Environmental Assessment of Soil for Monitoring. Volume I: Indicators & Criteria

S. Huber, G. Prokop, Dominique D. Arrouays, G. Banko, Antonio Bispo, R.J.A. Jones, M.G. Kibblewhite, W. Lexer, A. Moller, R.J. Rickson, et al.

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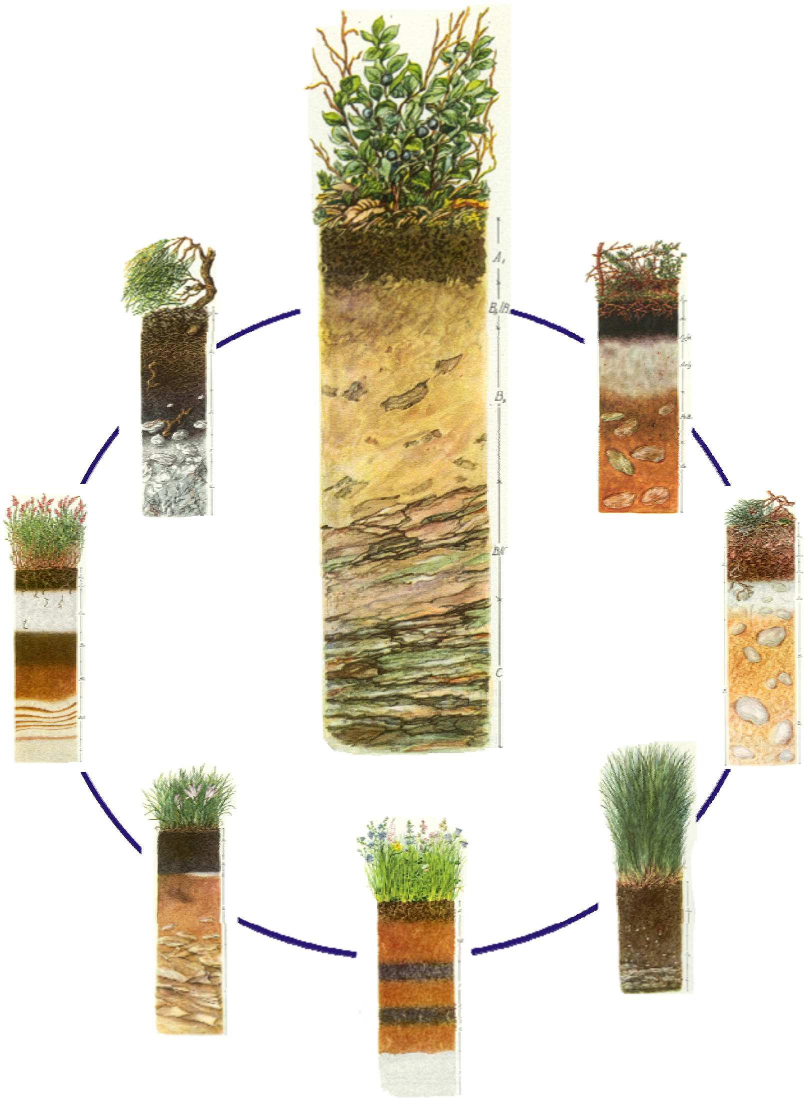

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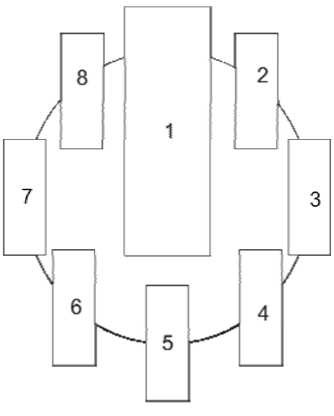

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Preface

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 22 of these procedures were evaluated in 28 Pilot Areas in the Member States (Volume IV). In conclusion, a European Soil Monitoring System (Volume VI), comprising a network of sites that are geo-referenced and at which a qualified sampling process is or could be conducted, is outlined.

Volume I identifies 290 potential indicators relating to 188 key issues for nine threats to soil identified in the Commission's Thematic Strategy for Soil Protection. These threats are: erosion, organic matter decline, contamination, sealing, compaction, loss of biodiversity, salinisation, landslides and desertification. Sixty candidate indicators that address 27 key issues, covering all these threats, were selected on the basis of their *thematic relevance*, *policy relevance* and *data availability*. Baseline and threshold values are presented and three priority indicators for each threat are identified. Fact sheets describe the priority indicators in more detail. Existing soil inventory and monitoring systems in the EU Member States have been evaluated (Volume II) to establish the extent to which the 27 priority indicators are represented.

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29 June 2008

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EXECUTIVE SUMMARY

The main threats to soil have been identified by the European Commission in an official Communication (European Commission, 2002). These 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 in this report because it falls outside the anticipated scope of a future soil framework directive. The process of desertification relates to several threats, including Soil Erosion, Decline in Soil Organic Matter, Soil Salinisation and Decline in Soil Biodiversity; as such it is a key cross-cutting issue.

The purpose of this report is 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 to select the most valuable and scientifically sound indicators for each key issue.

Building on the completed work of the technical working groups formed to support implementation of the Thematic Strategy for the Protection of Soil (Van-Camp *et al.,* 2004a-f), a literature review has identified candidate issues and indicators. From an extended candidate list, a selection was made 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. The main criteria for selection were indicator significance, methodological soundness, measurability and policy relevance. Consistent with a tiered approach to implementation of soil monitoring, a sub-set of three priority indicators (TOP3) is proposed for each threat. The TOP3 indicators 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.

For each of the selected indicators an analysis was made of the availability of baseline and threshold values. The possibility of their derivation was examined or, where these values are 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 where a reference value is not exceeded.

Data requirements for calculating indicator values and deriving baseline and threshold values were identified. It is recommended that these requirements are reflected in future proposals for monitoring soil in the European Union. Fact sheets were prepared describing the TOP3 indicators in more technical detail.

The data requirements identified in this report are being compared with current data availability in a subsequent Work Package (WP2) for the identification of gaps in data quantity and quality. These data requirements are also an important basis for the database design (WP3), while the indicator fact sheets will contribute to the documentation of soil monitoring procedures and protocols (WP4). The priority indicators (TOP3) will be evaluated further in selected pilot areas in Europe (WP5).

Overview of TOP3 indicators

Soil Erosion

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

Decline in Soil Organic Matter

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

Soil Contamination

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

Soil Sealing

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; $ha\ y^{-1}$, $ha\ d^{-1}$	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

Soil Compaction

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

Decline in Soil Biodiversity

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

Soil Salinisation

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

Landslides

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

Desertification

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

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European Commission (2002). Communication of 16 April 2002 from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions: Towards a Thematic Strategy for Soil Protection. COM 2002, 179final http://europa.eu.International/scadplus/printversion/en//lvb/l28122.htm (last accessed 04/04/2007).

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1 INTRODUCTION

This chapter provides general information about the main activities carried out in Work Package 1 (WP1) of the ENVASSO Project. The approach chosen for each of the tasks carried out in WP1 is described in Chapter 2, and Chapters 3 -10 contain a short description of 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. For some threats, specific data and user requirements are given. The length of the text in the different threat chapters is not an indication of importance, but due to the variable number of indicators proposed. 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 covered in Chapter 11. The relevant indicators are defined and documented under each threat. For each threat, three priority indicators (TOP3) have been selected and fact sheets for these are presented in Annex I.

1.1 Literature review

An extensive literature review on existing indicators was carried out, which formed the basis for the selection process. In particular the reports of the Technical Working Groups on the Soil Thematic Strategy (see Van Camp *et al.,* 2004a-f) were taken into account. 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 soil threats were listed. As far as possible, relevant information for each indicator was collected according to the standard guidelines (see Chapter 2).

1.2 Selection of key issues and indicators

This part summarises the results of the work carried out to define key issues and associated indicators for future European soil monitoring. The selected key issues are linked directly to the threats to soil identified in the Soil Communication (European Commission, 2002) and are intended to fulfil the needs for soil information to support the EU Thematic Strategy for Soil Protection. The set of indicators recommended for use, in the environmental assessment of soils at the European scale, were selected in view of their thematic relevance, policy relevance and data availability. The selection process was also based on common guidelines (see Chapter 2). Some selected indicators may be subject to later readjustment and 'fine-tuning' by the project team, pending feedback from the testing in selected pilot areas during Work Package 5.

The work followed a hierarchical scheme for indicator selection (see Chapter 2):

- Thematic groups each linked to one soil threat were established.
- Each group conducted an evaluation of the indicators collected or proposed during the literature review, 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. This process was supported by guidelines and documented by each thematic group.
- The 'TOP3' indicators for each threat were selected, using specific criteria, to facilitate a stepwise implementation of the proposed indicators.

1.3 Baselines and thresholds

Use and interpretation of the proposed indicators requires baseline and threshold values. Changes in relation to a baseline are of interest, as well as comparisons with thresholds to assess soil conditions and any need for protective action. Due to 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 common definitions and methods for estimation should be used.

Within the project the following definitions are used (see also the ENVASSO Glossary of Key Terms):

Baseline: Minimum or starting point of an indicator value (e.g. 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, which limits or threatens sustainable functioning of the soil (e.g. guideline value for heavy metal content, limits for crop production or soil remediation). A threshold is a point or level, which, if approached or exceeded, should trigger consideration of policy or other actions in order to alleviate adverse impacts either on the environment or human and animal health (based on EEA, 2005).

Data and user requirements: Based on the information gathered during the literature review, the data needs for calculation of the selected indicators were compiled. These include input parameters as well as requirements for quality and spatial resolution. A minimum detectable change for an indicator is proposed as the user requirement (see tables in Chapters 3-11). 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.

Fact sheets: The indicator fact sheets prepared in this report (see Annex I) follow a format originally designed by the European Environment Agency and used for many years to provide information for the EEA environmental indicators e.g. 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 and meta-information on data used and their quality. ENVASSO focuses on providing the relevant approach for a monitoring system that is scientifically sound and robust enough to provide an assessment at a European scale when implemented rather than an actual assessment of the situation. The fact sheets for the TOP3 indicators for each threat are presented in Annex I. Where possible, examples of indicator reporting are included. It is expected that further examples will become available following testing of measurement, assessment and reporting procedures for indicators to be conducted in pilot areas by Work Package 5.

1.4 References

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2 METHODOLOGY

The Work Package was organised according to defined tasks:

Task 1 Literature Review

Task 2 Criteria and Indicators

Task 3 Baselines and Thresholds

Task 4 Data and User Requirements

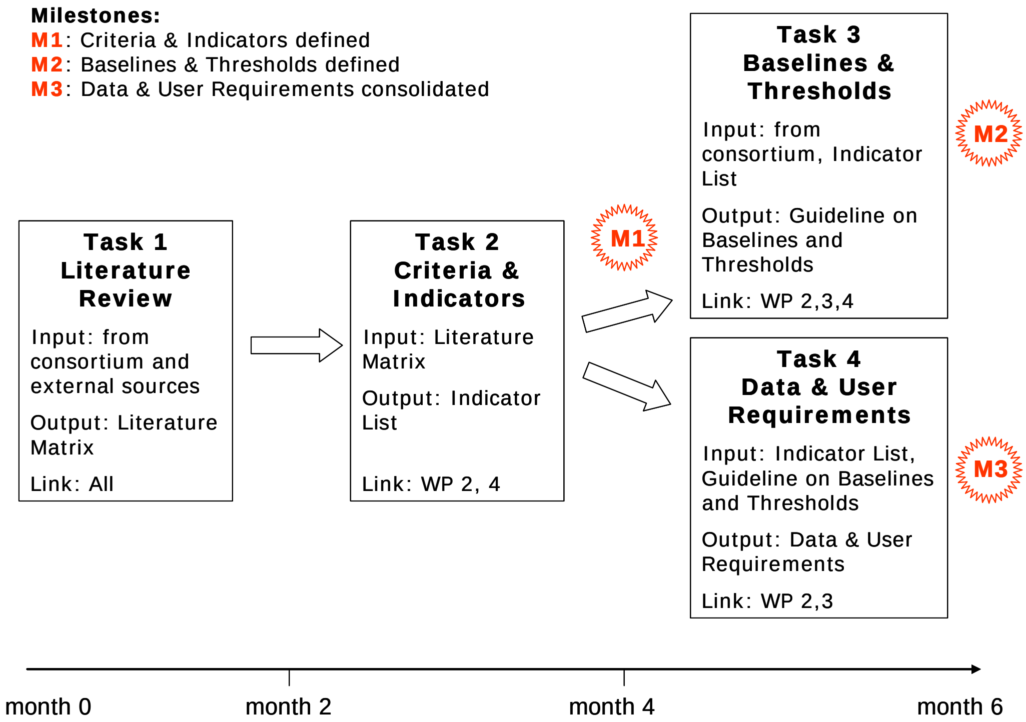


Figure 2.1 Organisation of ENVASSO Work Package 1 'Indicators and Criteria'

2.1 Task 1 Literature review

Objective

The purpose of the literature review was to collate and evaluate key issues and their related indicators that have been proposed for the characterisation of soil status, especially at the European scale. The review scope and focus were informed directly by the threats to soil identified by the European Commission (2002).

