param1	Param2	Param3	Param4
1	S	2.5	13.2	4.5
2	G	0.5	10.4	4.8
3	G	0.1	11.8	5.3
4	K	0.0	9.5	6.6
5	K		7.6	7.2

List design

Horizon	Parameter	Value	Unit
1	1	S	
1	2	2.5	mg/kg
1	4	4.5	
2	1	G	
2	2	0.5	ppm

Figure 5: Spreadsheet and list design of database tables

An example for a national database is given in Figure 6. In the spreadsheet design adopted, parameters populate columns, while the values populate the rows of the table. In the list design, for each value in a row, the parameter to which it relates has to be stated. The advantage of the latter is that new parameters can be added without changing the table structure, missing values do not occupy disc space, values of re-analyses or replicates can be stored without much effort, and queries can simply be adapted by changing the query criteria, but not query fields. The spreadsheet design adopted is more intuitive and needs less effort when several parameters are queried.

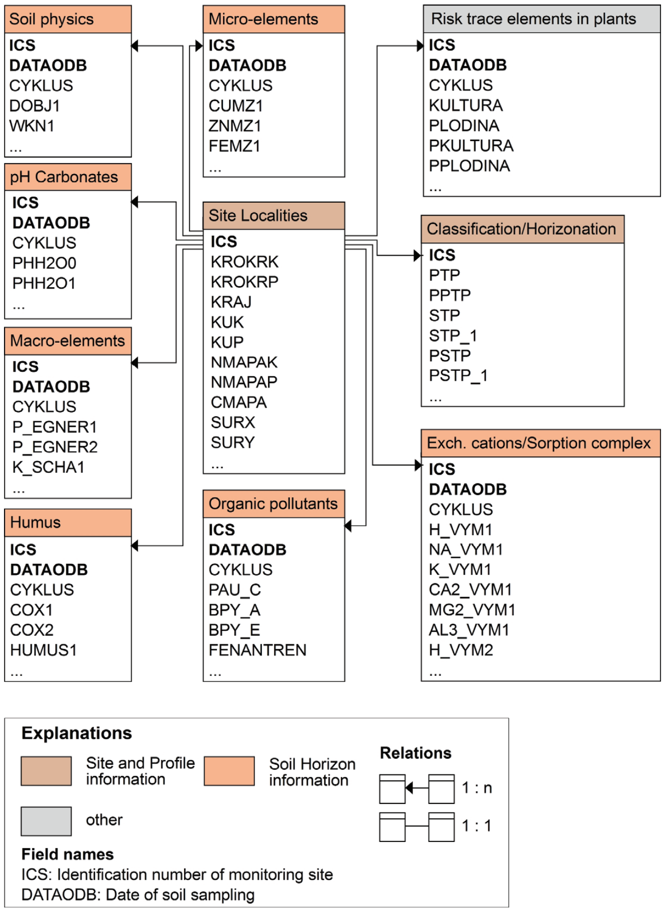

Figure 6: Table structure of the soil monitoring database of Slovakia

4.2 Development of a solution for soil data management (SoDa)

Generic design principles

It should not be expected that available soil information (soil profile descriptions, soil analyses) is always translated and harmonised prior to its use for environmental reporting, data distribution), nor, for the reasons set out above is this necessarily desirable. In any case, the great variety of soil data in Europe means that a generic scheme for storage and exchange is needed.

The basic schema for soil information is presented in Figure 7. It was based on the idea of a map database, for example Finke *et al.* (1998), but it should be capable of storing soil monitoring data and make them dynamically available for map-based evaluations. Furthermore, it should be independent of a specific map scale and should be capable of hosting data for several map series in one database. As a result, the model integrates soil description and analytical data as well as map unit information and the link between both entity groups.

The following basic principles were defined for the soil database environment:

1. Data should be stored wherever possible by the organisation that collected the samples.
2. Data should be stored on the method of data production.
3. Databases should contain real values wherever possible, although alternative data calculated by robust, tested pedo-transfer functions can be introduced to complete data sets for modelling purposes.
4. Metadata should be stored for any item of data.
5. Data storage should be clearly separated from data harmonisation and from data evaluation.
6. Agreed data transfer rules are the beneficial for sound cross-boundary data evaluation.
7. Soil profile observational and analytical data must be linked dynamically to soil maps for spatial evaluation.

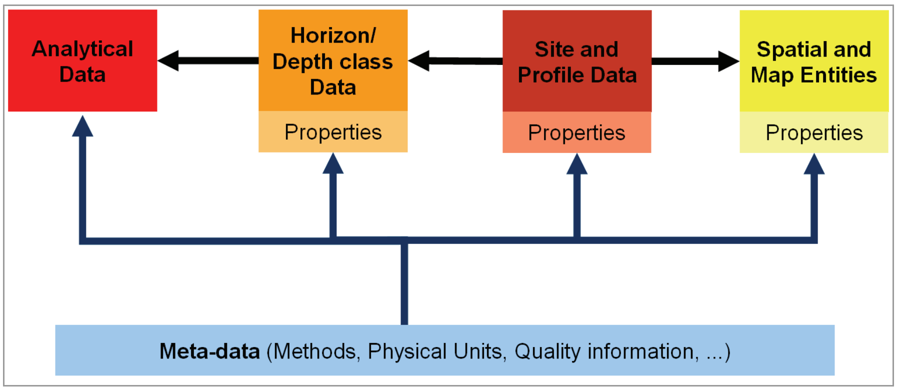

Figure 7: Simplified data model of SoDa

From these considerations, the following basic design principles were adopted:

- Data storage is clearly separated from data harmonisation/evaluation: data are coded and stored together with meta-data, and are easily retrievable. Thus, harmonisation before data entry is not required, and can be achieved on the basis of the data stored in SoDa.
- SoDa can serve as both a global and a local database solution, which is designed to provide consistent soil information within distributed soil database systems (i.e. collection of multiple, logically interrelated databases distributed over a computer network).
- New parameters can be introduced without increasing the number of tables (together with code lists for classified parameters).
- Metadata can be stored at each level of data storage in the database.
- Profile data can be dynamically connected to map data/spatial units; thus SoDa can act as a map, profile and soil analytical database simultaneously, even for various map scales.
- It is possible to store data obtained from various monitoring projects such as data received from subsamples (such as satellite samples or sub-sites), or from repeated sampling and analysis.

Model solution

Figure 8 presents an overview of the data model used in SoDa. Soil data can be related to the whole profile (including site information), or to a part of the profile. A profile part may be a fixed depth (for example for assessing topsoil contents of metals) or a pedogenic horizon. This is necessary because much analytical soil information is not accompanied by pedological information (e.g. soil horizons). Rather, soil quality monitoring/programmes (e.g. to assess soil contamination) focus on depth class sampling for comparability of the data, and to support inventory simplification.

Descriptive site data, metadata and analytical values obtained from laboratory analyses can be linked to profile data. For fixed depths it is assumed that horizons are not morphologically described but only sampled. Profile or horizon parameters can have be free values (e.g. upper and lower depth) or classified according to schema listed in field guides, where the surveyor has to select one value from a pre-defined code list. Hence, a two-fold structure for storing these data is provided (as well as for meta-parameters).

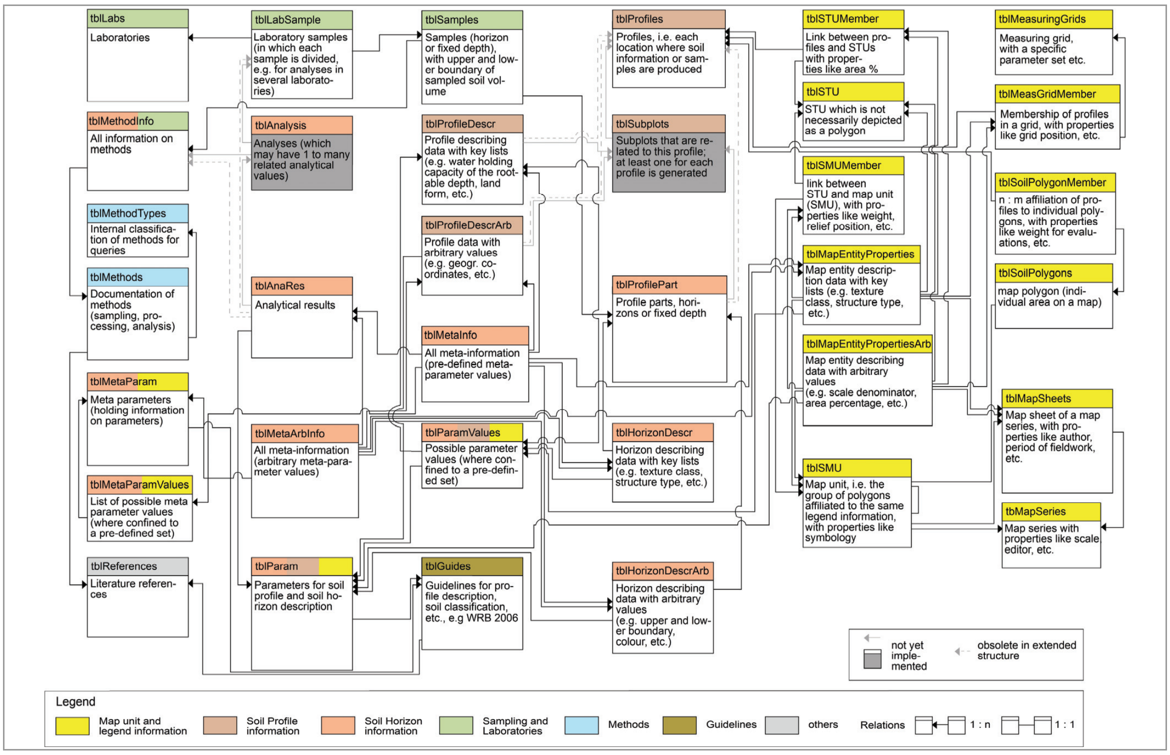

Figure 8: SoDa data model

(The two tables, marked in grey, are proposed additionally so that the data model can be extended conveniently to include detailed soil biodiversity data and to reduce potential redundancy of metadata stored for analytical values)

The structure for storing analytical results is somewhat complex to define, but this is an essential step in integrating a large amount of information during data interpretation and to enable the data user to comprehend data quality. The adopted design allows for the storage of data from repeated sampling, which is necessary for monitoring). Data may refer to the whole horizon or only parts of it. Data can be stored as results from a laboratory database, but also capture information related to individual samples prior to sample submission to the laboratory. There is also a facility to support sample division between different laboratories. Thus, a ‘laboratory sample’ level has been provided so that laboratory information can be captured in the database.

For each datum, whether it relates to a profile or a horizon, or consists of an analytical result, meta-information must be stored, for example the unit of a number or quality information.

Another kind of meta-information is the specification of sampling, sample processing and analytical methods. Because this kind of information is structurally different from the other metadata, an independent table structure has been designed for methodical information.

The model has been implemented as a MS Access database called SoDa (Soil Database). Parameters for profile descriptions and soil classifications have been implemented according to of the FAO Guidelines (1990, 2006), the WRB (1998, 2006), the SOTER Manual (1995), the German Soil Mapping Guidelines (4th and 5th editions) and parameter specifications of the Slovenian Soil Information System. In addition, many analytical parameters have been included.

The data specifications of other national nomenclatures (parameters, codes, categories or classes) can be added as well. More stress is laid on data import into the SoDa structure than on manual data entry, because most users already have data stored in electronic form.

Data communication rules and procedures

Data communication is based on the eXtended Mark-up Language (XML). Basically, XML codes data by mark-ups (called tags) in simple text files. The tags allow the receiving system to recognise the structure of the incoming data. Both text file and tags, can easily be created by the delivering database, and can be imported into each database with an interface (or filter). The XML name definitions for some basic entities are given in the SoDa manual. Furthermore, a basic XML scheme is proposed so that national data, not yet defined, can be exchanged as well.

Testing of the database design

The concept and design of the data model, and the software implementation of the ENVASSO soil database (SoDa), were presented to all project partners during several project workshops in Sofia, Athens, Lisbon, Clusj, Ljubljana and Miskolç. Furthermore, SoDa was demonstrated as a solution for local data management to partners during specific meetings/workshops in Budapest, Ljubljana, Aberdeen and Hannover. As a result, the software was applied for pilot area data management by Bulgaria, Catalonia (Spain), France, Hungary, Ireland, Portugal, Romania, Saxony (Germany), Scotland (United Kingdom) and Slovenia. Copies of SoDa were also requested by partners from Slovakia and Greece. Figure 9 gives an overview of the testing of SoDa in the pilot area Chemnitz 1:250,000.

The following experiences were reported from testing SoDa:

- SoDa successfully demonstrated the flexibility necessary for storing data of various provenances that can be realized while retaining consistent data storage.
- The current table structure could be expanded with two more tables to conveniently include sub-plot sampling (e.g. for biodiversity sampling) and to avoid redundancies in metadata storage for analytical data.
- The data exchange specifications and the SoDa data import/export module worked well. Tests proved that it would be possible to automate the construction of SQL statements needed for SoDa export routines. This is important if a database is to be capable of responding automatically to specific data requests within, for example, an Internet-enabled web soil service.
- The SoDa software is largely intuitive. The data import procedures from existing digital soil data appeared especially useful and efficient. Implementation of the SoDa design in another relational database management system would be possible if it were to be developed further with higher requirements for multi-user access, data security, etc.
- Documentation of sampling or analytical methods should be expanded to allow for better data evaluation.

4.3 Soil Information Systems

The design and operation of systems for storing and processing soil information should facilitate user access. Soil information systems provide the relevant conceptual and technical solutions. They can be divided into sub-systems for data production and processing distinct from that for data management and accessibility. For example, data processing includes the investigation of soil quality and its change, and the linkage with geo-data, land use and climate, and susceptibility to pressures.

Currently, most soil information systems in Europe have been developed within Member States. Europe-wide systems host data in several databases and some provide access via a soil portal. These databases are static map databases: they contain data related to mapping units (for the most part virtual profiles); they lack a link with real soil monitoring data as well as mechanisms for regular updating.

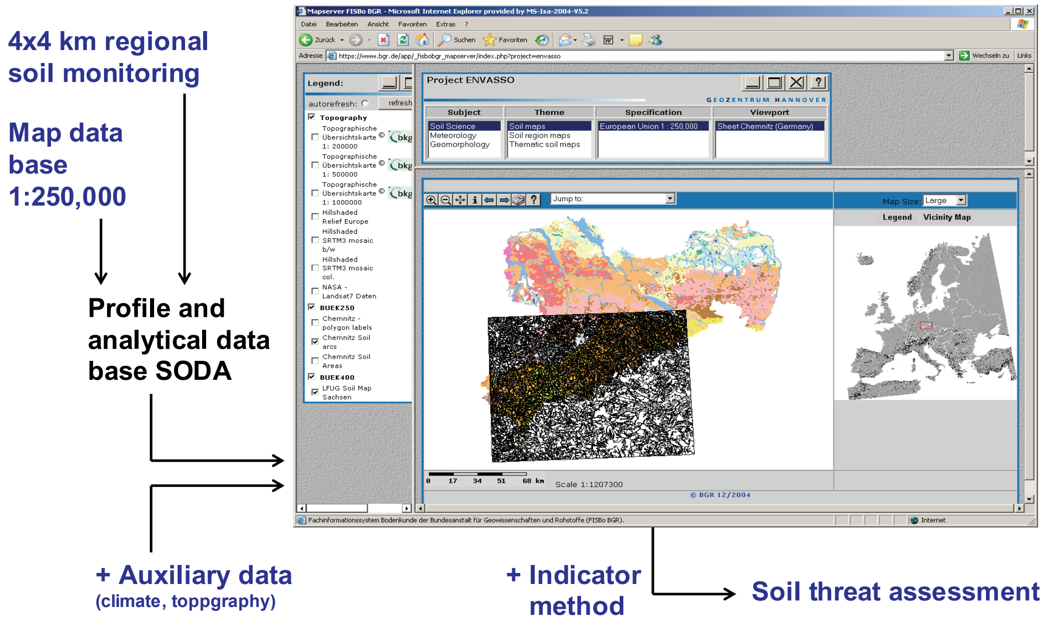

Figure 9: Testing of the database SoDa in the ENVASSO pilot area Chemnitz

Future soil information systems should comply with legal initiatives (e.g. INSPIRE) and the need to provide up-to-date soil information. They should make use of synergies between information systems. These requirements can be met by emerging web-based information systems operated by the user with an internet browser. They bring together soil and auxiliary data from different databases, harmonise and evaluate these using specific local or remotely implemented procedures, and present the resulting information as tables, reports, graphs, or maps - including with web mapping and web feature services.

4.4 Conclusions and recommendations

In their fundamental analysis of available world wide soil information, Van Ranst *et al.* (2004) concluded that "there is a demand for relevant, reliable and more timely information about soils. This can be provided within reasonable costs only by making full use of the existing data while applying new technology". These conclusions became the guiding principles for the design of a soil database (SoDa). At the same time, the ideas of Van Ranst *et al.* (2004) were extended to accommodate the need for more elaborated evaluation procedures, as well as Internet-based communicating systems for data storage, evaluation and presentation. SoDa was intended to act as a prototype technical platform for improved management of soil data from heterogeneous sources in Europe. This ambition was realised as the prototype was tested successfully in several Member States.

The variety of both database management systems and hardware platforms which are used for managing soil data in the EU Member States, when combined with the variable availability of local technical know-how, makes it unlikely that agreement could ever be reached between soil institutions in the Member States on one agreed data model for adoption everywhere. Therefore it is important to design data communication rules and procedures that can be used to transfer a wide variety of existing data from system to system without loss of information. In this way, only an interface for data communication is needed for each system, with the subsequent handling of imported data being an issue for the receiving (processing) database. Moreover, this approach need not be one-way in its operation, so that the receiving database can export other information back to local databases.

Considering the growing requirements of environmental and agricultural research and regulation, future soil information systems should provide and utilise web-based services, to facilitate extensive exchanges about the distribution, properties and state of soil. ENVASSO has illustrated how the data can be harmonised and evaluated with local or remote procedures, and the resulting information provided as tables, automated reports, graphs and maps, with information requests, data uploads etc launched using standard Internet browsers.

Link with stakeholders

Currently, a new activity of the ISO TC 190 (Soil Quality) SC 1 (Evaluation Criteria, Terminology and Codification), WG 3 (Data codification and management) is developing a new work item - N 12: Recording and exchange of soil related data. The ENVASSO results are highly relevant to this item, particularly the SoDa XML specifications. ENVASSO partners were, thus, asked to participate in this activity. The main output of ENVASSO's database design has been reviewed by the European Soil Data Centre (ESDAC), hosted at DG JRC.

Within the INSPIRE process of drafting implementation guidelines, an ENVASSO author was responsible for the writing of the Annex III theme SOIL as input to the deliverable D2.3 (Definition of Annex Themes and Scope) of the Drafting Team 'Data Specifications'.

5. Procedures and Protocols

The objective of ENVASSO was to define a fully documented consistent set of definitions, procedures and protocols for the harmonised characterisation and assessment of European soils for monitoring. The final result is a set of formal procedures for the characterization and the efficient monitoring of soil at the European scale, published in Volume V.

These procedures and protocols define how to derive an indicator value, at an individual monitoring site in Europe, which is harmonised in its measurement, calculation and expression throughout Europe. The initial indicator value will be part of an inventory, except where the site is already part of an inventory or monitoring system that conforms to the ENVASSO definition of a soil monitoring site.

Indicator Fact Sheets are listed in Volume I and these are complemented by metadata from Member States on existing Soil Monitoring Networks (SMNs). Recommendations are made for their pan-European harmonisation. These outputs have been combined and developed further by additional reviewing of the scientific literature, by inputs from experts from both within and outside of the ENVASSO Project and by assessment of the results of pilot testing. The conclusions have informed the selection, definition and documentation of procedures and protocols for estimating indicators for which the current development of parameter measurement and indicator estimation is sufficient. An additional output is the ENVASSO glossary (Volume V, Appendix 2), which records, for common reference, the definition and description of key terms that have been used throughout the project and in the published volumes.

Some of the selected procedures and protocols are already established in soil science or other disciplines. Others have been selected, developed and documented within the project. The procedures and protocols report a step-by-step approach for each indicator covered, together with all the ancillary information required, to arrive at robust indicator values for the threats to soil at each inventory/monitoring site. In addition, guidelines are given for the visualisation (presentation) of indicator values, where possible accompanied by examples from pilot studies completed within the overall project. Procedures and protocols for other monitoring tasks, for example sampling, are described or the relevant International Standards Organisation (ISO) documents identified. The full details of the selected procedures and protocols are provided in Volume V.

For each indicator, an overview and detailed technical information on the procedures and protocols to be adopted is documented. A cover sheet provides a stepwise guide that should be followed sequentially (Figure 10). Directly underneath the threat name is the indicator name (and code) followed by the ENVASSO definition. Terms in the definitions that are underlined feature as separate entries in the ENVASSO glossary. The first table to the right side of the page lists the input parameters, while a second table lists the specific materials and equipment required. The procedure for deriving an indicator value at an inventory or monitoring site is listed on the left side of the page, as a series of steps that must be followed sequentially.

Both the tables and the step-by-step description refer to a number of annexes where the required detailed information is given. These annexes are attached to each relevant indicator cover sheet, to create 'stand alone' procedures and protocols. Specific elements that are common in the procedures for several indicators are presented as Appendices. Full reference is made to the relevant ISO documents, from which agreed definitions and methods have been adopted in ENVASSO where they exist and are appropriate.