Approach

The starting point was the reports of the Technical Working Groups of the consultation process instigated by DG ENV to establish a Thematic Strategy for Soil Protection in Europe (Van-Camp *et al*. 2004a-f). Further important sources are those of European organisations dealing with environmental indicators, such as the European Environment Agency, Eurostat, the UN-ECE and the Joint Research Centre of the European Commission at Ispra. Finally, national and regional reports on soil (indicators) provided much needed detail, as did a large number of scientific publications. Special attention was given to key issues and indicators which have been published already and applied currently in the EU or could be applied across the EU with existing data.

Method
A literature table containing relevant information about criteria, indicators, baselines and thresholds was produced, based on the expertise of the partners of the consortium. A document of defined terms was proposed to establish a common understanding (see the ENVASSO Glossary of Key Terms). The content of the table provides sufficient information for the selection of key issues and indicators suitable at the European scale. UBA-A provided a template to be filled in by the partners contributing to WP1. The table is a collection of the templates received from the contributors. The draft of the table was discussed at the first meeting of WP1. A final version was produced by UBA-A after an update exercise, co-ordinated by the partners responsible for specific soil threats. The template and final tables were prepared in Microsoft Excel.

The following guidance for filling in the columns of the template was provided:

Table 2.1 Guidance for filling in the literature template

Key issue/question	The key issue or question must be policy relevant and be directly related to the soil threat of the specific worksheet. It can be focused on a specific type of the soil threat (e.g. soil erosion by water or wind).
Indicator	For each indicator a short name containing the key information should be provided.
DPSIR class	The type of the indicator should be specified according to the DPSIR scheme of the EEA.
Indicator set	Where the indicator is part of a European (or national) indicator set, the set should be identified in order to facilitate easier access to further information.
Methodological approach	The technical definition of the indicator, the method of measurement and calculation (e.g. ratio, function, model) and specific conditions for it should be described in keywords. For further explanations a reference to literature sources should be given.
Input variables	All (descriptive and measurable) variables needed to calculate the indicator should be listed. Specific additional information for stratification should be identified as well.
Data source	Data sources containing the indicator or/and the input variables should be listed, especially the level of aggregation (EU, national, regional scale) and the source type.
Type of data	The type of data should be described in general terms (e.g. categorical variables, analytical values, satellite images, maps or descriptive statistics) and in statistical terms (nominal, ordinal, interval and ratio), for each parameter separately.
Spatial resolution	The data should be classified as either point or polygon data. Depending on this distinction the type of sampling (distance between points) or the resolution of the information (i.e. scale as, for example, 1:25,000; aggregation level such as field, community, district or state should be provided.
Geographical coverage	As far as possible the actual or potential coverage in the EU and beyond should be provided. If this is not possible, the regional or national situation should be indicated (percentage of coverage or regions or just test areas).
Time period and frequency	If an indicator is already implemented, the first time of investigation and the frequency of updates should be provided.
Data quality actual	The actual data quality in relation to the geographical coverage should be classified into low-medium-high, if not sufficient very low or very high can be added. Criteria for the judgement are comparability and scientific soundness of methodology.
Data quality required	The data quality should be stated that is required to support 'fit-for-purpose' soil monitoring using the selected indicators.
Range of values	The minimum and maximum value that can occur for the indicator in the EU, accompanied by its physical unit (e.g. 20 ha d^{-1}), should be provided.
Baseline	If a baseline value is available, it should be identified along with the corresponding literature source or area of application. A proposal for a baseline value can be made where none is currently available.
Threshold	If a threshold value is available, it should be identified along with the corresponding literature source or area of application. A proposal for a threshold value can be made where none is currently available.
Literature source	Relevant literature sources (at least one) related to the indicator, baseline and threshold should be named in order to get more information if needed.
Contributor	The contributor who provided the information in this row should be indicated by its institution's acronym and, in parentheses, the name of the expert.

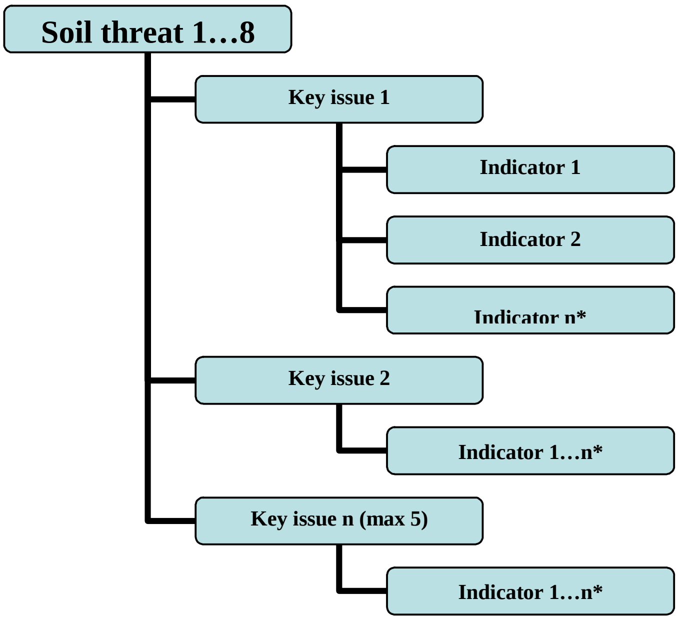
2.2 Task 2 Criteria and indicator selection

Each key issue itself is related to one of the eight threats to soil and the indicators related to one or more of the key issues (see Figure 2.2). The input for the selection process was the matrix produced by the literature review. It contained relevant information for evaluating the proposed key issues and related indicators, such as measurement methodology, input parameter definition, geographical coverage, spatial resolution and availability of baselines and threshold values.

The first step was to analyse the key issues given in the table, to review and summarise them and to select not more than five key issues per soil threat. This was a pragmatic approach in order to focus on the most relevant issues only and to reduce the number of indicators.

The second step was to perform an indicator evaluation. Selection criteria (see below) were evaluated for each indicator of the selected key issues.

The third step was to select a minimum indicator set, based on a weighted analysis. As the classifications of the selection criteria are different (varying ordinal classes), and the criteria are of different importance, a judgement is complex. In order to harmonise the judgement, a prioritisation (ranking) of the selection criteria was proposed (see below). The application of such a ranking leads to a weighted analysis and can be done on a numerical basis. The weighted analysis provided the basis for the indicator selection.



n* = as many as required

Figure 2.2 Indicator selection scheme

For each of the key issues, the aim was to select as small a number of indicators as possible for the final indicator set. The optimal situation would be to select just one indicator per key issue to facilitate management of the full indicator set. This selected indicator would have to represent the key issue comprehensively. If representation was not achieved, one or more complementary indicators were defined for a key issue.

For example: Whether it is necessary to have information not only on the status of a soil threat (e.g. measured soil loss per year), but also on the risk or vulnerability of the soil for a soil threat (e.g. predicted soil loss per year).

Finally, the result of the selection was summarised for each soil threat, and the arguments for selection were described. The report for each soil threat was structured as follows:

- Key issues (short description and reasoning of selection)
- Argument of indicator selection (most relevant criteria, advantages and disadvantages)
- List of indicators including following information:
    - Key issue
    - Clear target definition (key question to be answered),
    - DPSIR class,
    - Applicability at EU level (short or medium term),
    - Monitoring generally or only in areas at risk,
    - Actual or required frequency of updates (number of years)
    - Actual or required spatial resolution (scale)

2.2.1 Selection criteria

The selection criteria are adapted from the OECD (2003) system. In total seven criteria with different priorities were defined. The prioritisation was done by expert judgement considering the importance for a selection of indicators to be implemented at the European scale. In the numerical analysis of the indicators each criterion was given a weight of 3, 2 or 1 respectively with decreasing priority.

2.2.1.1 Selection criteria with high priority:

Significance
Significant indicators are meaningful to the problem under consideration, i.e. they must provide relevant information with regard to the respective key issue.

The following classification was used:

1. *= information of little relevance concerning the threat*
2. *= relevant information on the threat*
3. *= key information on the threat*

Analytical soundness
The methodological approach to calculate the indicator has to be technically and scientifically sound, based on international standards and international consensus about its validity and its suitability for linkage to economic models, forecasting and information systems.

The following classification was used:

1. *= little evidence in literature*
2. *= medium evidence in literature*
3. *= considerable evidence in literature*

2.2.1.2 Selection criteria with medium priority:

Measurability
Practicability of indicators depends on efforts needed for monitoring, data gathering and for indicator calculation. For wide application of the indicators the complexity as well as the effort and costs of data gathering and calculation of the indicator values should be acceptable for decision makers. This criterion is linked strongly with data availability. In order to be operational, indicators should be easily measurable and quantifiable.

The following classification was used:

1. *= large effort needed for data collection (e.g. intensive soil monitoring necessary)*
2. *= moderate effort needed for data collection (e.g. extensive soil monitoring necessary)*
3. *= small effort needed for data collection (e.g. only available soil data and/or statistical data necessary)*

Policy relevance
Policy relevance of indicators is expressed by their thematic coincidence with key topics within the current European soil policy agenda. In order to be of value for policy decision-making, key issues and indicators should be related to policy objectives for soil (in particular those in the EU Thematic Soil Strategy) and to environmental or other policy agendas where soil management is a central issue.

The following classification was used:

1. *= indicator not relevant for policy development and implementation*
2. *= indicator relevant to policy making or envisaged to become relevant in near future (by 2008 -2010)*
3. *= indicator relevant for existing legislation or perceived to be important for soil protection policy implementation in Europe*

Geographical coverage
Geographical coverage indicates the area where the indicator or the input parameters needed to calculate the indicator have already been monitored. For the selection of indicators special attention should be given to indicators already implemented, especially if the coverage across Europe is extensive. The advantage is a high applicability and most likely a high acceptance. But this should not hinder new developments, if another indicator is more suitable to illustrate the key issue.

The following classification was used:

0. *= indicator not measured so far*
1. *= indicator exclusively measured in non-EU countries*
2. *= indicator partially measured at local or regional scale (i.e. in test regions, test sites of one or more Member States)*
3. *= indicator partially or completely measured at the Member State scale*
4. *= indicator completely measured at EU scale (EU 27)*
5. *=indicator completely measured at EU scale (EU 27) and also in other European countries*

2.2.1.3 Selection criteria with low priority:

Availability of baseline and threshold data
This criterion indicates whether or not baseline and or threshold values have been established for the evaluated indicator. In order to have the possibility of relative comparison over time the availability of baseline and threshold data is important. Baselines and thresholds enable an assessment of a suitable use of soil and needs for effective measures to avoid a critical status of soil degradation. If no baseline or threshold values are available yet, their development should be possible with reasonable effort.

The following classification was used:

1. *= baseline and threshold values not available*
2. *= baseline value available, but no threshold value available*
3. *= threshold value available, but no baseline value is available*
4. *= baseline and threshold values available*

Comprehensibility
Comprehensibility describes the level of expert knowledge needed to understand the information on the situation of a soil threat provided by an indicator. The indicators should be generally understandable in order to facilitate communication of results provided by indicators to the public and political decision-makers. The final information should be clear and easy to interpret. Behind it, complex functions/models can be used, but those have to be combined in a logical and clear structure.

The following classification was used:

1. *= detailed soil expertise necessary*
2. *= basic soil expertise necessary*
3. *= general environmental knowledge sufficient*

2.2.2 TOP3 selection

The TOP3 indicators are proposed as a minimum set for monitoring where the complete set of proposed indicators is too comprehensive. These indicators can be a starting point for implementation of soil monitoring. For each threat the TOP3 indicators were selected, but without a ranking among them. The selection of the TOP3 indicators considered the following important aspects:

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

2.3 Task 3 Baseline and threshold values

Potential baseline and threshold data for the selected indicators described in the literature were reviewed. Relevant information, such as ranges of values, was also collated and reviewed. Furthermore, different methods used for derivation of baseline and threshold values were explored - such as calculation of percentiles, benchmarking, risk assessment or political negotiations.

As a result of this work, the potential was identified for the scientific derivation of baseline and threshold values for the selected indicators for all threats, with identification of information gaps. Advice on consideration of land use, soil type and climatic conditions or other influencing factors were included, where relevant. In some cases possible baseline and threshold values are described but not recommended to be used at the EU level as they are more appropriate for use at the Member State or regional scale.

2.4 Task 4 Data and user requirements

The literature review was used as a basis for defining data requirements. In cases where the indicators are already established at the European level, use of existing information is recommended, unless it is not of the necessary quality, e.g. insufficient resolution or based on outdated methodology. Where there is no current use of the selected indicators, data requirements for application at the EU level were defined based on expert knowledge. The main features defining requirements are the input variables, the geographical resolution and the frequency of monitoring, which is necessary to provide scientifically sound and representative assessments. If the requirements are distinct for one or more input variables of one indicator information for the variables was provided separately.

It is important that indicators are able to detect changes in the extent of ‘threats to soil’ which are meaningful in relation to risk assessment and risk management, including the potential need for protective measures. This can be interpreted as a performance specification, defining the minimum detectable change in the indicator value which should be observable over a given time.

Recommendations for such specifications are provided in the table of data requirements. They were defined based on literature review and expert knowledge. Where there are existing well-described baselines and thresholds for indicators, the performance requirement for detecting a change can be assessed in terms of a percentage of the baseline or threshold values. It is useful to note that these specifications are not equivalent to the detection limits for testing methods, which relate to only one part of the process of indicator measurement and do not take account of either sampling errors or spatial variability in indicator values.

2.5 References

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3 SOIL EROSION

Soil erosion is a natural process that has been largely responsible for shaping the physical landscape we see around us today through distribution of the weathered materials produced by geomorphic processes. A number of definitions of soil erosion exist (see Jones *et al.,* 2006, p.24-5). The ENVASSO Glossary of Key Terms defines soil erosion as: “The wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere” (based on Soil Science Society of America, 2001). When the term ‘soil erosion’ is used in the context of being a threat to soil, it refers to ‘accelerated soil erosion’, i.e. “Soil erosion, as a result of anthropogenic activity, in excess of accepted rates of natural soil formation, causing a deterioration or loss of one or more soil functions” (ENVASSO Glossary of Key Terms).

Most present-day concerns about soil erosion are related to accelerated erosion, where the natural rate has been increased significantly by human activities. These activities include: stripping of natural vegetation, especially clearing of forests for cultivation; other changes in land cover through cultivation; grazing; controlled burning or wildfires; levelling of the land surface; intensification of land management; and inappropriate land use, for example through poor maintenance of terrace structures and cultivation of steep slopes. The consequences of soil erosion for society are relatively severe, estimated by Pimentel *et al.* (1995) to cost $44 billion each year in the U.S.A.

Soil erosion has many causes and mechanisms. Soil erosion by water occurs through rills, inter-rills, and gullies, as a result of rainfall, snowmelt, and slumping of banks alongside rivers and lakes. Disturbance or translocation erosion results from tillage, land levelling, harvesting of root crops and trampling or burrowing by animals. Wind erosion is caused by strong air movements displacing bare soil particles, and wave action erodes the coast. Landslides and debris flows are other significant erosion processes, and a hidden form is dissolution erosion by underground water flows, dissolving mainly, carbonate soil minerals.

Water erosion involves detachment of material essentially by two processes, raindrop impact and flow traction. Transportation of soil particles occurs either by saltation through the air or by overland water flow. Combinations of these detachment and transport processes give rise to the main processes of ‘rain splash’, ‘rain wash’, rill wash’, and ‘sheet wash’ (Gobin *et al.,* 1999). Runoff by rainfall and from snowmelt is the most important direct driver of severe soil erosion by water. The most dominant effect is the loss of topsoil, which, although often not conspicuous, is potentially very damaging and, in view of the fact that most soils in Europe have taken at least the last 10,000 years to form, irreversible.

The Soil Thematic Strategy Technical Working Group on Soil Erosion undertook a detailed analysis of the monitoring of soil erosion and concluded that it should be an indicator-based approach (Vandekerckhove *et al.,* 2004), where any proposed indicator should be based on:

1. Estimated (or predicted) soil loss calculated by an appropriate tool (e.g. an erosion model);
2. Measurements of actual soil erosion rates (t ha^{-1} yr^{-1}) at a limited number of representative sites. The measurement sites (plots and catchments) should include those with moderate to high erosion risk and be representative of an agro-ecological zone.
3. Upscaling of results from local measurements to larger areas and extrapolation to assess the state of soil erosion in areas where no measurements have been made, whilst accounting for local conditions of the factors affecting soil erosion.

3.1 Key issues

Eleven keys issues were identified at the start of the selection process (see also Table 3.1):

- Water erosion (3 types)
- Water erosion control
- Dissolution erosion
- Wind erosion
- Wind erosion control
- Tillage erosion
- Coastal erosion
- Desertification
- Landslides

Water erosion is the most important key issue because it is the most extensive form of accelerated erosion occurring in Europe. Water erosion takes place through rills, inter-rills, gullies and sheet wash as a result of excess surface runoff (Jones *et al.,* 2004) and these are the types of water erosion, accelerated by human activity, that are of most concern with respect to soil protection. Water erosion is most severe in Mediterranean environments because here long dry periods are often followed by heavy bursts of rain, creating particularly erosive conditions on steep non-vegetated soils. Boix-Fayos *et al.* (2005) have reviewed a large number of erosion studies in south-east Spain, which is one of the most severely affected areas in Europe. Long term field plots are used for direct measurement of soil loss by rill, inter-rill, and sheet erosion. For gully erosion, direct field measurements are more difficult, partly because of its episodic nature (Imeson and Kwaad, 1980).

Dissolution erosion is essentially a natural (geological) process driven by water that is relatively unaffected by human activity, and therefore considered to be a minor threat in Europe. This is the main reason for its exclusion from the final list, although areas that suffer from this type of erosion can be identified easily from soil and geological maps if this is considered worthwhile in the future.

Wind erosion may be the dominant type of soil erosion in some 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 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 been fully appreciated and documented only 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.

Coastal erosion causes severe damage in many areas, with high costs for society. Commonly, there is no problem until structures are built within the impact zone of storm surges or close to soft rock cliffs, although there are some parts of the European coastline (e.g. east coast of England) where the loss of land is substantial. Flooding is probably the most important consequence of coastal erosion (Jones *et al.,* 2004) but it is the subject of separate policy initiatives. Coastal erosion is still open to debate for inclusion in the final indicator list although it is not agreed that this is a form of erosion leading to soil loss that is large enough to warrant separate consideration. Furthermore, coastal erosion is well-documented by civil authorities in the Member States and is not generally affected by land use or management. Coastal erosion generally takes place in such a way that it is hard to formulate any component of a Directive on Soil Protection that could alleviate or change it.

Erosion control is the implementation of techniques that minimise or arrest erosion by water and/or wind. Commonly these techniques include contour ploughing, minimum or no-tillage, terracing, planting ground cover crops, re-afforestation, reduction in stocking densities, installing of geo-textiles, wind-breaks etc. All these control measures are responses to soil erosion that has already occurred or is currently being observed (Van Camp *et al.,* 2004b), hence 'erosion control' is a proxy key issue for soil erosion.

Desertification has been – and still is – mainly associated with soil erosion (Martinez-Fernandez and Esteve, 2005) but, in the context of the ENVASSO project, it is a cross-cutting issue that is also associated with decline in soil organic matter, soil salinisation and decline in soil biodiversity. Desertification was originally identified as a key issue for soil erosion, but the proposed indicators have been extracted from this section and described, with baseline and threshold values, in Chapter 11.

Landslides are a separate threat to soil and indicator definition and selection are described in Chapter 10

Table 3.1 Overview of key issue selection for Soil Erosion

Erosion type	Key issue selection		Description
	In	Out	
Water erosion	Water erosion		by rill, inter-rill, sheet, gully (includes by snowmelt, irrigation and riparian erosion)
	Water erosion		by suspended sediment load in rivers and streams
	Water erosion		extent of erosion features, e.g. rills and gullies
		Erosion control	erosion control measures: contour ploughing, terracing, cover cropping
		Dissolution erosion	by water flowing underground
Wind erosion	Wind erosion		by strong desiccating winds
		Erosion control	erosion control measures: windbreaks, cover cropping
Tillage erosion	Tillage erosion		by tillage, land levelling and crop harvesting
Coastal erosion		Coastal erosion	slumping caused by wave action
Desertification		Desertification	Cross-cutting issue (salinisation, decline in soil organic matter, decline in soil biodiversity)
Mass movement		Landslides	By debris flows, mud flows, rock flows, rock falls, earth slides

Table 3.1 shows that six key issues – water erosion control, dissolution erosion, wind erosion control, coastal erosion, desertification, and landslides – were excluded from the final selection. Erosion control (wind or water), as stated above, is essentially a response to erosion that has already occurred. Using the existence (or rate of implementation) of control measures as an indicator for erosion is not considered practicable as a front-line indicator, but the evidence for erosion control could be used for validating results from erosion models. Dissolution erosion is not selected mainly because of the limited anthropogenic component. Coastal erosion is a more contentious issue, but has been omitted for reasons of scale and limited anthropogenic causes. Finally, landslides and desertification are omitted here because they have been recognised as separate threats to soil (see Chapters 10 and 11 respectively).

3.2 Indicators

This section describes firstly the results of the indicator selection process, listing the selected indicators along with their disadvantages and advantages (Section 3.2.1). Secondly, existing and/or proposed baselines and thresholds for the selected indicators are discussed (Section 3.2.2).

Thirdly, the data and user requirements for implementing the selected indicators in a European soil monitoring system are presented (Section 3.2.3). Finally, the three most important indicators (TOP3), according to expert judgement, are proposed (Section 3.2.4).

3.2.1 Indicator selection

Initial proposals by the subgroup identified 47 indicators for 11 key issues. Several of these indicators were duplicates and were merged into a smaller number of clearly defined key issues and indicators (28); most duplication involving water erosion. In the past, a number of proxy-indicators have been proposed for erosion. Gobin *et al.* (2004) reviewed a number of these and concluded that the most appropriate indicator for water erosion is a regional model that estimates the risk of soil erosion combined with periodical monitoring of actual soil erosion in selected test areas.

A numerical ranking system for the proposed indicators was employed, with expert judgement applied at the final stage because several of the selection criteria essentially relied on expert judgement in the first place. Following consultations at two subgroup meetings backed up by email exchanges, three key issues and eight indicators were selected (see
Figure 3.1) The highest ranking selection criteria (by expert judgement) were:

1. Acceptability or the extent to which the indicator is based on ‘sound science’;
2. Practicability or the measurability of the indicator;
3. Policy relevance and utility for users;
4. Geographical coverage.

The first three criteria are similar to those proposed by the OECD (2003). Geographical coverage, though not an intrinsic property, is an important consideration for ENVASSO because of the need to identify gaps in geographical coverage to fulfil the project’s aim of developing recommendations to harmonise soil monitoring in Europe. Table 3.2 lists the indicators selected for the key issues. The advantages and disadvantages of these selected indicators are described below.

Eight indicators were selected for inclusion in the final proposal for soil erosion monitoring (see below and
Figure 3.1. The 20 indicators that were not selected were mostly relevant for key issues that were not included (see Section 3.1) and are as follows:

- Gully erosion, because there is no methodology available that can be applied at the European scale at the present time;
- Erosion control, because these are essentially proxy-indicators and it was considered that observed features (ER04) are more appropriate. Furthermore, data on erosion control measures are not standardised nor widely available;
- Crops associated with erosion, because very accurate georeferenced cropping statistics would be needed to make its use practicable;
- Actual extent of water erosion in agricultural areas, because of limited data resolution but the concept behind it was included in ER01 and ER02;
- Decrease in depth of topsoil, because the soil data needed for application at European scale are not readily available;
- Others: the USLE factor K was rejected because, at the European scale, soil erodibility taken in isolation was not considered to be a comprehensive indicator of erosion (the interactions of the USLE factor K with erosivity (R), vegetation cover (C), and slope length (L) and gradient (S) are crucially important).

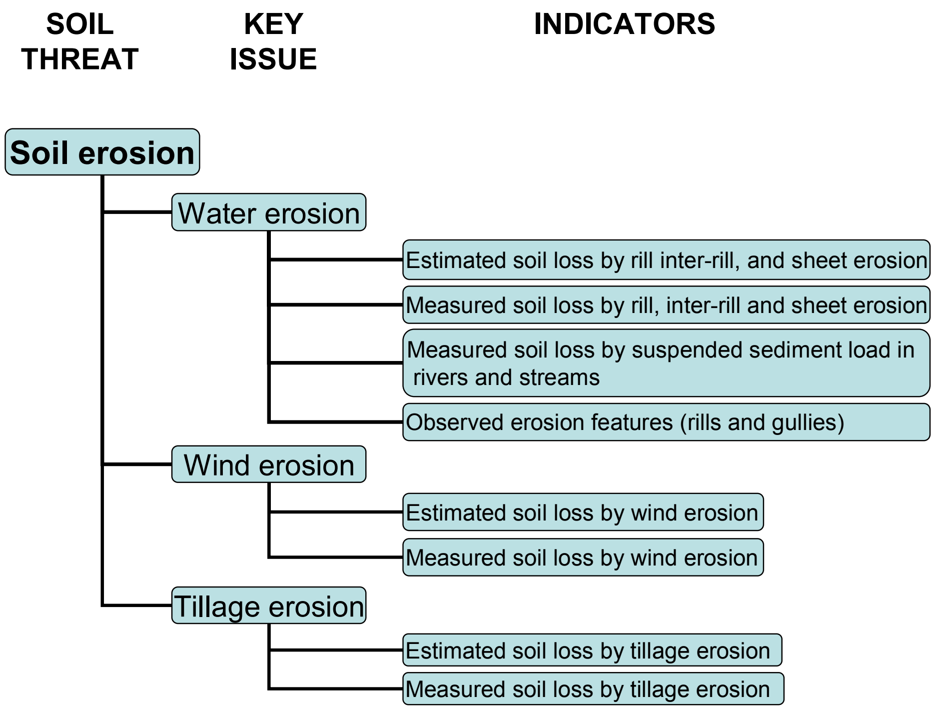

Figure 3.1 Key issue and indicator selection for Soil Erosion

3.2.1.1 Water erosion

Indicators are proposed for:

i) Estimated and measured soil loss by rill, inter-rill, and sheet erosion; included in this form of erosion are soil loss by snowmelt, irrigation runoff, and wave action of rivers and streams (riparian erosion).
ii) Measured suspended sediment load in river and streams;
iii) Extent of erosion features caused by overland flow.