The ENVASSO system for monitoring threats to soil in Europe is harmonised to provide consistent information on the state and trends of soil for developing policy at the European scale. The intention is that the same indicators could be used throughout Europe with the same units of measurement, following the same procedures and protocols. However, data availability and the access to material and equipment is not the same throughout Europe and, therefore, differences in specific technical details in the methods employed for deriving indicator values may differ as well. In the preferred methods, parameters, materials, and equipment are clearly identified as such and presented in black font. Alternative options are identified and displayed in grey font.

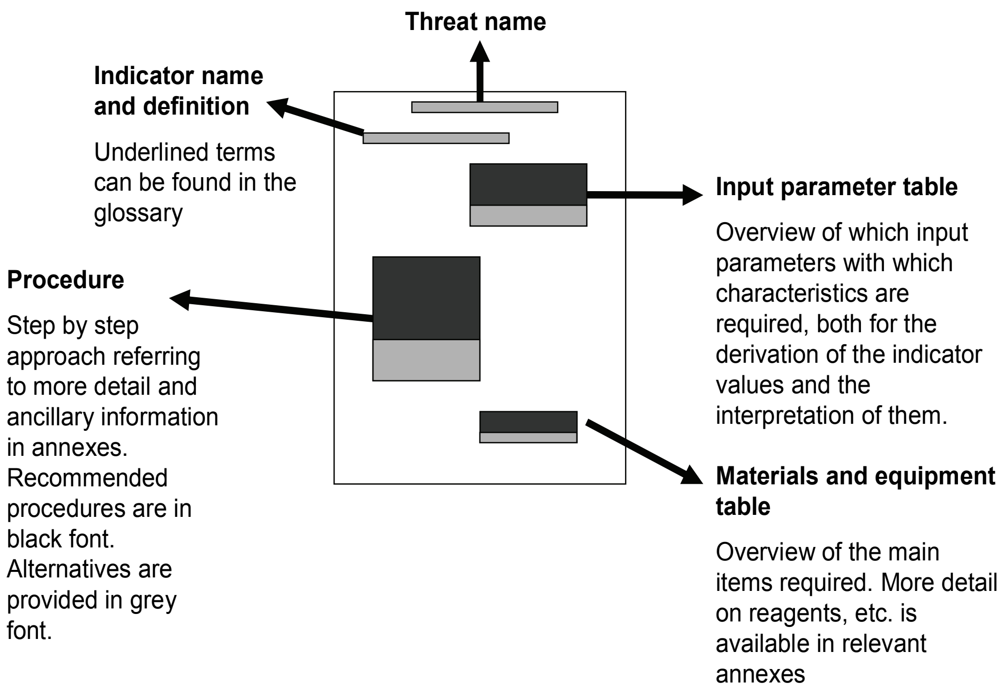

Figure 10: Template for the cover sheet of a procedure and protocol

The procedures and protocols for the indicators listed in Table 13 are fully defined in Volume V, whereas those listed in Table 14 need further research and/or evaluation before they can be implemented in a functioning soil monitoring system in Europe.

The results of indicator testing (Vol IVa & IVb) have provided the basis for assessing the status of each indicator, displayed as green, amber, pink, red or yellow in Volume V, the criteria adopted being as follows:

Green

1. Overall, indicator was applied successfully in the pilot areas
2. Monitoring could start tomorrow
3. Either no modifications of procedures & protocols required, or only some minor modifications/extensions

Amber

1. Indicator performance was partially successful in the pilot areas
2. Monitoring could not start tomorrow
3. With some structural modifications to the procedures & protocols monitoring could start within a year

Pink

1. Indicator performance showed major difficulties in one or more pilot areas
2. Monitoring could not start within a year

Red

1. Substantial technical/scientific progress is still required for this indicator to be monitored in a harmonised way throughout Europe, but is expected to be possible within 2-3 years,
2. Indicator was found to be unsuitable for harmonised monitoring at European level at the present time.

Yellow

1. Indicator already established and in use in some Member States; not selected for further testing by ENVASSO

6. Prototype Evaluation

6.1 Working Methodology

The prototype evaluation activities were based on using existing data in the Member States and were performed in pilot areas and study groups. Working plans and activities for pilot studies for each threat to soil were defined in small workshops guided by the work package leader and additional experts who were appointed as 'threat leaders'.

The main steps for the evaluation studies were as follows:

- Identification of ENVASSO experts to act as leaders for each threat
- Definition of Pilot Areas (PA) and identification of a leader for each pilot study
- Organisation of workshops to define data requirements and methods of evaluation
- Pilot area studies
- Evaluation workshops
- Preparation of pilot area study reports
- Preparation of summary reports for each threat
- Preparation of the prototype evaluation report (see Volume IVa)

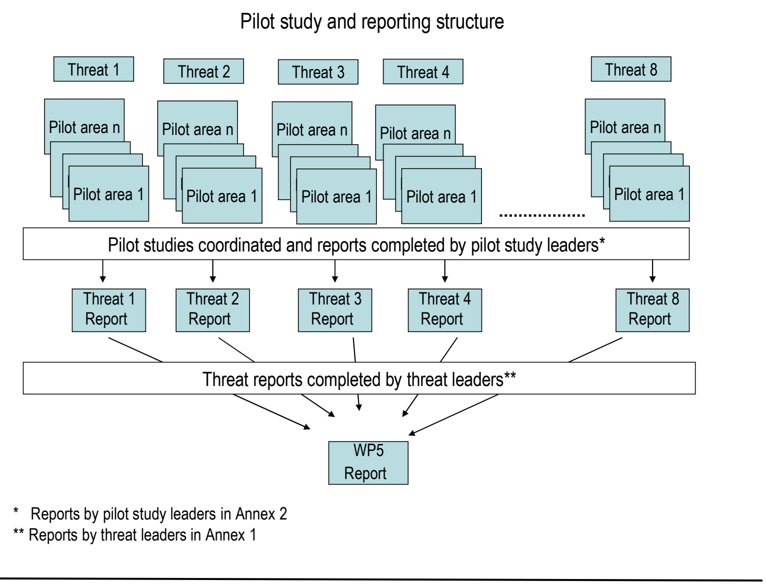

Figure 11: The structured approach adopted for indicator testing

The pilot area selection was based on the following criteria:

i) Availability of data of sufficient quality;
ii) Coverage of a wide variety of geographical;
iii) Climatic and land use conditions,
iv) Representing broad geographic distribution; and
v) Where possible use of transnational (trans-boundary) pilot areas.

The pilot results are documented in pilot area reports (see Volume IVb) and summarized in threat reports as illustrated in Figure 11.

6.2 Pilot Areas and Indicators Tested

The following sections describe the locations of the Pilot Areas (PA) selected and indicators tested within each Pilot Area.

6.2.1 Soil erosion

Pilot area (PA) studies on soil erosion were performed only for indicator ER01 (estimated soil loss by water runoff). The preferred ENVASSO method – PESERA_GRID model - for estimating soil loss by water erosion (ER01), was implemented in eight pilot areas (Figure 12, Table 4) representing a variety of climates, topography and parent materials. This proved successful in six areas, but final maps showing the distribution of soil loss were not produced for the pilot areas in Italy and Scotland.

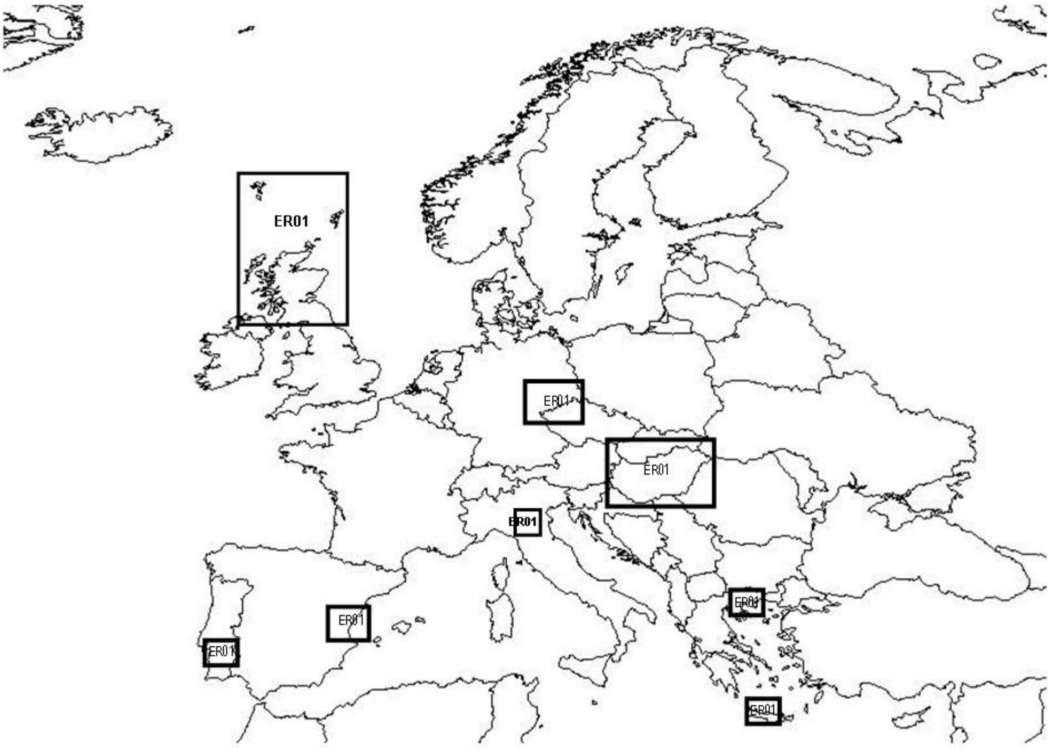

Figure 12: Pilot areas testing indicator ER01 for soil erosion

The different experience of partners who had used PESERA was discussed in-depth at the ENVASSO Final Consortium Meeting, held in Bordeaux in November 2008. All project partners involved agreed that the greatest challenge was compiling the input data to run the PESERA_GRID model, in part because data sources, scales, spatial resolution, and definitions were different between the Member States. A significant need was also identified for more detailed documentation about the coding and input of data, particularly for the soil parameters. Some improvements have been incorporated into the procedures and protocols for ER01 in Volume V.

Harmonisation is essential before meaningful comparisons can be made and to some extent this was achieved through visualising the results from the six PAs where PESERA was applied successfully. SoDa was not used because PESERA and other soil erosion estimation models require data to be formatted precisely, in accordance with bespoke programming structures. In future, it may be possible to use SoDa for data preparation and storage.

The indicator for estimated soil loss by wind erosion (ER03) was not tested by ENVASSO: models for wind erosion are less well developed and the input data needed are less available in Europe than those for water erosion. The third indicator selected, soil loss caused by tillage erosion (ER07), was not tested either because tillage erosion is field-based and the models that exist to estimate amounts of soil lost (e.g. Teron) are not appropriate for application at a European scale given the current availability of data on field management and micro-topography.