Four indicators are proposed:

3.2.1.1.1 ER01 Estimated soil loss by rill, inter-rill, and sheet erosion

Advantages:

i) Accurate estimates of soil loss can be obtained from erosion models that already exist, for example: PESERA (Kirkby *et al.* 2004); USLE (Wischmeier and Smith, 1978); RUSLE (Renard *et al.,* 1997); Morgan *et al.* (1984) and Morgan (2001).
ii) These estimates exist for the whole of Europe.

Disadvantages:

i) Rill, inter-rill, and sheet erosion is difficult to estimate because of the complexity of erosion processes involved and a lack of sufficiently accurate data.
ii) Gully erosion is not estimated – there is no reliable method or model for estimating soil erosion by gully erosion.
iii) Modelling errors contribute to uncertainty of estimated values.
iv) Very few sites exist in Europe where water erosion has been measured systematically enough to provide sufficient data for model calibration and validation.

Conclusion:
The primary indicator for water erosion by rill, inter-rill, and sheet erosion should be estimated soil loss from a calibrated model, which is subsequently backed up by a secondary indicator of measured soil loss by water erosion (ER02) for continuing model validation, and quantification of data uncertainty.

3.2.1.1.2 ER02 Measured soil loss by rill, inter-rill, and sheet, erosion

Advantages:
- i) Methods exist for measuring soil loss by water running off plots of varying sizes.
- ii) There are few sites in most Member States where measurements have been made regularly or periodically.

Disadvantages:
- i) Rill, inter-rill and sheet erosion are difficult to measure and the experimental errors are often large.
- ii) This indicator cannot be used separately at the European scale because insufficient sites (plots) are available where erosion has been measured, or is measured currently. However, soil erosion measurements could play an important part in calibrating, and subsequently, validating estimated soil losses from models.

Conclusion:
This indicator of measured soil loss by water erosion, as the support indicator for ER01, should be used to provide continuing validation of, and quantification of uncertainties in, model estimates. However, resources allocated to measuring water erosion will need to be increased significantly for this to prove successful.

3.2.1.1.3 ER03 Measured soil loss by suspended sediment load in rivers and streams

Advantages:
- i) Experimental procedures exist for measuring sediment loads in rivers and streams and there are established procedures for using the subsequent deposition of eroded sediments in lakes and reservoirs (Van Rompaey *et al.,* 2005) to calculate sediment delivery ratios for specific landscapes and soils in different climatic zones.
- ii) Measuring sediment loads can also provide estimates of soil loss from catchments, which are often management units, and these estimates can facilitate implementation of erosion control.

Disadvantages:
- i) Suspended sediment in water courses only provides a measure of overall soil loss from a catchment and masks the erosion and subsequent deposition of eroded material which does not reach water courses.
- ii) It is seldom possible to identify the real source of eroded sediments.

Conclusion:
This indicator is not suitable for universal application across Europe at the present time, but could provide valuable data for validating soil loss estimated by erosion models.

3.2.1.1.4 ER04 Observed erosion features (rills and gullies)

Advantages:
- i) Documented procedures are available for using field observation and remote sensing for measuring the size (depth, width, length) of erosion features such as rills, deep rills and gullies (Martinez-Casasnovas, 2003; Ritchie, 1996).
- ii) Erosion features are normally easy to recognise.
- iii) Once an inventory of gullies has been made, monitoring becomes less resource intensive.

Disadvantages:

i) Observed features are clear evidence of active and past erosion but, at present, remote sensing techniques are not sufficiently well developed to support comprehensive monitoring at the required scale.
ii) Considerable variations have been found between remotely sensed methods and more conventional methods, due to temporal averaging, study area characteristics, resolution of the data used and methods for the determination of sediment production and deposition (Martinez-Casasnovas, 2003; Betts and De Rose, 1999).
iii) The use of remote sensing techniques necessitates large-scale data collection, processing and interpretation.
iv) Gully erosion is episodic and some gullies are only active once in 10-100 years

Conclusion:
This indicator is not suitable for universal application across Europe but, with future developments in remote sensing, it could provide valuable data for validating estimated soil losses from erosion models, in support of any future European soil monitoring network.

3.2.1.2 Wind erosion

Two indicators are proposed:

3.2.1.2.1 ER05 Estimated soil loss by wind erosion

Advantages:

i) As for water erosion by rills inter-rills and gullies, it is not (nor may it ever be) practicable, to measure wind erosion everywhere in Europe. However, accurate estimates of soil loss by wind are needed to implement soil protection measures and these can be obtained from existing wind erosion models (see Quine *et al.,* 2006).
ii) The processes leading to wind erosion are well researched and understood.

Disadvantages:

i) Wind erosion is even more difficult to estimate than water erosion and modelling errors are potentially large.
ii) There are far fewer data on wind strength and direction in Europe than there are rainfall data, which contributes further to the uncertainty of model estimates.
iii) Wind erosion has been measured at even fewer sites in Europe than water erosion.

Conclusion:
The primary indicator for wind erosion should be 'estimated soil loss by wind erosion', backed up by a secondary indicator of 'measured soil loss by wind erosion' (ER06), for continued calibration, model validation and quantification of uncertainty.

3.2.1.2.2 ER06 Measured soil loss by wind erosion

Advantages:

i) Methods for measuring soil loss by wind from field plots are well documented (Bocharov, 1984; van Donk and Skidmore, 2001; Sutherland, 1992).

Disadvantages:

i) Experimental errors are generally larger than for water erosion measurement (Chappell, 1999)
ii) There are very few monitoring sites in Member States and they tend to be located only where wind erosion is active or has been a problem historically.

Conclusion:
This indicator cannot be used separately because of the sparsity of experimental plots. However, it should play an important part in future calibration and validation of estimated soil loss from wind erosion models. Therefore, this indicator of 'measured soil loss by wind erosion' should be considered as supporting ER05 for continuing model validation and quantification of uncertainties. The resources allocated to measuring wind erosion will need to be increased significantly if this approach is to prove successful.

3.2.1.3 Tillage erosion

Two indicators are proposed:

3.2.1.3.1 ER07 Estimated soil loss by tillage erosion

Advantages:

i) As for water erosion by rill, inter-rill and sheet erosion, it is not (nor may it ever be) practicable to measure tillage erosion everywhere in Europe where agriculture in practiced. However, models that estimate soil loss from tillage operations are available (e.g. Govers *et al.,* 1996, Van Oost *et al.,* 2000).

Disadvantages:

i) Tillage erosion is more difficult to estimate than water erosion and modelling errors are potentially significant (Quine *et al.,* 2006).
ii) Application of this indicator will depend on detailed data on tillage equipment and techniques employed, information which is widely lacking at the required scale for Europe.

Conclusion:

The primary indicator for tillage erosion should be ‘estimated soil loss by tillage erosion’ from a calibrated model that has been validated, backed up by a secondary indicator of ‘measured soil loss by tillage erosion’ (ER08) for continued validation and quantifying uncertainty.

3.2.1.3.2 ER08 Measured soil loss by tillage erosion

Advantages:

i) Methods are available for measuring soil loss by tillage operations from field plots (Bazzoffi *et al.,* 1989; Quine *et al.,* 2006).

Disadvantages:

i) Experimental errors are large and there are very few sites in the Member States where tillage erosion has been, or is being, measured systematically.

Conclusion:

This indicator of ‘measured soil loss by tillage erosion’ is secondary to ER07, and is included because of the importance of continued validation and quantifying uncertainties in model estimates. The resources allocated to measuring tillage erosion will need to be increased significantly.

Table 3.2 Overview of proposed indicators for Soil Erosion

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
ER01	**Water erosion**	**What is the current status of water erosion in Europe?**	**Estimated soil loss by rill, inter-rill and sheet erosion**	**$t\ ha^{-1}\ yr^{-1}$**	**S**	**S**	**G**	**1**	**1 km x 1 km aggregated data, pending WP2 results**
ER02	Water erosion	What is the current status of water erosion in Europe?	Measured soil loss by rill, inter-rill and sheet erosion	$t\ ha^{-1}\ yr^{-1}$	S	S	G	1	Point data from field plots
ER03	Water erosion	What is the current status of water erosion in Europe?	Measured soil loss by suspended sediment load in rivers and streams	$t\ yr^{-1}$	S	M	R	1	Point data, from 5-100 m^2 to river course length or lake-sized units, pending WP2 & WP5 results
ER04	Water erosion	What is the current status of water erosion in Europe?	Observed erosion features (rills and gullies)	$m^3\ ha^{-1}\ yr^{-1}$	S	M	G	1	1 m x 1 m (remote sensed images), pending WP2&5 results
ER05	**Wind erosion**	**What is the current status of wind erosion in Europe?**	**Estimated soil loss by wind erosion**	**$t\ ha^{-1}\ yr^{-1}$**	**S**	**S**	**G**	**1**	**1 km x 1 km aggregated data, pending WP2 results**
ER06	Wind erosion	What is the current status of wind erosion in Europe?	Measured soil loss by wind erosion	$t\ ha^{-1}\ yr^{-1}$	S	S	G	1	Point data from field plots
ER07	**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**	**$t\ ha^{-1}\ yr^{-1}$**	**S**	**S**	**G**	**1**	**1 km x 1 km aggregated data, pending WP2 results**
ER08	Tillage erosion	What is the current loss of soil by tillage practices, land levelling and crop harvest (root crops)?	Measured soil loss by tillage erosion	$t\ ha^{-1}\ yr^{-1}$	S	S	G	1	1 km x 1 km aggregated data, pending WP2 results

Abbreviations: Indicator ID: ER = Soil erosion, DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response; Applicability: S = short-term, M = medium-term; Monitoring: G = generally, R = in risk areas only; TOP3 indicators in bold letters.

3.2.2 Baseline and threshold values

A baseline is defined as the 'minimum or starting point of an indicator value' (see the ENVASSO Glossary of Key Terms for a full description). Therefore, a detailed inventory is required to define a *baseline* for soil erosion in a particular area. In areas of Europe that are not currently eroding, the baseline is 0 t $ha^{-1}yr^{-1}$. The remaining land is subject to varying degrees of soil erosion where baselines are greater than zero.

There have been attempts to map soil erosion in a number of areas in Member States (Dostal *et al.,* 2004; Landscape Atlas of the Slovak Republic, 2002; Øygarden, 2003; Sanchez *et al.,* 2001; Schaub and Prasuhn, 1998), but to establish an accepted overall baseline for erosion in Europe remains a challenging task.

Jones *et al.* (2004) report a number of other soil erosion studies which provide a European overview, but these are based mostly on models or expert judgement (some including observation). These approaches more commonly produce assessments of erosion risk rather than estimates of actual soil loss, with baseline and/or threshold values rarely mentioned.

In the context of soil erosion, the true baseline is the amount of soil or sediment that is lost from a defined spatial unit under current environmental conditions. However, it is not practicable to measure the actual loss of soil caused by erosion processes over the whole of Europe to determine a universal baseline. It is more realistic to estimate baseline data for Europe by modelling the factors known to cause erosion. The estimated baseline soil losses should then be validated, using actual measurements from the few experimental sites that currently exist, augmented in future by measurements from additional 'benchmark' sites. This leaves undefined the spatial unit over which any baseline would apply.

The search for a baseline of soil loss in Europe leads to examination of the concept of an average rate of soil erosion because most baselines are established following a study of averages. Pimental *et al.* (1995) have reviewed erosion rates around the world and suggest an average of 17 t $ha^{-1}yr^{-1}$ for Europe. This is a crude approximation since it is based on plot data, which are in acute shortage. Furthermore, data from plot experiments are not a good basis for regional generalisation.

Several researchers quote soil erosion rates in Europe of between 10 and 20 t $ha^{-1}yr^{-1}$ (Lal *et al.,* 1989; Richter, 1983), whereas Arden-Clarke and Evans (1993) state that water erosion rates in Britain vary from 1-20 t ha^{-1} yr^{-1} but that the higher rates are rare events and localised. Ryszkowski (1993) estimates average rates of water erosion at 0.52 t ha^{-1} yr^{-1}, based on suspended sediments in rivers and a sediment delivery ratio. Boardman (1998) challenges the usefulness of an average rate of soil erosion for Europe, concluding that the rates vary too much in time and space.

Clearly, the lowest baseline is 0 t ha^{-1} yr^{-1} for areas that suffer no soil erosion. An acceptable or 'tolerable' baseline, for areas known to erode, deserves more consideration though this is certainly more contentious. In addition to soil, slope and precipitation conditions, land use and land cover play an important part in defining any baseline greater than 0 t ha^{-1} yr^{-1}. This poses the question whether or not baselines are needed for different land uses, climatic zones, and/or soil-landscapes (and combinations of these factors). Soil, terrain, climate and land use factors are very important for determining the amount of erosion and associated baselines. Therefore, it appears that a regional approach is needed to formulate regional baselines.

Publications on baseline soil erosion rates refer mostly to water erosion, yet baselines for other forms of erosion, for example by wind and tillage, are also needed. Recent work in Eastern England reported mean wind erosion rates of 0.1-2.0 t ha^{-1} yr^{-1} (Chappell and Warren, 2003), though severe events are known to move much larger quantities (>10 t ha^{-1} yr^{-1}) of soil (Böhner *et al.,* 2003). Mean gross rates of tillage erosion have been reported to be in the order of 3 t $ha^{-1}yr^{-1}$ (Govers *et al.,* 1996; Owens *et al.,* 2006).

Breshears *et al.* (2003) researched the relative importance of soil erosion by wind and by water in a Mediterranean ecosystem and found wind erosion to exceed water erosion in shrubland and forest sites, but not on a grassland site. Wind driven transport of soil material from horizontal flux measurements were projected to annual timescales for shrubland (ca. 55 t ha^{-1} yr^{-1}), grassland (ca. 5.5 t ha^{-1} yr^{-1}) and forest (ca. 0.62 t ha^{-1} yr^{-1}). In a similar study, Goossens *et al.* (2001) found lower values (ca. 9.5 t ha^{-1} yr^{-1}) for arable fields in lower Saxony, Germany. It is important to note that 'transport' does not necessarily equate to 'erosion' as deposition nearby often occurs. This issue is also important, although perhaps to a lesser extent, for water erosion and needs to be considered when setting thresholds and when developing a methodology for measuring erosion in relation to proximate deposition.

There has been much discussion in the literature about thresholds above which soil erosion should be regarded as a serious problem. This has given rise to the concept of 'tolerable' rates of soil erosion that should be based on reliable estimates of natural rates of soil formation. However, soil formation processes and rates differ substantially throughout Europe.

Alexander (1988) determined soil formation rates for 18 small, non-agricultural, non-carbonate substrate watersheds by measuring values of silica inputs and outputs and relating these to soil formation. The range was from 0.02 to 1.9 (average = 0.56) t ha^{-1} yr^{-1}, where the latter represents a Scottish peat soil. Wakatsuki and Rasyidin (1992) used similar geochemical mass balance methodologies to calculate soil formation at a global scale as ranging from 0.37 to 1.29 (mean=0.7) t ha^{-1} yr^{-1}. However, Pillans (1997) found substantially lower soil formation rates on basaltic lava flows in semi-arid tropical Australia of approximately 0.004 t ha^{-1} yr^{-1} (assuming bulk density at 1.3 kg dm^{-3}). Also, in areas where aeolian deposition occurs, the picture of soil formation is more complex.

Simonson (1995) reviewed the significance of airborne dust to soils and quotes estimates of approximately 3 t ha^{-1} yr^{-1} of dust deposition on average for soils between the Rocky Mountains and the Mississippi River. For Europe the amounts of dust deposition are likely to be lower because the major source area (the Sahara) tends to deliver most of its dust to the North Atlantic. Nihlen *et al.* (1995) measured the soil formation rate from Saharan dust fall-out on Crete to be 0.2 t ha^{-1} yr^{-1}.

Considering the reported rates of soil formation, it appears reasonable to propose a global upper limit of approximately one t $ha^{-1}yr^{-1}$ for mineral soils, although under specific conditions, e.g. extremely high precipitation combined with high temperatures, actual soil formation rates can be substantially greater, for example 5.7 t $ha^{-1}yr^{-1}$ is quoted by Wakatsuki and Rasyidin (1992) for a basic pyroclastic watershed in south-western Japan. However, it would be advisable to apply the precautionary principle to any policy response to counteract soil erosion; otherwise soils with particularly slow rates of formation will steadily disappear. Therefore, future differentiation of formation rates for soil – land use – climate combinations is needed, and quantitative pedogenesis modelling (e.g. Hoosbeek and Bryant, 1992) may provide an appropriate methodology.

In some cases, rates of soil erosion larger than 1 t $ha^{-1}yr^{-1}$ are regarded as tolerable from the wider perspective of society as a whole, for example for economic considerations. In Switzerland, the threshold tolerated for soil erosion is generally 1 t ha^{-1} yr^{-1}, though this rate is increased to 2 t $ha^{-1}yr^{-1}$ for some soil types (Schaub and Prasuhn, 1998). In Norway, 2 t ha^{-1} yr^{-1} is adopted as the threshold for tolerable soil loss (Arnoldussen, pers comm.).

Consequently, it may be realistic to propose different rates of soil erosion that are tolerable in different parts of Europe. Hence in Table 3.3 threshold values proposed for southern Europe are higher than for northern Europe, though this aspect needs further discussion with regional experts before finalisation.

In a very recent study of continental erosion and sedimentation, Wilkinson and McElroy (2007) give an exhaustive analysis of rates of subaerial denudation in the Phanerozoic, a period of 542 million years spanning the Lower Cambrian to the Tertiary Pliocene. They estimate that erosion averaged 5Gt yr^{-1} during this period, and increased irregularly to about 16 Gt yr^{-1} in the Pliocene. The global land area fluctuated throughout the Phanerozoic, but using a continental area of 118 million km^2, 5Gt yr^{-1} equates to a natural erosion rate of 0.42 t $ha^{-1}yr^{-1}$, and 16Gt yr^{-1} in the Pliocene equates to1.36 t ha^{-1} yr^{-1}, which may be considered a maximum natural erosion rate.

Wilkinson and McElroy (2007) go on to estimate annual net riverine flux of all weathering products to global oceans to be of the order of 21Gt (1.78 t $ha^{-1}yr^{-1}$) and erosion from present day farmland to be ~75Gt yr^{-1} (6.36 t $ha^{-1}yr^{-1}$). These data confirm that 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 ~ 0.4 – 0.5 t $ha^{-1}yr^{-1}$. In some circumstances, 1.5 t $ha^{-1}yr^{-1}$ might be considered a tolerable rate because it does not differ greatly from the estimated maximum natural erosion rate during the Pliocene period.

Table 3.3 Baselines and thresholds for Soil Erosion

Key issue	Key question	Candidate Indicator	Units	Baseline	Threshold
Water erosion	What is the current status of water erosion in Europe?	ER01: Estimated soil loss by rill, inter-rill and sheet erosion[a]	t ha^{-1} yr^{-1}	N Europe: 0-3 t ha^{-1} yr^{-1} S Europe: 0-5 t ha^{-1} yr^{-1}	N Europe: 1-2 t ha^{-1} yr^{-1} S Europe: 1-2 t ha^{-1} yr^{-1}
	What is the current status of water erosion in Europe?	ER03: Measured soil loss by suspended sediment load in rivers and streams	t yr^{-1} t ha^{-1} yr^{-1}	0.5 t ha^{-1} yr^{-1}	1-2 t $ha^{-1}yr^{-1}$
	What is the current status of water erosion in Europe?	ER04: Observed erosion features (rills and gullies)	m^3 ha^{-1} yr^{-1}	n/a	n/a
Wind erosion	What is the current status of wind erosion in Europe?	ER05: Estimated soil loss by wind[b]	t ha^{-1} yr^{-1}	N Europe: 0-2 t ha^{-1} yr^{-1} S Europe: 0-2 t ha^{-1} yr^{-1}	N Europe: 2 t ha^{-1} $yr^{-}1$ S Europe: 2 t ha^{-1} yr^{-1}
Tillage erosion	What is the current loss of soil by tillage practices, land levelling and crop harvest (e.g. root crops)?	ER07: Estimated soil loss by tillage erosion[c]	t ha^{-1} yr^{-1}	N Europe: 0-3 t ha^{-1} yr^{-1} S Europe: 0-5 t ha^{-1} yr^{-1}	N Europe: 2 t ha^{-1} yr^{-1} S Europe: 2 t ha^{-1} yr^{-1}

n/a – not available; [a] Includes its secondary indicator ER02; [b] Includes its secondary indicator ER06; [c] Includes its secondary indicator ER08.

3.2.3 Data and user requirements

Table 3.4 Summary of data and user requirements for Soil Erosion

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum for detection of meaningful change
ER01	**Estimated soil loss by rill, inter-rill, and sheet, erosion**	**Rainfall intensity and amount; soil texture, water storage capacity and structure; land use/land cover; topography (slope gradient, length and form)**	**Europe: complete coverage with soil data at 1:250,000 scale; detailed soil profile data; full climate data sets at 10km resolution; up-to-date land use**	**1km x 1km**	**Europe at higher resolution: 100% of EU for climate, DEM, CORINE; 100% of EU at scale 1:250k for soils, some countries have better detail (1:50k, 1:25k)**	**5 years**	**high**	**t ha^{-1} yr^{-1}**	**0.5 t ha^{-1} yr^{-1}**
ER02	Measured soil loss by rill, inter-rill, and sheet erosion,	Soil loss (sediment yield); Rainfall intensity and amount; soil texture, water storage capacity and structure; land use/land cover; topography (slope gradient, length and form);	Many more sites measuring soil loss by water erosion in EU Member States	Point data, 5 – 100 m^2 to field areas	Many more experimental/research sites (and plots) needed	annual	high	t ha^{-1} yr^{-1}	0.2 t ha^{-1} yr^{-1}
ER03	Measured soil loss by suspended sediment load in rivers and streams	weight of sediments	More sites measuring sediment suspended in national and trans-national drainage systems	Up to 10,000 km^2	More measuring devices in European catchments	annual	high	t yr^{-1}	100t yr^{-1}
ER04	Observed erosion features (rills and gullies)	rills' gullies width, depth and number; Volume of sediment	Continuous coverage of Europe by 10m resolution RS data	5m x 5m	Many more experimental/research sites (and plots) needed	annual	high	m^3 ha^{-1} yr^{-1}	1000 m3 ha^{-1} yr^{-1}
ER05	**Estimated soil loss by wind erosion**	**Wind velocity and duration; soil texture, water storage capacity and structure; land use/land cover; topography (slope gradient, length and form)**	**Europe: complete coverage with soil data at 1:250,000 scale; detailed soil profile data; full climate data sets at 10km resolution; up-to-date land use**	**1km x 1km**	**Europe at higher resolution: 100% of EU for climate, DEM, CORINE; 100% of EU at scale 1:250k for soils, some countries have better detail (1:50k, 1:25k)**	**5 years**	**high**	**t ha^{-1} yr^{-1}**	**0.5 t ha^{-1} yr^{-1}**
ER06	Measured soil loss by wind erosion	Wind velocity, duration; soil texture, water storage capacity and structure; land use/land cover; topography (slope gradient, length, curvature)	Many more sites measuring soil loss by water erosion in EU Member States	Point data, 5 - 100m^2 to field areas	Many more experimental/research sites (and plots) needed	Events	high	t ha^{-1} yr^{-1}	0.5 t ha^{-1} yr^{-1}
ER07	**Estimated soil loss by tillage erosion**	**Rainfall intensity and amount, soil texture and structure, soil moisture deficit; land use/land cover; topography (slope angle, length, curvature)**	**Europe: complete coverage with soil data at 1:250,000 scale; detailed soil profile data; full climate data sets at 10km resolution; up-to-date land use**	**1km x 1km**	**Europe at higher resolution: 100% of EU for climate, DEM, CORINE; 100% of EU at scale 1:250k for soils, some countries have better detail (1:50k, 1:25k)**	**5 years**	**high**	**t ha^{-1} yr^{-1}**	**0.5 t ha^{-1} yr^{-1}**
ER08	Measured soil loss by tillage erosion	Soil loss; Rainfall, soil type, harvesting technique, agronomic practices, crop yield	Many more sites measuring soil loss by tillage erosion in EU Member States	Point data, 5 – 100 m^2 to field areas	Many more experimental/research sites (and plots) needed	annual	high	t ha^{-1} yr^{-1}	0.5 t ha^{-1} yr^{-1}

3.2.4 TOP3 indicators

Table 3.5 TOP3 indicators for Soil Erosion

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 – selected as a headline 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 but not by other methods. ER02 is the support indicator for calibration and validation of model estimates.