Table 4: Pilot areas testing indicators for soil erosion (ER)

Pilot Area, Institute (member state)	ER01	ER05	ER07
Vale do Gaio, INIAP (Portugal)	X		
Chania Crete, AUA (Greece)	X		
Philippi Macedonia, AUA (Greece)	X		
Valencia transect, CSIC-CIDE (Spain)	X		
Hungary, SIU (Hungary)	X		
Sheet Chemnitz , BGR-LfUG-CUA (Germany-Czech Rep.)	X		
Scotland, MLURI (UK)	(x)		
Samoggia, Emilia-Romagna, SGSS-RER (Italy)	(x)		

(x) Data for PESERA_GRID were compiled but no output map was produced.

6.2.2 Decline in soil organic matter

All three indicators for the threat 'Decline in Soil Organic Matter' were tested. The four pilot areas (Figure 13, Table 5) that performed the evaluations represent northern, Mediterranean and continental climatic conditions. One of the pilot areas was transnational and this allowed exploring issues and practices relating to data harmonization. In addition to testing of indicators OM01, OM02 and OM03, two additional special studies supported the evaluation; one with a broad literature study and comparative measurements of soil organic carbon determinations by different methods, and the other on methodologies for estimating the depth of peat layers.

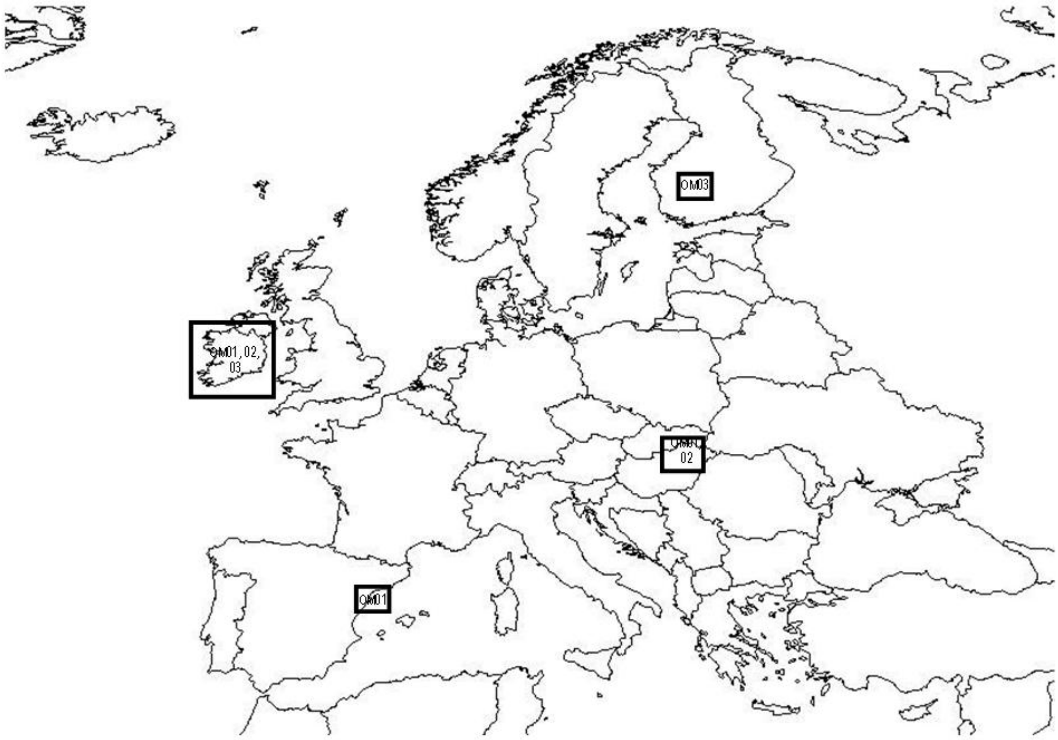

Figure 13: Pilot areas testing indicators for decline in soil organic matter

The indicator and method evaluations were successful and led to recommendations for improving methods. Where soil organic carbon content varies strongly with depth and especially where there is an organic-rich sub-surface horizon, sampling for OM01 can be in two depth increments (0-15 and 15-30 cm). When monitoring soil organic carbon stocks (OM2), additional steps are required: a second sample should be taken from the maximum depth of the first sample to a depth of 50 cm (possibly deeper for those soils with deep organic-rich horizons); volumetric stone content should be estimated and subtracted from the total soil volume.

Terminologies used for the threat description (OM for the threat, OC for the indicator) may cause confusion in interpreting the data. The pilot studies for OM03 concluded that further research or a new indicator is needed for estimation of peat stocks, mainly because of a gap in feasible and effective methods for describing the distribution of depths over larger areas.

Table 5: Pilot areas for testing indicators for decline in soil organic matter (OM)

Pilot Area, Institute (member state)	OM01	OM02	OM03
Orivesi, MTT (Finland)			X
Republic of Ireland, TEAGASC/UCC (Ireland)	X	X	X
Terres de l'Ebre and Ebro Delta, SARA (Spain)	X		
Bodrogköz (transnational), UNIMIS-SSCRI (Hungary-Slovakia)	X	X	

6.2.3 Soil contamination

For soil contamination, four pilot areas (Figure 14, Table 6) were selected for indicator evaluation, one being transnational. Since soil contamination is not climatically or environmentally specific, selection of the pilot areas was based only on data availability and access. Three pilot studies evaluated CO01, and two studies evaluated CO08. All of the pilots were successful in testing the ENVASSO procedures and protocols for soil contamination.

However, a generic problem was identified: a wide range of different testing methods and spatial sampling strategies and densities have been used to monitor heavy metal contents, making their harmonisation difficult. The transnational pilot area was especially useful in this regard, because it illustrated the difficulties of harmonizing data produced by different institutions using different sampling strategies, sampling depths, testing procedures and data analyses.

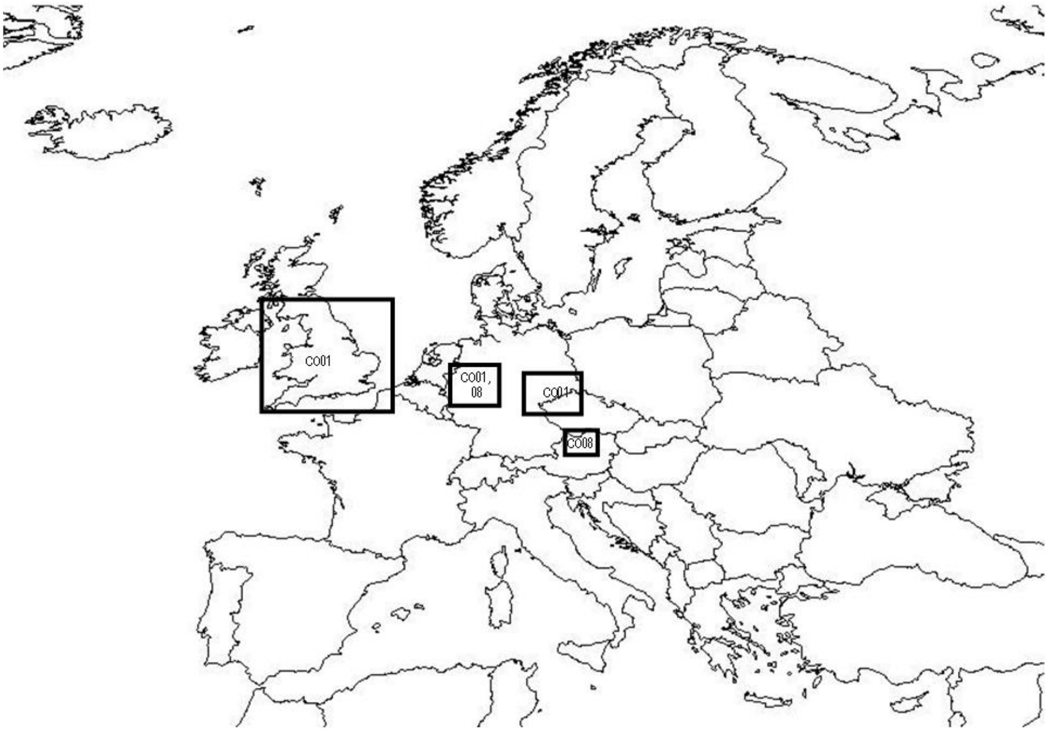

Figure 14: Pilot areas testing indicators for soil contamination

An important conclusion of these pilot studies was that geo-statistical methods should be applied to eliminate data for areas with excessive anthropogenic contamination (i.e. local soil contamination), when estimating background/baseline values and making comparisons with threshold values. A special study was performed on the alternative methods for estimating background concentrations of heavy metals in soil, using data from the United Kingdom and Slovenia: this underlined the importance of rigorously defining the specific meaning of ‘background’ depending on the purpose of its assessment.

Table 6: Pilot Areas testing indicators for soil contamination (CO)

Pilot Area, Institute (member state)	CO01	CO07	CO08
Ruhr Area, LANUV (Germany)	X		X
1:250,000 Sheet Chemnitz, BGR-LfUg-CUA (Germany – Czech R.)	X		
City of Linz and Surrounding Area, UBA (Austria)			X
England and Wales, CU (United Kingdom)	X		

ENVASSO adopted the methodology for CO07 from the ICP 'Manual of Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution'. Monitoring of this indicator is well established in several EU Member States and therefore CO07 was not tested by the ENVASSO Project.

6.2.4 Soil sealing

The evaluation of the indicators for soil sealing was performed on four pilot areas with one transnational pilot area (Figure 15, Table 7). Three studies evaluated the applicability of SE01 and two of them evaluated the land take percentage (SE04). The third indicator SE05 (percentage of new settlement area established on previously developed land) was not evaluated due to a lack of access to the necessary data. However, an additional indicator SE03 (land consumed by settlements and transport infrastructure) was evaluated in two pilot areas.

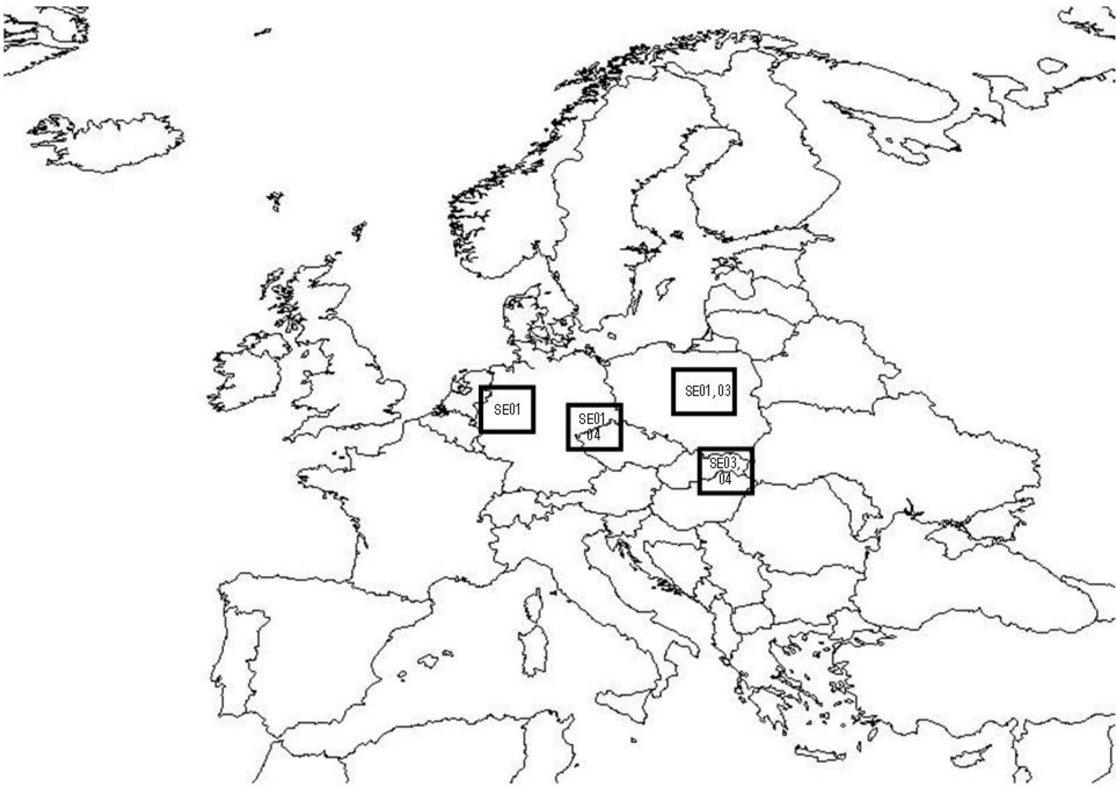

Figure 15: Pilot areas testing indicators for soil sealing

The results showed that successful indicator estimation and data harmonization depend on the heterogeneity of the source materials. Direct measurements of sealed area are time-consuming and costly, so models based on topographic maps, satellite images and cadastral data are recommended.

Table 7 Pilot Areas for testing soil sealing (SE)

Pilot Area, Institute (member state)	SE01	SE04	SE05	SE03
Warsaw, WUT (Poland)	X			X
North Rhine Westphalia, LANUV (Germany)	X			
Chemnitz, LUA (German part)	X			
Chemnitz, CUA (Czech part)		X		
Bodrogköz, UNIMIS (Hungary)		X		X

6.2.5 Soil compaction

Indicators of soil compaction were tested and evaluated within two pilot areas (Figure 16, Table 8). The testing and evaluation of the TOP3 indicators were successful and this was complemented by testing of a further 3 indicators (CP03, CP04, CP05) and also with indirect models.

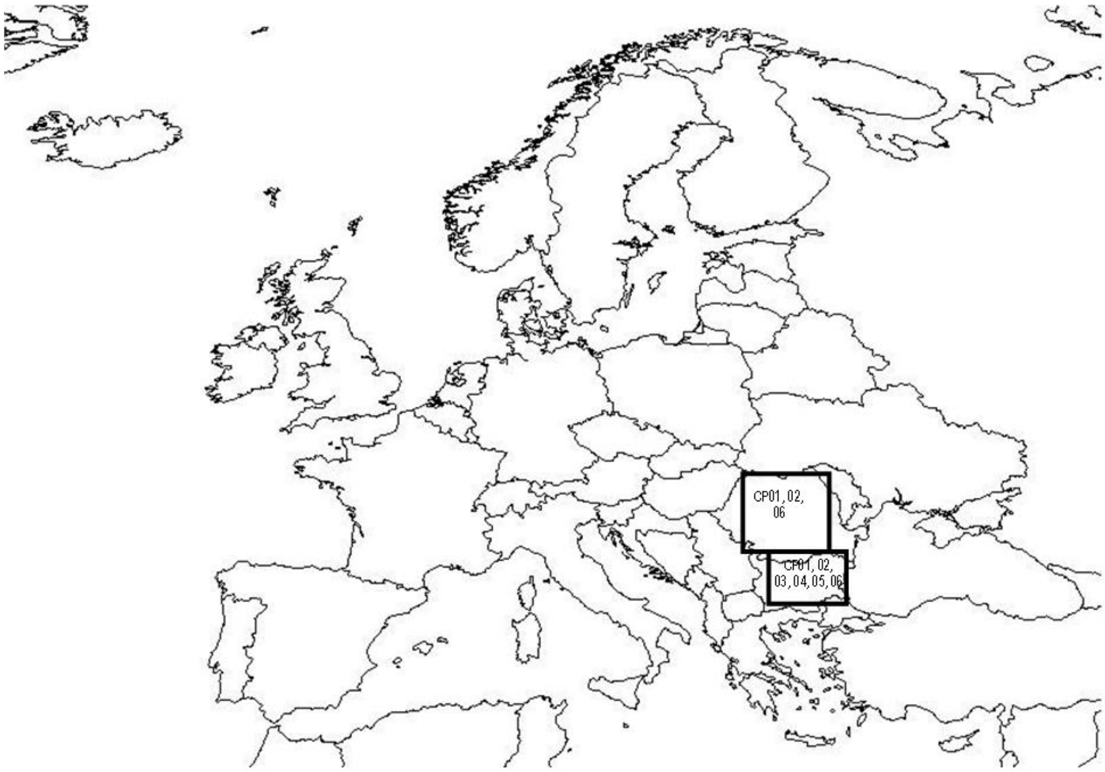

Figure 16: Pilot areas testing indicators for soil compaction

The pilot studies concluded that measured and modelled data provide different results and that the vulnerability indicator (CP06) should be further refined with respect to climatic conditions. It was also noted that the ENVASSO indicators consider mainly topsoil parameters, but subsoil compaction is very important because it greatly influences soil the functions.

Table 8: Pilot Areas testing indicators for soil compaction (CP)

Pilot Area, Institute (member state)	CP01	CP02	CP06	CP03, CP04, CP05 Indirect methods
Tsalapitsa, ISSNP (Bulgaria)	X	X	X	X
Romania, ICPA (Romania)	X	X	X	X

As for other threats, it was confirmed that geo-statistical techniques should be used to specify sampling and support analysis of results.

6.2.6 Decline in soil biodiversity

The three selected indicators for decline in biodiversity were all tested and evaluated. Two PAs tested all three and one PA tested two of the indicators (Table 9). The three pilot areas performed detailed evaluations (Figure 17). Beside the pilot studies, special contributions on methodology and additional data analyses supplemented the ENVASSO prototype evaluations.

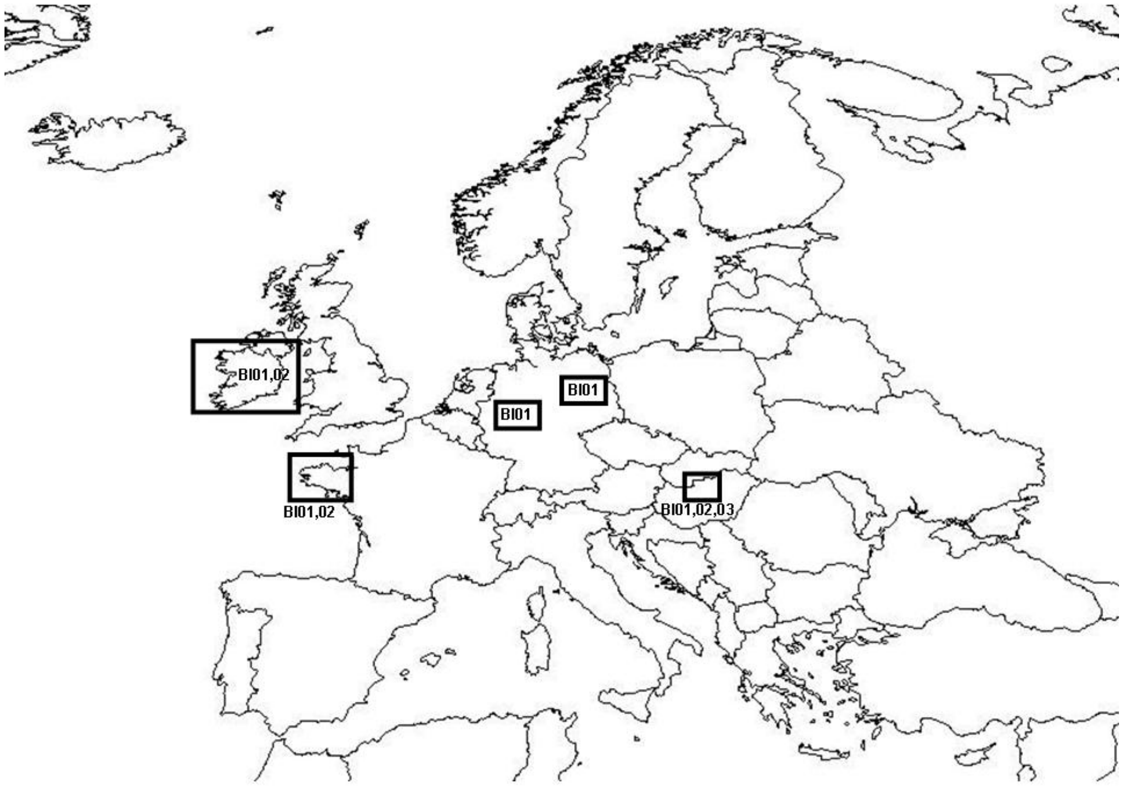

Figure 17: Pilot areas testing indicators for decline in soil biodiversity

The procedures and protocols were found to be feasible and applicable. However, a systematic harmonized sampling (period, size, method etc.) is necessary for the main soil types and land uses across Europe, before drawing firm conclusions on baselines and thresholds. The development of a common presentation of the results was also recommended.

Table 9: Pilot Areas testing indicators for decline in soil biodiversity (BI)

Pilot Area, Institute (Member State)	BI01	BI02	BI03
RMQS Biodiv, ADEME (France)	X	X	X
Józsefmajor, SIU/RISSAC (Hungary)	X	X	X
Republic of Ireland, TEAGASC/UCD (Ireland)	X	X	

SoDa was tested and special requirements for biodiversity data structure and data presentation were identified for the system.

6.2.7 Soil salinisation

Testing and evaluation of the indicators for soil salinisation was made in three pilot areas (Figure 18). Two of them were transnational (Romania, Hungary), where soil classification and methodology harmonization were performed as well. The testing of indicators SL01 and SL02 were successful (Table 10). It was concluded that the sources of the salts are important in the definition of sampling periods and depth.