ER05 – selected in TOP3 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 – recently recognised as a significant form of soil erosion in Europe, tillage erosion can be modelled to provide estimated soil loss with ER08 as the support indicator for calibration and validation.

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4 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.

The ENVASSO project has adopted the SSSA (2001) definition of SOM, i.e. "the organic fraction of the soil exclusive of undecayed plant and animal residues". Living soil flora and fauna are excluded by this definition, and are dealt with in detail under a separate threat Decline in Soil Biodiversity (Chapter 8). Decline in Soil Biodiversity, as a threat, is defined in the ENVASSO Glossary of Key Terms as: "a negative imbalance between the build-up of soil organic matter and rates of decomposition, leading to an overall decline in soil organic matter contents and/or quality, causing a deterioration or loss of one or more soil functions". The main component of SOM (by weight) is organic carbon, which is mostly measured by analytical methods for SOM content. The soil organic carbon (SOC) values are often converted to SOM values using an empirical conversion factor of 1.724 (Kononova, 1958) which is based on the assumption that SOM contains approximately 58% C. Many scientific studies have shown that this factor varies greatly, i.e. from 1.4 to 3.3 for soils under different land uses (Körschens *et al.,* 1998) and from 1.7 to 2.0 for arable soils (ISO 10694:1995). In this report, therefore, only SOC is used when referring to measured values.

Organic matter is an important component of soils because of its influence on soil structure and stability, water retention, cation exchange capacity, soil ecology and biodiversity, and as a source of plant nutrients. Soil organic matter plays a major role in maintaining soil functions. Although the quantitative evidence for critical thresholds for organic matter content is slight (Körschens *et al.,* 1998; Loveland and Webb, 2002), there is a widely-held belief that soil cannot function optimally without adequate levels of soil organic matter (Van-Camp *et al.,* 2004). Carbon is a major component of soil organic matter, which in turn plays a major role in the global carbon cycle. Therefore, recent attention to rising concentrations of atmospheric CO_2 has directed attention to the stocks of SOC and to their changes (IPCC, 2003).

Soil organic matter decline is of particular concern in Mediterranean areas (Jones *et al.,* 2005). 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 main 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: 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.

Soil organic matter quality relates to the nature and properties, and relative proportions, of soil organic matter components and their combined influence on soil functions. From the quality point of view, soil organic matter is considered to encompass a set of attributes linked to soil functions rather than being a single entity. For instance, changes in soil organic matter quality may impact on soil biodiversity, transport of substances within and through the soil, microbial activity, etc. (Van Camp *et al.,* 2004).

Causes of changes in soil organic matter content are the factors controlling organic matter dynamics in the soil. Some of them are inherent soil properties, e.g. 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.,* 2004).

Peat soils represent the highest concentration of organic matter in all soils. Peat is slowly accumulated material, consisting of at least 30% (dry mass) of dead organic material (see Glossary of Key Terms), and it forms where the activity of decomposing organisms is suppressed by waterlogging (anaerobic conditions) and /or climate. It ranges in character from moss peat in arctic, subarctic, and boreal regions; via reed/sedge peat and forest peat in temperate regions; to mangrove and swamp forest peat in the humid tropics (Driessen *et al.,* 2001). Peat exploitation over the past century, through cultivation and extraction, has caused a significant decline in the extent of peatlands and their organic matter status (Hooghoudt *et al.,* 1961; Hutchinson, 1980).

4.1 Key issues

Six key issues were identified at the start of the selection process:

- Soil organic matter status
- Soil organic matter quality
- Natural causes of soil organic matter change
- Human-induced causes of soil organic matter change
- Desertification
- Peatlands

Soil organic matter status is the most important key issue identified, because it is linked to both soil functioning, by its influence on many soil properties, and climate change through gas exchange between soil and atmosphere. SOM content is the result of slower decomposition rates than rates of OM inputs, via roots and litter and OM additions in soil management. SOM decomposition rates generally increase with increasing soil aeration (linked to soil porosity and soil wetness) and increasing temperatures (linked to climate, climate change, and land use). Relevant questions are: 'What are the present contents of organic matter in European soils? Are there trends in changes to these contents (decline, increase)? Could these trends be described at the European scale?'

Soil organic matter quality refers to the nature and the properties of soil organic matter compounds which influence soil functions, i.e. water retention, soil structural stability, porosity, nutrient retention, and nutrient source. Soil organic matter quality may be approached from a soil physical, chemical, and/or biological viewpoint. Generally, the most important factor contributing to a greater SOM quality is the nitrogen content of SOM. This key issue addresses these questions: 'What is the present organic matter quality in European soils? Are there trends in changes in soil organic matter quality in European soils? Could these trends be described at the European scale?'

Table 4.1 Overview of key issue selection for Decline in Soil Organic Matter

	Key issue selection		Description
	In	Out	
Soil organic matter characteristics	Soil organic matter status		Contents of organic matter in European soils and trends in changes to these contents
	Soil organic matter quality		Soil organic matter composition in European soils and trends in changes to this composition
		Peatlands	Covered under soil organic matter status key issues
Causes of decline in soil organic matter	Human-induced causes of changes in SOM		Human activities inducing changes in soil organic matter status or soil organic matter quality
		Natural causes of changes in SOM	Mainly the natural components of soil erosion and climate change, which are both covered in other parts of ENVASSO as a separate threat (Chapter 3) and a cross-cutting issue, respectively (Chapter 12).
		Desertification	Identified and implemented as a separate threat (see Chapter 11)

Peatlands
Peatlands refer to areas, with or without vegetation, where a natural peat layer of at least 30 cm has accumulated at the surface. Peatlands are estimated to contain up to one third of the global soil organic matter store. Land use and management practices could potentially accelerate the decomposition of peat soils and thereby contribute substantially to global warming. Montanarella *et al.* (2006) have estimated the extent of European peatlands, providing an invaluable basis from which to answer the key questions 'what is the extent of peat in Europe?' and 'what stocks of organic matter do peatlands contain?'

Human-induced causes of soil organic matter change
This is an important key issue as it relates to the identification of practices that influence soil organic matter contents: the associated key question is 'how are the controlling factors of organic matter status and quality changing in Europe'.

Natural causes of soil organic matter change
The most important natural factors causing SOM contents to change are climate, soil parent material, land cover and vegetation type, and topography. Climatic conditions, especially temperature and rainfall, exert a dominant influence on the amounts of organic matter found in soils. When moving from a warmer to a cooler climate, the organic matter content of comparable soils tends to increase, because the overall trend in the decomposition of SOM is accelerated in warm climates, whilst a lower rate of decomposition is the case for cool regions.

Effective soil moisture also exerts a very positive control upon the accumulation of SOM. In general, under comparable conditions, SOM content increases as the effective moisture becomes greater. This is explained by the fact that soil fauna and flora are more active, and the humification of SOM more rapid in areas of moderate to low rainfall, which tend to have less vegetation than wetter areas. Hence, if the climate becomes warmer and drier then SOM contents are likely to decline.

Desertification
When climatic conditions become more arid, the vegetation cover decreases, resulting in less organic matter being added to the soil (Kirkby *et al.,* 1996). This process is exacerbated by increasing aridity. Because of its cross-cutting nature, desertification is dealt with separately in ENVASSO (see Chapter 12).

4.2 Indicators

This section describes firstly the results of the indicator selection process, listing the selected indicators along with their disadvantages and advantages (section 4.2.1). Secondly, existing and/or proposed baselines and thresholds for the selected indicators are discussed (section 4.2.2). Thirdly, the data and user requirements for implementing the selected indicators in a European monitoring system are presented (section 4.2.3). Finally, the three most important indicators (TOP3), according to expert judgement, are proposed (section 4.2.4).

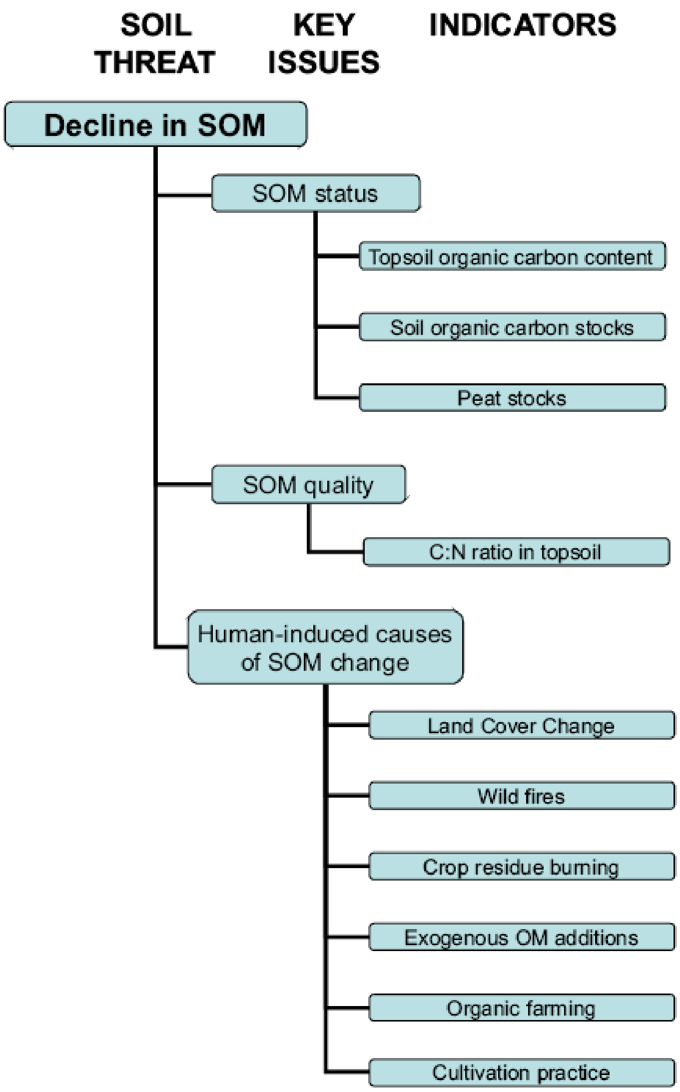

Figure 4.1 Key issue and indicator selection for Decline in Soil Organic Matter

4.2.1 Indicator selection

Initial proposals by the subgroup identified 39 indicators for four key issues. Several of these indicators were duplicates and were merged into a smaller number of clearly defined key issues and indicators (36). Most duplications involved soil organic matter contents. A numerical ranking system for the proposed indicators was employed, with expert judgement applied at the final stage. Following consultations at two subgroup meetings backed up by email exchanges, three key issues (see Figure 4.1) and ten indicators were selected.

The highest ranking selection criteria (by expert judgement) were:

1. Acceptability or the extent to which the indicator is based on ‘sound science’;
2. Practicability or the measurability of the indicator;
3. Policy relevance and utility for users;
4. Geographical coverage.

The advantages and disadvantages of these selected indicators are described below.

4.2.1.1 Soil organic matter status

Indicators are proposed for:

- Topsoil organic carbon content
- Soil organic carbon stocks
- Peat stocks

4.2.1.1.1 OM01 Topsoil organic carbon content

Advantages

i) Topsoil organic carbon content can be measured directly*.*
ii) Topsoil organic carbon content is an indicator relevant to potential risk of soil erosion and ‘Decline in soil Biodiversity’, as well as for the cross-cutting issue ‘Desertification’.
iii) Data on the organic carbon content in the topsoils of Europe are available in most Member States.

Disadvantages

i) The data are dispersed, not always easily accessible and are not harmonised.
ii) Discrepancies between European wide data can arise from differences in analytical methods (i.e. wet oxidation vs. dry combustion) and/or from differences in sampling depth (usually ranging from 0 to 15, sometimes down to 30 cm).
iii) As changes in soil organic carbon contents are rather slow, the minimum time interval over which changes can be observed (and therefore measurements are justified) is typically > 5 yr. As topsoil organic carbon content is highly variable spatially, small changes (< 5%) at a given site cannot be detected without using a large number of replicates (>100) (Conen *et al.,* 2004, Smith, 2004).

Conclusions

Soil organic carbon (SOC) content is measured routinely in surface horizons during soil surveys and on experimental sites, and hence there are sufficient data to apply this indicator at national and European scales.

4.2.1.1.2 OM02 Soil organic carbon stocks

Advantages

i) Organic carbon stocks are more relevant than organic carbon contents for assessing the role of soils in the global C cycle and monitoring overall changes in SOM.
ii) Organic carbon stocks can be calculated from two direct measurements.
iii) Measurement of density is also relevant to the threats ‘Soil Compaction’, ‘Decline in soil Biodiversity, and ‘Desertification’.

Disadvantages

i) Stocks require more sampling effort because of the need to determine bulk density, which is even more spatially and temporally variable than organic carbon contents, particularly in soils under arable land use.

Conclusions

This is an important indicator of soil condition, especially under the influence of climate change. However, resources for particularly bulk density measurements will have to be increased substantially to achieve accurate estimates.

4.2.1.1.3 OM03 Peat stocks

Advantages

i) This indicator is essential for assessing the role of soils in the global C cycle.
ii) It is also relevant to other threats such as soil erosion and Decline in Soil Biodiversity.