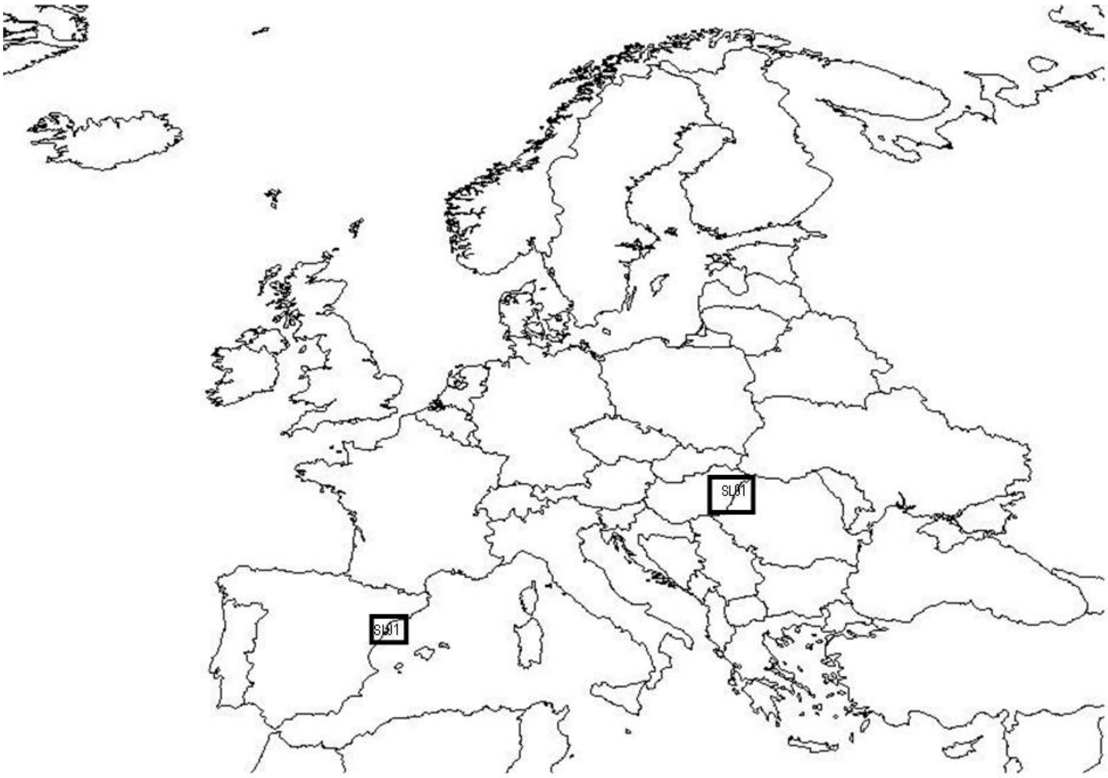

Figure 18: Pilot areas testing indicators for soil salinisation

It was concluded that further specification was needed before qualification of indicator SL03. In addition to the proposed ENVASSO methods, electromagnetic sensor-based measurements for salinity monitoring were performed successfully in the Spanish pilot area. Hence it is suggested that this additional method be referenced on the ENVASSO Procedures and Protocols (D9) to complement the analytical methods.

Table 10: Pilot Areas testing indicators for soil salinisation (SL)

Pilot Area, Institute (member state)	SL01	SL02	SL03
Körös-Berettyó Basin, RISSAC/ICPA (Hungary)	X	X	
Oradea region (Bihor county), ICPA (Romania)	X	X	
Northern bank of Ebro Delta, Catalonia, SARA (Spain)	X	X	

6.2.8 Landslides

A lack of data and expertise available to the ENVASSO consortium meant that only one indicator LS01 (occurrence of landslide activity) was tested in a single pilot area (Figure 19, Table 11), the Samoggia catchment of Emilia-Romagna in Italy.

Figure 19: Pilot areas testing indicators for landslides

Nevertheless the assessment, using a locally developed methodology, was judged to work well. The study also identified the different types of landslides.

Table 11: Pilot Areas testing indicators for landslides (LS)

Pilot Area, Institute (Country)	LS01	LS02	LS03
Samoggia, Emilia-Romagna, SGSS-RER (Italy)	X		

A crucial point is the scale of monitoring as the Samoggia study used a spatial resolution of 100 m which may not be feasible or appropriate at a continental scale.

6.2.9 Desertification

For desertification only the indicator DE01 (land area at risk of desertification) was tested, using the MEDALUS model. Three pilot areas (Figure 20, Table 12) tested the model successfully at different scales. The conclusions were that more development is needed of standard procedures for data specification to allow integration of data into a GIS mechanism. Input data harmonisation is also an important requirement for comparing results for different regions.

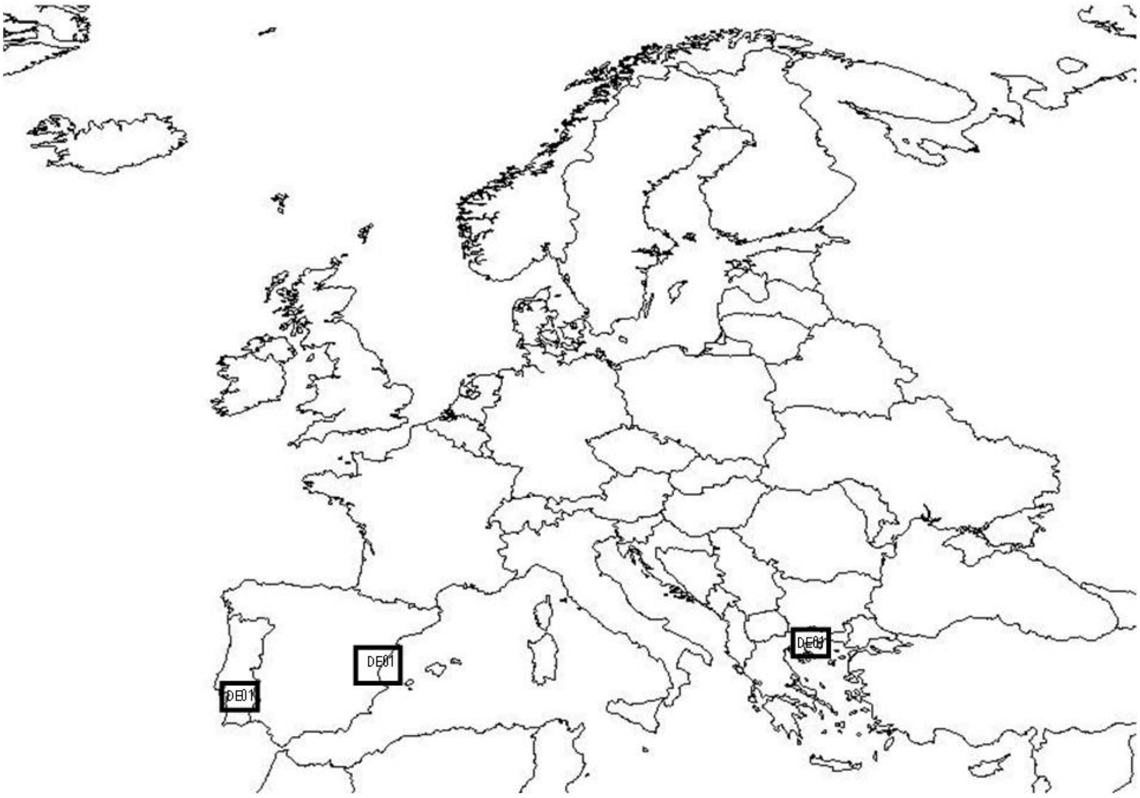

Figure 20: Pilot areas testing indicators for desertification

It was also noted that land impact of forest fires can vary more broadly than the ENVASSO indicator DE02 ‘land area burnt by wild fire’ expressed in km^2 yr^{-1} may suggest.

Table 12: Pilot Areas testing indicators for desertification (DE)

Pilot Area, Institute (Country)	DE01	DE02	DE04
Transect North of Valencia, CSIC (Spain)	X		
Vale do Gaio watershed, INIAP (Portugal)	X		
Philippi-Macedonia, AUA (Greece)	X		

It is recommended that further research is conducted on the relatively complex interpretation of impact and resilience. Indicator DE04 (topsoil organic matter content in desertified land) was evaluated, but in relation to the threat ‘decline in soil organic matter’ (see Section 6.2.2).

6.3 Conclusions and Recommendations

The testing of the indicators in the 28 pilot areas was successful and provided highly relevant practical conclusions that are valuable to support the ENVASSO recommendations for a harmonized Soil Monitoring System for Europe. Most indicators for the eight threats defined in the European Thematic Strategy for Soil Protection performed well and were judged to be applicable at the European scale. In some cases, specific modifications or changes were suggested and subsequently included in the Procedures and Protocols described in Volume V.

Several pilot studies (mainly the transnational ones) concluded that data sources (methods, scale, etc.) vary between countries to the extent that harmonisation of results is difficult. The development and application of geo-statistical principles in sampling and analyses are important in the evaluation, harmonisation and presentation of monitoring results. SoDa performed well for those indicators that were not based on models. It offers a good potential as foundation for establishing a common data platform and tool for data harmonisation.

7. Soil Monitoring System for Europe

7.1 Introduction

The body of work that is the end result of the ENVASSO project builds on that of the Technical Working Groups formed under the EC Thematic Strategy for Soil Protection (Van Camp *et al.* 2004a-f), in particular the Technical Working Group Monitoring that compiled meta-information. ENVASSO has expanded this output substantially, both by further collation of existing information and also by developing and testing of methods for a set of priority indicators. The result is a documented set of procedures and protocols constituting a design for a European Soil Monitoring System (ESMS) and technical proposals for its implementation.

With regard to the draft Soil Framework Directive, a harmonised monitoring scheme needs to be implemented across the European Union to:

- inform the assessment of risk/priority areas for threats to soil resources
- evaluate the effectiveness of risk management measures adopted within risk/priority areas
- define baseline soil conditions and provide information on trends
- provide data for modelling the impact of changed land management and climate change on soil resources and the functions which they provide for European citizens
- contribute to related reporting requirements (e.g. Water Framework Directive, CAP/cross compliance, UNFCCC, UNCCD)
- support European environmental assessments.

7.2 Design recommendations

7.2.1 Qualification of indicators for implementation

A literature review identified and described a large number of potential indicators related to issues relevant to threats to soil. Using a formal process and with the objective of identifying a set of priority indicators, 27 indicators have been selected that provide effective coverage of issues linked to threats (except flooding) as well as desertification. The non-selected indicators include many that remain useful for more detailed monitoring such as might be needed to inform management of locally predominant threats.

The majority of the indicators selected as priority ones (see Table 13) has been qualified for implementation within an ESMS in terms of having:

- an agreed definition
- an agreed measurement methodology
- been tested in a pilot trial.