Disadvantages

i) To calculate peat stocks accurately, measures of variations in soil depth and bulk density are needed.
ii) Determining bulk density in peat (organic) soils is notoriously difficult because it is not easy to take undisturbed samples.
iii) Many peat soils are very deep, and measuring their thickness is rarely practicable.

Conclusions

This is an important indicator because peat constitutes a significant part of the SOM in Europe as a whole. However, resources for bulk density and depth measurements will have to be increased substantially to achieve accurate estimates.

4.2.1.2 Soil organic matter quality

Indicators are proposed for:

- C:N ratio of topsoil

4.2.1.2.1 OM04 C:N ratio of topsoil

Advantages

i) The C:N ratio is a relatively simple indicator of soil organic matter quality.
ii) Numerous data are already available on topsoil C:N ratio in the soils of Europe

Disadvantages

i) The data are dispersed and not always easily accessed and not harmonised.
ii) Discrepancies between European wide data can come from differences in analytical methods for both carbon (i.e. wet oxidation vs. dry combustion) and nitrogen (i.e. Kjeldahl vs. dry combustion) and/or from differences in sampling depth (usually ranging from 0-15 to 0-30 cm)

Conclusions

Possible changes in this indicator are expected to occur mainly in the topsoil although changes in C:N ratio are rather small except where there are changes in land cover, for example conversion from forest to farmland. Numerous data are already available on topsoil C:N ratio in the soils of Europe. Other indicators of SOM quality are described in the literature but it was concluded that these cannot be readily applied throughout Europe, as they are either essentially research techniques and costly, and/or lack general acceptance by the scientific community (see below 'non-selected indicators').

4.2.1.3 Soil organic matter change – human induced causes

Indicators are proposed for:

- Land cover change
- Wild fires
- Crop residue burning
- Exogenous OM application – including farmyard manure (FYM) and biowaste
- Organic farming
- Cultivation practice

4.2.1.3.1 OM05 Land cover change

Advantages

i) Changes in land cover strongly influence soil organic matter dynamics and are major human-induced pressures or responses that are relevant to all soil threats

ii) Changes in land cover are already monitored across Europe at 10 year intervals (Corine Land Cover and LUCAS programme)

Disadvantages

i) The spatial resolution achieved (ca. 25 hectares for Corine Land Cover, and only point maps for LUCAS) does not allow adequate detection of changes in mixed and complex landscapes including small adjacent fields with various land cover.

Conclusions

This is a relevant pressure indicator that is also cross-cutting and also relevant for soil erosion, soil contamination, Decline in soil Biodiversity, Landslides and Desertification.

4.2.1.3.2 OM06 Wild fires

Advantages

i) The existing European forest fire database can be used to map the extent of probable soil damage from wild fires (http://ies.jrc.cec.eu.int/inforest.html).

Disadvantages

i) At current levels of detection, it is sometimes difficult to estimate the extent to which fire has damaged the topsoil, e.g. whether or not the organic matter in the soil has been burnt as well as the overlying vegetation.

Conclusions

This indicator is important for its capacity to monitor SOM change and is equivalent to the desertification indicator DE02, but the requirements for spatial data resolution (1 hectare) are different for its application to SOM changes.

4.2.1.3.3 OM07 Crop residue burning

Burning of crop residues is an ancient practice, essentially human-induced, whereas wildfires are normally accidental.

Advantages

i) Burning of crop residues affects both SOC contents and SOM quality.
ii) Crop residue burning is readily observed.

Disadvantages

i) There is no harmonised database on crop residue burning practices in Europe

Conclusions

Crop residue burning deprives the soil of an additional source of organic matter. Straw, the residue from cereal crops, is the most commonly burnt material. This is an important indicator that requires a harmonised methodology and database for monitoring in Europe.

4.2.1.3.4 OM08 Exogenous OM additions

Advantages

i) Exogenous inputs of OM, e.g. 'farmyard manure' are widespread in Europe and can, if applied at high rates, alter the soil organic matter status and quality substantially.
ii) Applications of some forms of exogenous OM, e.g. sewage sludge, are linked to soil contamination (e.g. heavy metals) and are therefore important to monitor.

Disadvantages

i) It is very difficult to estimate the production of slurries, manure and other exogenous organic wastes in Europe, as only a few Member States have published data (Van-Camp *et al.,* 2004).
ii) Harmonised European data are not available

Conclusions

The disposal of exogenous organic wastes is an important problem and this indicator is important to inform policy.

4.2.1.3.5 OM09 Area of organic farming

Advantages

i) It has been reported that soils within organic (or ecological, or biological) farming systems have higher organic matter contents than conventional mineral fertilized soils (Drinkwater *et al.,* 1998).

Disadvantages

i) Harmonised data on areas under organic farming systems are not available at the European scale.

Conclusions

This is a proxy indicator for soil organic matter contents. However, because the actual soil organic matter content depends on many other factors, the 'area of organic farming' is an incomplete and uncertain indicator. This indicator is similar to the indicator CO03.

4.2.1.3.6 OM10 Cultivation practice

Cultivation practices include conservation tillage such as zero tillage or minimum tillage, and contour ploughing to reduce soil erosion losses.

Advantages

i) This indicator is highly relevant for intensively farmed land and is also important for soil erosion.
ii) Tillage practices have a direct effect on organic matter profiles in soil and on mineralization rates.

Disadvantages

i) There are few harmonised data at the European scale.
ii) The data that do exist are often georeferenced to administration unit level (e.g. NUTS), and thus insufficient for risk area identification.

Conclusions

The extensive list of parameters to monitor this indicator (frequency of tillage, depth of tillage, tools for tillage, etc.) as well as uncertainties about their interpretation, suggest that this is not a practical indicator for application in the short-term.

4.2.1.4 Indicators proposed but not selected

A number of indicators were not selected for reasons of:

- poor geographical coverage at present and large resources being required to achieve adequate coverage in future;
- poor or absent scientific consensus on protocols or methodology;
- insufficiently robust methods being available at present.

The indicators that were rejected by the selection process are described in more detail below:

Total carbon stocks down to 1 m depth and *soil organic matter profiles down to 1 m depth* would be useful indicators for assessing the role of soil carbon on greenhouse gases and climate change. Globally, it has been shown that 30-60% of the total organic carbon in soil is held in layers deeper than 30 cm (Batjes, 1996). This organic carbon in deep layers may play an important role in the long-term global carbon cycle as the mean residence time of organic carbon is much higher in deep layers than in topsoil (Rumpel *et al.,* 2002). However, the geographical coverage of SOC measurements to this depth in existing soil monitoring networks is very poor (see WP2 report) and their introduction would require considerable resources.

The *soil organic matter stratification ratio* is defined by the SOC at the soil surface divided by the SOC at a lower depth (e.g. deeper than the tillage layer); this normalises the assessment and simplifies the comparison of values recorded under different climatic-soil conditions (Leifeld and Kögel-Knabner, 2005; Franzluebbers, 2002), but there is no accepted methodology to derive this indicator. Further research is needed before establishing recommendations for implementing this indicator.

Depth of 'A_p' or ploughed horizon might be important to consider as a SOM status indicator, in order to assess the effect of ploughing depth on SOM 'dilution' and homogenisation of the SOM contents, or as a 'causes of SOM changes' indicator. However, most of the present soil monitoring networks use fixed depths and do not take into account the depth of tillage. Moreover, to be efficient, the monitoring of this indicator would require the measurement of a starting value, followed by relatively short time steps and numerous field observations.

Dissolved organic carbon to total soil organic carbon ratio could be an indicator of SOM quality, and an indicator of SOM impact on water. In situ measurements are so spatially and temporarily variable that they would be very time and costly to implement. Further research is needed to define laboratory measurements within a generally accepted protocol.

Soil respiration rate is an indicator of soil microbial activity which is partly related to SOM quality. This indicator is sensitive to soil moisture and temperature, and to inputs of fresh organic matter. Therefore, the time steps required to monitor this indicator and to interpret its variations restrict its potential use to research sites (see Chapter 9).

The *chemical composition of organic matter* as determined on the total SOM or on physically separated pools, might be a good indicator of its recalcitrance to mineralisation (Derenne and Largeau, 2001), but current techniques are too costly to implement at the European scale. Some promising and low cost techniques (e.g. Near-Infra-Red Spectroscopy) might be recommended in the future if these are developed further and agreement can be reached on a common testing and data analysis methodology.

Recalcitrant SOM is a fraction of SOM which is thought to be protected from biodegradation, either because of its chemical composition (Derenne and largeau, 2001), or because of its physical localisation in soil (Balesdent *et al.,* 2000), or due to physico-chemical interactions with other soil components (Rumpel *et al.,* 2002). Research is still needed to establish a commonly accepted measurement methodology.

Particulate organic matter is a labile fraction of SOM which is very sensitive to changes in soil management and rapidly depleted when virgin soils are cultivated (Arrouays *et al.,* 1995; Balesdent *et al.,* 2000). Particulate organic matter has been shown to be more physically protected from biodegradation when it is within soil aggregates (Puget *et al.,* 1995; Besnard *et al.,* 1996). Although this indicator is widely used in research, harmonisation of methods is still necessary before it can be implemented at the European scale.

SOM molecules size/weight might be an indicator of the degree of polymerisation of SOM molecules and of their recalcitrance. It might be considered as a sub-indicator of the indicator 'chemical composition of organic matter'. This research measurement is not suitable for inclusion in a European-wide monitoring system.

Table 4.2 Overview of proposed indicators for Decline in Soil Organic Matter

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
OM01	**SOM Status**	**What are the present organic matter contents in topsoils of Europe?**	**Topsoil organic carbon content (measured)**	**%**	**S**	**S**	**G**	**5 to 10**	**16 km x 16 km for forests, to be discussed for other land uses after WP2 results**
OM02	**SOM Status**	**What are the present C stocks in topsoils of Europe?**	**Soil organic carbon stocks (measured)**	**$t\ ha^{-1}$**	**S**	**S**	**G**	**5 to 10**	**16 km x 16 km for forests, to be discussed for other land uses after WP2 results**
OM03	**SOM Status**	**What are the peat stocks in Europe?**	**Peat stocks (calculated or modelled)**	**M t**	**S/I**	**S**	**R**	**10**	**National inventories; European soil and organic carbon topsoil databases**
OM04	SOM Quality	What is the present organic matter quality in topsoil in Europe?	C:N ratio of topsoil (measured)	Number	S	S	G	5 to 10	16 km x 16 km for forests, to be discussed for other land uses after WP2 results

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
OM05	SOM Changes – human-induced causes	Are there changes in Land Cover that might affect SOM dynamics? Where?	Land Cover Change (estimated by remote sensing, Corine land cover, or statistics)	km^2	P/R	S	G	1 to 10	25 ha
OM06 Same as (DE02)	SOM Changes – human-induced causes	Where and to what extent are the areas affected by wild fires?	Wild fires (estimated by remote sensing or statistics)	km^2	P	S	R	1	50 ha
OM07	SOM Changes – human-induced causes	What (and where) are the areas affected by straw burning?	Crop residue burning (estimated by statistics)	km^2	P	S	G (except for forests, deserts)	1	NUTS 3
OM08	SOM Changes – human-induced causes	What (and where) are the inputs of exogenous organic matter to soils in Europe, as farmyard manures & slurries?	Exogenous organic matter additions – farmyard manure and other biowaste (proxy indicator, estimated from statistics on livestock and population)	$t\ ha^{-1}$	P/I	S	G (except for forests, deserts)	1	NUTS 3
OM09 same as (CO03)	SOM Changes – human-induced causes	What (and where) are the areas under organic farming in Europe?	Organic farming (proxy indicator, area estimated from statistics)	%	R	S	G (except for forests, deserts)	1	NUTS 3
OM10	SOM Changes – human-induced causes	Where are the areas in which cultivation (incl. conservation) practices might induce significant changes in soil organic matter?	Cultivation practice (proxy indicator, estimated by statistics, need to define a tillage classification)	%	P/R	M	G	1	National statistics; NUTS 1 to 3

Abbreviations:
Indicator ID: OM = Decline in soil organic matter
DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response;
Applicability: S = short-term, M = medium-term;
Monitoring: G = generally, R = in risk areas only;
TOP3 indicators are in bold.

4.2.2 Baseline and threshold values

The quantitative evidence for critical thresholds for soil organic matter content (SOM) is slight (Körschens *et al.,* 1998; Loveland and Webb, 2003) but there is a widespread belief that without adequate levels of SOM the soil will not be able to function optimally (Van-Camp *et al.,* 2004). Baselines could be defined as the present status of soil organic matter, but the concept of a baseline for SOM is questionable, as SOM is often not in equilibrium and so current contents may alter regardless of directly human-induced causes (IPCC, 2003; Smith, 2005; Bellamy *et al.,* 2005).