Within the scope of the project it was not possible to establish new monitoring activities, but the ENVASSO procedures and protocols have been tested by conducting trials using data from existing schemes covering representative regions and land uses in a majority of Member States, with the inclusion of some transnational trials to directly assess challenges to European harmonisation. Although these existing schemes use approaches which do not fully correspond to international standards (e.g. soil nomenclature World Reference Base 2006 (FAO, 2006), or ISO methods), account was taken of these non-conformities in the ENVASSO evaluation.

Based on evaluation following the trials, 20 indicators have been qualified for potential inclusion in an operational ESMS, covering the threats of soil erosion, decline in soil organic matter, soil contamination, soil sealing, soil compaction, decline in soil biodiversity, soil salinisation and desertification. The performance of these indicators has been judged to be sufficient to support their application now, although gaps remain which could not be filled within this project, specifically including:

- the need for formal agreement on standard methods for some parameters and the adoption of existing procedures in some Member States
- insufficient auxiliary data of necessary quality (e.g. climatic data for erosion modelling).

Table 13: Qualified ENVASSO indicators

Threat / Issue	Ind_No.	Indicator Name
Soil erosion		
Water erosion	**ER01**	Estimated soil loss by rill, inter-rill, and sheet erosion
Decline in soil organic matter		
Soil organic matter status	**OM01**	Topsoil organic carbon content (measured)
	OM02	Topsoil organic carbon stocks (measured)
Soil contamination		
Diffuse contamination	**CO01**	Heavy metal contents in soils
	CO07	Critical load exceedance by S and N
Local contamination	**CO08**	Progress in management of contaminated sites
Soil sealing		
Soil sealing	**SE01**	Sealed area
Land consumption	**SE04**	Land take [to urban & infrastructural development]
Brownfield re-development	**SE05**	New settlement area established on previously developed land
Soil compaction		
Compaction and structural degradation	**CP01**	Density
	CP02	Air-filled pore volume at specified suction
Vulnerability to compaction	**CP06**	Vulnerability to compaction
Decline in soil biodiversity		
Species diversity	**BI01**	Earthworm diversity and biomass
	BI02	Collembola diversity
Biological functions	**BI03**	Microbial respiration
Soil salinisation		
Salinisation	**SL01**	Salt profile
Sodification	**SL02**	Exchangeable sodium percentage
Potential salinisation/ sodification	**SL03**	Potential salt sources
Desertification		
Desertification	**DE01**	Land area at risk of desertification
Desertification	**DE02**	Land are burnt by wildfire

See Section 5, p.44, for full description of indicator categorisation

Monitoring could start tomorrow (ER01 excluded: green) · Monitoring could start in < 1yr (orange) · Already established & in use (yellow)

Measurement methods are not available or could not be adequately specified for a small number of the selected indicators (see Table 14), which would allow their inclusion for monitoring within a year. Substantial scientific/technical progress is still needed before several of these indicators could be included in monitoring programmes, but it is expected to be possible within 2-3 years.

Research is needed to evaluate methods for estimating wind and tillage erosion because the number of quantitative studies within Europe of these forms of soil erosion is limited and not conclusive in terms of optimum methodology. These forms of erosion are locally significant depending on soil type, topography and cultivation and need to be quantified better.

Table 14: Non-qualified ENVASSO indicators

Threat / Issue	Ind_No.	Indicator Name
Soil erosion		
Wind erosion	**ER05**	Estimated soil loss by wind erosion
Tillage erosion	**ER07**	Estimated soil loss by tillage erosion
Decline in soil organic matter		
Soil organic matter status	**OM03**	Peat stock
Landslides		
Landslide activity	**LS01**	Occurrence of landslide activity
	LS02	Volume/mass of displaced material
Landslide vulnerability	**LS03**	Landslide hazard assessment

See Section 5, p.52, for full description of indicator categorisation

Monitoring could start in < 1yr | Monitoring could not start within 1yr | Substantial technical/scientific progress still needed

Peat stocks represent a large and important reservoir of terrestrial organic carbon and better estimation of these stocks as well as monitoring of trends is critical for future management of organic carbon in European soils. The pilot trials conducted within ENVASSO have identified quite severe problems for robust estimation of carbon stocks within peat, including:

- a lack of reliable methods for estimating the depth of peat at landscape scales
- the variability in peat composition, within the profile and across the landscape
- the design of sampling which delivers representative data for especially lowland peats that often present as linear landscape features and so may be under or over sampled by grid-based sampling approaches.

Although a pilot for the indicator LS01, occurrence of landslide activity, was completed successfully, this was only possible because detailed historical data had been collated for the region. Such data are thought to be quite rare, which suggests that implementation at a continental scale may not be feasible at present.

7.2.2 Specifications for a European Soil Monitoring Network

The establishment of a soil monitoring network (SMN) – comprising a network of sites that are geo-referenced, characterised and at which a qualified sampling process is conducted - is foundational to the realisation of an European Soil Monitoring System (ESMS). A two-tiered approach is proposed for an ESMS, with the second tier comprising a sub-set of first tier sites for which there is a more extended and intensive monitoring activity, together with larger reference ones, such as small watersheds for erosion monitoring. This approach has already been shown to be efficient within the UN/ECE ICP forests monitoring scheme.

First-tier network

ENVASSO recommends a minimum spatial density for first tier sites of 1 per 300 km^2, which corresponds approximately to the density achieved by implementing a regular grid with sampling sites 16 to 17 km apart. Whether the proposed density of sampling plots is realised through a grid-based design or stratified sampling-based modelled approach can be decided on a case-by-case basis. Within ENVASSO, the objective was to describe an approach that would be representative of soil types and land uses at the continental scale (roughly corresponding to 1:1,000,000 or +/- 1 km). The spatial density of sampling that has been proposed will ensure that almost all soil type and land use combinations in Europe will be represented. Further work is needed to assess whether the proposed density of sites provides sufficient replication.

While it is important to fully explore options for coordinating an ESMS network with others (such as those that may be established to support implementation of the Water Framework Directive), to avoid duplication and encourage congruent outcomes, care is needed to avoid compromising effectiveness. In particular, there is a risk when using sampling sites established for another purpose that may not be sufficiently representative of soil types, land uses and their combinations.

When establishing new monitoring sites, it is recommended that some preliminary studies are made to characterise landscape and within-site heterogeneity and so inform an optimal choice of sampling strategy and techniques, bearing in mind that the sites within an ESMS will need to be sampled in the field and also assessed remotely, for example to determine current land cover.

The field sampling protocols, applied at each monitoring site, are critical. ENVASSO recommends that the area sampled should be between 100 m^2 and 1 ha and be homogeneous in terms of soil profile development. Within the site area, a minimum of 4 sub-samples for every 100 m^2 of sampling area should be taken, with greater sampling densities depending on the extent of soil profile variation due for example to varying hydrological conditions. The exact location from which sub-samples are taken should be recorded and these should be avoided in subsequent sampling events. To assist standardisation, ENVASSO recommends that samples are taken as cores from the surface to a fixed depth with pedogenic horizon sampling within adjacent profile pits to support site characterization.

The time interval between sampling events needs to be long enough to allow for changes that can be detected within measurement errors. A time interval of less then 10 years would not be sufficient to detect change in most indicators, and longer intervals would be required to detect changes in others. An important consequence of this is the required longevity of soil monitoring systems if they are to provide useful information that requires institutional stability.

The ENVASSO procedures and protocols documented in Volume V recommend methods of sample preparation and testing. The most serious barrier identified, which limits the harmonisation of data from existing SMNs, is the wide variety of testing methods that have been employed historically. There are some opportunities for harmonising data, which has been collected using different testing methods, for example by regression analysis, but these are limited. There is a critical need to adopt standard testing methods, ideally those recommended by ENVASSO, which in many cases have ISO status. In addition, the proficiency of different laboratories when performing the same methods varies considerably and to control inter-laboratory variation a combination of quality measures must be introduced and sustained, including the use of available reference materials and inter-laboratory proficiency trials.

Second-tier network

The purpose of the second-tier is to address requirements that cannot be implemented feasibly at the first tier, or for which only a smaller set of sites needs to be investigated, because:

- the measurement procedures are too demanding (e.g. some biological, gaseous flux and physical measurements including measurement of soil erosion)
- highly intensive sampling is needed to characterise processes that allow interpretation of indicator trends (e.g. detailed assessment of sub-soil and lower horizons, connectivity to landscape processes such as catchment inputs and outputs)
- special investigations of error sources (e.g. intensive collection and testing of sub-samples are needed to determine an optimum number for application in the first tier)
- proficiency exercises are insufficient, to assess variability associated with different field teams (e.g. estimates of stone contents and texture).

An important additional purpose of a second tier network of an ESMS is to provide a set of reference or benchmark sites for soil typological units (STUs). These are required for:

- training in STU identification and description to support its harmonised application
- reference indicator measurements to corroborate modelled indicator estimates.

7.2.3 Data collation, management and reporting

Within ENVASSO, the SoDa system has been designed and tested. This supports a structured entry and validation of data as well as its analysis and reporting for indicator estimation, at Member State and European scales. Our experience is that this is an essential tool to ensure that data are complete and of known and documented quality. However, the approach taken should be one of both data providers and users being increasingly connected, so that original data and all supporting information are fully available to the user. Current European scale soil databases were created and populated long before the development of web-based interoperability. At that time, it was essential to harmonise data entry to a centralised database according to prescriptive and limited standards. The result is that the collated datasets are not easily updated, some information of value has been discarded and errors in transcription and validation are unavoidable.

SoDa is a tool for allowing a high degree of connectivity which makes progress towards overcoming these difficulties by accommodating differences in the existing databases at member state scale, while ensuring that the underlying data structure is maintained. Rapid technological advances in web-based database development and delivery means that important and valuable opportunities are emerging for developing SoDa, which is operational, but, in essence, a development prototype. This may be regarded as one of the most significant strategic opportunities available for increasing the extent, quality and availability to citizens of soil information in general, and of soil monitoring information specifically.

7.3 Implementation recommendations

7.3.1 First phase

There are two types of indicators that are more easily implemented within an ESMS. Firstly, there are those where ENVASSO has identified a widespread existing network of measurements.
This group includes:

- *topsoil organic carbon contents,*
- *heavy metal contents in soils*
- *critical load exceedance by sulphur and nitrogen.*

Secondly, there are indicators which rely either directly on existing remote-sensed data or use these data and other available information held in European and Member State geographical databases to model indicator estimates, or can be inferred from combining other data. This group includes

- *estimated soil loss by rill, inter-rill and sheet erosion,*
- *sealed area*
- *land take*
- *vulnerability to compaction*
- *land area at risk of desertification*
- *land area burnt by wild fire.*

In addition, there is a group of indicators for the threat of salinisation that are already widely implemented in those Member States and regions where this threat exists.
This group includes

- *salt profile*
- *exchangeable sodium percentage*
- *potential salt sources*

Taken together, these three groups of indicators provide a basis for partial monitoring of the threats soil erosion, decline in soil organic matter, soil contamination, soil sealing, soil compaction, salinisation and desertification. It is recommended that these qualified and more easily implemented indicators are included in the first phase of an operational ESMS.

7.3.2 Second phase

Apart from those indicators that are not qualified (see table 2), others pose operational challenges. Two indicators rely on administrative rather than scientific measures and their implementation within an ESMS depends on institutional procedures which are not present in all member states and that would require harmonisation.

- *Progress in the management of contaminated land* can only be assessed where there are existing inventories of contaminated land sites, which is only the case in certain Member States and regions. The development of such registers is envisaged within the draft Soil Framework Directive but is not anticipated in all member states in the near future.

- Similarly, *new settlement area established on previously developed land* can only be assessed where there is an inventory of such land, but this is not widely available or harmonised.

Pilot trials conducted within ENVASSO have demonstrated that some of the qualified indicators are viable, but relating point measurements to estimates of their general value in that landscape introduces uncertainty. Furthermore, measurement of these indicators is resource intensive.

The relevant indicators are
- *soil bulk density*
- *air capacity*
- *earthworm diversity*
- *Collembola diversity*
- *soil microbial respiration.*

An option for implementing these indicators within an ESMS may be to establish a relatively small number of reference sites and this is discussed below.

7.4 Establishment of a European Soil Monitoring Network

As discussed above, geo-referenced sampling sites are a basic requirement, at which field and remotely-sensed parameters are measured and for which indicator values are estimated. For the first time as a result of the ENVASSO project, a comprehensive picture has emerged of the main SMNs in the European Union. The existing SMNs in Member States are heterogeneous, together with existing European-wide networks such as ICP Forest Level I and II and BioSoil (under Forest Focus). In reality, the majority of these SMNs are strictly only inventory networks because the soils have been sampled only once. Nonetheless, the investment already made in these SMNs is large and the data collected from them at historic dates is valuable for estimation of baselines and, after re-sampling, of trends. This opportunity is of particular value when account is taken of the generally slow rates of change in soil properties, at least at landscape up to continental scales. It is recommended that an approach is taken that allows at least the majority of the existing Member State SMNs to be included. At present, the greatest disparity is between grid-based and stratified random sampling, for example on the basis of land use.

Within an ESMS, SMNs should be qualified for each Member State according to the following criteria:
- the overall spatial density of sites should not be less than 1 per 300 km^2
- sites should either be located at nodes of a grid or be selected using a rigorous random stratified sampling approach (the sites should not simply be existing sites that have been brigaded in to a sampling scheme without proper randomisation). This approach can also be applied to existing systems; it provides a basis to select sampling plots from a set of existing plots within the strata of interest; it also helps to identify strata for which additional sites are required.
- sites should be fully characterised, specifically the dominant soil profile should be described fully within the World Reference Base (WRB) system
- where already established in an inventory, qualified sites must be accurately georeferenced and past land use documented.

In the longer term, to support harmonisation and representativeness and to more effectively accommodate new requirements such as indicators for future threats, it is recommended that a systematic grid is extended across the European Union, which may most efficiently be achieved by extending the existing 16 km by 16 km forest SMN to non-forested land or by selecting a sub-set of existing nodes within finer grid-based SMNs in the Member States.

7.5 Advanced sampling and data processing techniques

Land use change is among the factors influencing soil conditions most strongly. Even for large-scale systematic plot-based monitoring systems, remotely sensed land use data can help to regularly update field data, and to guide optimal timing of re-sampling. Moreover, certain indicators can be assessed best by remote sensing, such as those for soil sealing and desertification.

Land use data combined with soil map data provide a basis for interpreting plot monitoring data at regional or larger scales, as is a common requirement to meet policy needs. In particular such exercises are likely to be required to support delineation of risk areas for soil threats as envisaged in the draft Soil Framework Directive.

Modern environmental monitoring techniques offer increasingly powerful mechanisms to collect and process digital soil data to produce accurate, consistent and rapid results. These techniques include non-invasive sampling, smart sampling (where the location and timing of physical sampling action is determined by a non-invasive method or observation of particular events), automated sampling, 'on-the-go' sampling (using devices attached to tillage implements) and remote sensing. Automated sampling encompasses the application of novel soil sensors, such as near-surface geophysical sensors (e.g. electromagnetic conductivity meters and ground penetrating radar) combined with geographic positioning systems (GPS). Such methods offer the option of frequent observation of SMN sites, to derive temporal information about variability in soil conditions. The same holds true for smart sampling, which supports the matching of sampling to the variability of topography and soil conditions to improve effectiveness and efficiency.

Both policy and research have detected the great potential of combining and presenting geo-data from various sources through spatial data infrastructures (EC 2007). Present and future information systems should support distributed systems providing interoperable information for web-based data accessibility and exchange. Such data can be made available to environmental observation or early warning systems. For example, with regard to soils, the European GEO-initiative work plan intends that national and regional data are combined to a geo-spatial data infrastructure targeted to provide a data platform for agricultural monitoring.

7.6 Harmonisation of monitoring data

Most national soil inventory data are based on methods that have not been agreed internationally. Therefore, specific harmonisation processes and systems are needed to establish a European Soil Monitoring System (ESMS). However, the extent of harmonisation achieved will depend largely on the degree of compliance with agreed procedures and protocols. Nevertheless, several approaches applicable for developing a harmonised framework for large-scale soil monitoring do exist in Europe. In particular, one which comes closest to the requirements proposed by ENVASSO is the UN/ECE Level 1/BioSoil monitoring for forest soils; EC regulation No.2152/2003 provides for a "Community scheme for broad-based, harmonised and comprehensive long-term monitoring of the conditions of forests" (UN/ECE ICP Forests, 1994).

Existing programmes related to soil monitoring in Europe include:

- Soil mapping 1:1,000,000 (Lambert et al., 2001)
- Soil mapping 1:250,000 (Finke et al., 1998 [updated 2001])
- UN/ECE ICP Forests (UN/ECE ICP Forests, 1994, 2006; FSEP and FSCC, 2003 and 2006)
- UN/ECE ICP Integrated Monitoring (ICP IM Programme Centre, 2004)
- World Reference Base for Soil Resources WRB (1998, 2006) according to of the FAO Guidelines (1990, 2006).

It is clear from experiences of monitoring (UN/ECE), soil mapping (ESBN) and classification (FAO) schemes, that guidance and coordination are essential. Successful establishment of an ESMS will require a programme coordination centre and expert panels that have proved to be essential within the UN/ECE monitoring programmes.

This coordination infrastructure is needed to provide coordination, communication and methodical agreements in respect of:

- Manual adjustments and adaptation
    - Quality analysis and quality control:

    - Training (to reduce systematic bias during classification and sampling)
    - Coordination of proficiency testing (inter-laboratory comparisons)
    - Design and application of plausibility checks and evaluation routines
    - Integration and application of reference systems to adapt data described using different nomenclatures
- Data interpolation and re-calculation (adjusting data coming from different sampling campaigns over time)
- Agreement on data structures and exchange formats

With respect to soil sampling and classification, the general descriptions of sites (including land use, landscape, climate, vegetation, etc.) should follow the FAO Guidelines for soil description (2006) while classification of soils should follow the WRB (2006).

In summary, the experience within ENVASSO of comparing data and methods applied amongst 37 partners leads to the conclusion that harmonisation of both field sampling and testing procedures requires more infrastructure than can be achieved through simple collaboration. There is a need for training, central document and quality control, a well-maintained database and supporting advice, as well as method development (evaluation and harmonization), manual development, calibration, central archiving and reporting. This infrastructure will be secured more easily if a European centre is established to provide this essential infrastructure as well as acting as a reference laboratory for soil testing.

7.7 Summary

ENVASSO has been successful in reaching its objective, i.e. to describe a common framework to enable a progressive harmonisation of current and future soil monitoring activities in EU Member States. A comprehensive effort of reviewing the state-of-the art in soil science, combined with European-wide expert judgement, has delivered 27 priority indicators. Subsequent testing of these indicators on existing data in 34 pilot studies across Member States, including a number of transnational ones, has demonstrated the feasibility for implementation of the priority indicators. Twenty priority indicators were shown to be qualified and ready for inclusion in an operational soil monitoring system, covering the threats of Soil Erosion, Decline in Soil Organic Matter, Soil Contamination, Soil Sealing, Soil Compaction, Decline in Soil Biodiversity, Soil Salinisation and Desertification.

The performance of these indicators has been judged to be sufficient to support their early implementation within an operational soil monitoring system. However, there remain some relatively minor gaps that could not be filled within the ENVASSO Project. Priority indicators that could not be qualified at present include those for: wind and tillage erosion; peat stocks; landslides; re-use of previously developed land and progress in the management of contaminated land. ENVASSO recommends a concerted research effort by the scientific community focussing on the parameters, processes and model development in order to fill these gaps, so that these aspects of threats to soil can also be monitored robustly in the future.

The ENVASSO inventory of monitoring systems and data provides the most exhaustive review of European soil monitoring networks (SMN) to date. Harmonisation and coordination are essential, to achieve a minimum density of 1 site per 300 km². For many Member State SMNs new sites will be required. Indeed, considerable efforts are still needed to reach a common and acceptable standard of soil monitoring in Europe, based on a framework supporting harmonisation that allows data interpretation linked to geographical databases. The SoDa database and the ENVASSO Procedures and Protocols (Volume 5) form a good first basis to start a European Soil Monitoring system.

In conclusion, ENVASSO has developed a system to harmonise existing, mostly national soil monitoring networks and databases, to form a European-wide reference that can assess current and future soil status and support the sustainable management of soil resources. The participation in the ENVASSO Project, of leading national soil institutes in each Member State (EU 27) and Norway, will prove to be a major asset, facilitating any future implementation of a European Soil Monitoring system.

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Abstract
The ENVASSO Project (Contract 022713) was funded under the European Commission 6th Framework Programme of Research, 2006-8, with the objective of defining and documenting a soil monitoring system appropriate for soil protection at continental level. The ENVASSO Consortium, comprising 37 partners drawn from 25 EU Member States, reviewed almost 300 soil indicators, identified existing soil inventories and monitoring programmes in the Member States, and drafted procedures and protocols appropriate for inclusion in a European soil monitoring network of sites that are geo-referenced and at which a qualified sampling process is or could be conducted. This Volume (VI) summarises the results presented in volumes I-V and concludes with a proposed approach to monitoring soil conditions in Europe. A framework is proposed and the number of new monitoring sites needed to cover area, as yet not characterised, are estimated. The results of the ENVASSO Project (Volumes I-VI) provide a basis for implementing a soil monitoring programme in the near future but they are the scientific opinions of the ENVASSO Project Consortium, presented here without prejudice, and in no way represent the official position of the European Commission on soil monitoring in Europe.

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