4.2.2.1 Soil organic matter status

4.2.2.1.1 OM01 Topsoil organic carbon content

Baseline

It is unsound to define a single baseline for soil organic carbon content in all topsoils. The SOC and SOM contents depend strongly on geo-climatic factors (Jones *et al.,* 2005), on land use (McGrath and Loveland, 1992; Arrouays and Pelissier, 1994), on soil type and clay content (Arrouays *et al.,* 2001, 2006), on combinations of clay contents and precipitation (Verheijen *et al.,* 2005), and on management practices (Carter 1992; Soussana *et al.,* 2004). Therefore, baselines values should be area specific (i.e. the value measured over an area for a given date). Ranges of reference values specified for different land uses, clay content, and climate can be derived from soil data by analysis of inventories (Verheijen *et al.,* 2005). There is also some consensus that there is a well-defined relationship between lower limits for SOC in a soil and its texture (specifically, its clay and fine silt content) (see Table 4.3).

Table 4.3 Overview of SOC limit estimates relative to clay contents

Publication	Slope (m) of lower limit	Slope (m) of upper limit	Related soil particle size (µm)	n	Related environmental conditions	Sample, landuse and region
Körschens and Klimanek (1980)	0.04	ND	<63	11	Loess soils and temperate continental climate	Long term experimental 'nil' plots (Germany)
Körschens *et al.* (1998)	0.068	ND	<63	21	Loess soils and temperate continental climate	Long term experimental 'nil' plots (Germany)
Körschens *et al.* (1998)	0.035 - 0.045a	0.035 - 0.05a	<63	ND	Loess soils and temperate continental climate	ND
Hassink *et al.* (1997)	0.04	ND	<20	32	Temperate and tropical climates excluding Australian soils	Uncultivated and grassland experimental sites
Hassink *et al.* (1997)	0.037	ND	<20	39	Temperate and tropical climates (worldwide)	Uncultivated and grassland experimental sites
Loveland *et al.* (1997)	0.04	ND	<2	1261	Variety of soils and range of precipitation in temperate climate	Soil profile survey of arable and grassland on commercial farms (England and Wales)
Freytag (1980)	0.047	0.069	<2	numerous		Germany

a=determined from published data, ND=Not Determined
(adopted from Verheijen, 2005)

Although the magnitude of the relationship between SOC contents and fine particles (clay and fine silt) measurements is reaching consensus, a single baseline for SOC contents may not be appropriate because of variations in land use and management, which when combined with climate may alter the lower limit substantially. For upper SOC limits relative to clay contents, there is not sufficient evidence to form a consensus. Verheijen *et al.* (2005) developed a methodology to determine baselines, i.e. lower and upper limits, of SOC which they successfully applied on the National Soil Inventory dataset of England and Wales (McGrath and Loveland, 1992). Similar methodologies can be applied to other inventories in the EU as or when they are available (see for instance Arrouays *et al.,* 2006 for French soils).

Threshold

Although the lower threshold of 2% soil organic carbon has been used widely (Kemper and Koch, 1966; Greenland *et al.,* 1975), it is clear that a large proportion of intensively cultivated soils of Europe have already reached low levels (Loveland and Webb, 2003; Arrouays *et al.,* 2001, 2006) and even where the majority of soils have less than 2% SOC, i.e. for 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 disequilibrium in N-supply to plants might occur, leading to a decrease of both SOM and biomass production (Körschens *et al.,* 1998). Whatever the threshold, the depth of sampling is a major issue, because of the strong gradients in SOM with depth, and because the soil properties of interest might be important for the upper few centimetres (e.g. risk of erosion linked to aggregate stability) or for the whole arable layer (e.g. nutrient availability) or even to greater depths (e.g. available water capacity). The thresholds, if any, should depend on the properties and functions of soil that SOM influences (crop production and nutrient availability, available water capacity, aggregate stability, cation exchange capacity, porosity, etc.). Although some studies proposed ranges of values, i.e. lower and upper limits increasing with increasing clay content (Körschens *et al.,* 1998), we agree with Loveland and Webb (2003) who appear to have correctly concluded that there is no quantitative evidence for critical thresholds for SOM in relation to crop yields.

4.2.2.1.2 OM02 Soil organic carbon stocks

Baseline

For the same reasons as those cited above, there is no single baseline value for soil carbon stocks but, if enough data are available, it is possible, by using statistics, to propose ranges of values as for topsoil SOC contents (Arrouays *et al.,* 2001, 2006; Verheijen *et al.,* 2005).

Threshold

Considering only the ‘carbon sink’ function in relation to greenhouse gas inventories, then it may be appropriate to use a threshold of a neutral or positive carbon stock balance, at a large geographically aggregated scale, between two dates.

4.2.2.1.3 OM03 Peat stocks

Baseline and threshold

There are no precise measurements of the extent and depth of peat soils for the whole of Europe. However, Montanarella *et al.* (2006) provide the most comprehensive estimates of the area of peatlands based on the European Soil Database and some detailed national data sets. If it is accepted that peat is a valuable resource, that takes a long time to form and should be protected, a baseline and threshold value at the European scale could be the present total stocks of peat (Mt).

4.2.2.1.4 OM04 C:N ratio of topsoil

Baseline

As for soil organic matter content, it is difficult to define a single baseline for the C:N ratio in topsoil. Moreover, it is even more difficult as C:N ratio is even more dependent on climatic and vegetation factors. For cultivated soils, a wide range of *ca.* 8 to 30 might be considered as possible. Obviously, the baseline ranges, if any, should be related to climate, soil type and vegetation, and could be derived by using statistics as for OM01 and OM02.

Threshold
Not available

4.2.2.2 Soil organic matter change – human-induced

4.2.2.2.1 OM05 Land cover change

Baseline
The baseline can be defined as the land cover on a given date.

Threshold
It is difficult to fix a threshold value for changes in land cover. An acceptable threshold could be that the rates of changes known to decrease SOM contents in soils (e.g. changes from forests or permanent grasslands to arable lands) do not increase with time.

4.2.2.2.2 OM06 Wild fires

The baseline is very difficult to define, as it is highly dependent on climatic factors. There is considerable year to year variation in the location and extent of wild fires in Europe.

4.2.2.2.3 OM07 Crop residue burning

Baseline
The baseline should be the present area where crop residues are burned regularly. However, there is no harmonised database on the burning practices for straw and other residues in Europe. Furthermore, the regularity of burning would have to be defined.

Threshold
From a strict SOM point of view, the threshold for crop residue burning would be no burning with all crop residues returned to the soil.

4.2.2.2.4 OM08 Exogenous OM additions

Baseline
The baseline could be the amount of exogenous organic matter, especially farmyard manure (FYM) and other biowastes, which is applied to soil in a given reference year. However, it is very difficult to estimate the production of slurries and manure in Europe, as only a few Member States have published data (Van-Camp *et al.,* 2004). Even if the amounts of exogenous organic materials were known, it would be very difficult to establish precisely where these materials were applied.

Threshold
It is impossible to determine a threshold for exogenous OM applications in Europe. A target could be to maintain inputs at, or only slightly above, the baseline.

4.2.2.2.5 OM09 Organic farming

The area under organic farming is highly variable amongst regions in Europe. However, only national data are available at the European scale. A baseline could be the area under organic farming in a given year. However, a baseline or threshold does not appear applicable for this indicator. Some countries have defined target values between 10 and 20 % organic farming for the years 2005 or 2010 which could be used instead of a baseline.

4.2.2.2.6 OM10 Cultivation practice

Recording of tillage practices could be useful as a pressure or a response indicator. Tillage practices have a direct effect on organic matter profiles in soil and on mineralisation rates. However, the list of parameters to monitor (frequency of tillage, depth of tillage, tools for tillage, etc.) and the way to use them for monitoring are far from clear. The baseline could be determined by applying statistics on observed practices in a certain year which would include soil conservation practices. A threshold does not appear applicable.

4.2.3 Data and user requirements

Table 4.4 Summary of data and user requirements for Decline in Soil Organic Matter

Indicator ID	Indicator	Input parameter	Data source required	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
OM01	Topsoil organic carbon contents (measured)	OC content in g kg^{-1} in 0-10 cm to 0-30 cm layers (depth to be agreed) and/or in A or ploughed layers	harmonised point data from all countries	to be defined by WP2	EU	10 yr	high	g kg^{-1}	5% relative change
OM02	Soil organic carbon stocks (measured)	C stocks in kg m^{-2}, down to a depth to be agreed	harmonised point data from all countries	to be defined by WP2	EU	10 yr	high	kg m^{-2}	5% relative change
OM03	Peat stocks	total volume of peat	maps of peat depth for all countries	1km x 1km	EU	10 yr	high	km^3, Pg	5% relative change
OM04	C/N ratio in topsoil	C:N ratio in topsoil (in 0-10 cm to 0-30 cm layers (depth to be agreed) and/or in A or ploughed layers)	harmonised point data from all countries	to be defined by WP2	EU	10 yr	high	no unit	5% relative change
OM05	Land Cover Change	areas in which land Cover changes between two dates	more precise land use change matrix	25 ha	EU	5 yrs	high	ha, km^{-2}	1% relative change
OM06	Wild fires	Burnt area	EFFIS	50 ha	EU	annually	high	ha	5% relative change
OM07	Crop residue burning	Burnt area	regional enquiries	NUTS 3	EU	annually	high	ha	5% relative change
OM08	Exogenous OM additions	amounts of exogenous OM (biowaste) applied	enquiries at the municipality level	NUTS 3	EU	annually	high	tons	1% relative change
OM09	Organic farming area	percentage of area under organic farming	statistics at nut3 level	NUTS 3	EU	annually	high	%	1%
OM10	Cultivation practices	% area under soil various cultivation practices, including no-tillage and minimum tillage	statistics at nut3 level	NUTS 3	EU	annually	high	%	1%

4.2.4 TOP3 indicators

Table 4.5 TOP3 indicators for Decline in Soil Organic Matter

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 - Topsoil organic carbon content is a relatively simple indicator that can be measured directly. It is the indicator for soil organic matter which is currently most 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. measures to encourage 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 - Soil organic carbon stocks are related directly to the influence of soils on the Global Carbon Cycle and greenhouse gas budgets. Baselines could be estimated by statistical analysis of organic carbon stocks at a given date. One approach would be to set thresholds so that total carbon stocks over a given area should not decrease in time.

OM03 – Peat stocks is a crucial indicator, because peat soils are much richer in organic matter than mineral soils and, therefore, can be considered 'hot-spots' where decline in SOM content should be monitored. Moreover, peat soils are also hot spots for biodiversity, and they play a significant role on greenhouse gas exchanges between soil and the atmosphere (CO_2, CH_4, N_2O). This indicator is easy to interpret by policy makers. There is a consensus that peat soils should be protected, or even that formerly drained wetlands should be re-established. A baseline value could be the present status of peat stocks in Europe (Montanarella *et al.,* 2006). One approach could be to set threshold values so that no further decrease should occur in the mass of peat.

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5 SOIL CONTAMINATION

It is important to distinguish clearly between diffuse and local soil contamination. Diffuse soil contamination is the presence of a substance or agent in the soil as a result of human activity emitted from moving sources, from sources with a large area, or from many sources (adapted from ISO11074). Diffuse soil contamination is caused by 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. It 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 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 definition for ‘contaminated site’ and ‘potentially contaminated site’ (Table 5.1). The definitions published by the working group of the Soil Thematic Strategy are the most recent with the broadest recognition. The ISO 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.

Table 5.1 Selected definitions of contaminated sites

Terms relevant to soil contamination	Definitions
Contaminated site (1)	Site with areas of high concentrations of substances hazardous to soil and soil functions (ISO 11074)
Contaminated site (2)	A well-delimited area where the presence of soil contamination has been confirmed and the severity of possible impacts to ecosystems and human health are such that remediation is needed, specifically in relation to the current or planned use of the site. The remediation or clean-up of contaminated sites can result in a full elimination or reduction of these impacts (EEA 2006 / CSI015 fact sheet).
Hazardous site	A site which, by reason of the substances or agents present, is judged to be hazardous to human health or safety, or to the environment (ISO 11074)
Potentially contaminated site	Any site where soil contamination is considered possible but not verified and where investigations need to be carried out to verify whether relevant impacts exist (EEA 2006 / CSI015 fact sheet)
Potentially hazardous site	Site, the history of which or other information, leads to a possibility that it may be hazardous (ISO 11074).

5.1 Key issues

The three major pathways for the input of contaminants into soil are atmospheric deposition, agriculture, local sources (including flood events), waste disposal and accidents. To allow coverage of a wide variety of contaminants, with differing chemical properties, arising from a variety of sources by different pathways, five key issues were defined, four of which refer to diffuse soil contamination (see also Table 5.3).

1. Diffuse contamination by heavy metals and other inorganic contaminants (except nutrients)
2. Diffuse contamination by nutrients and pesticides
3. Diffuse contamination by persistent organic pollutants
4. Diffuse contamination by soil acidifying substances
5. Local contamination by point sources

Diffuse contamination by heavy metals and other inorganic contaminants (except nutrients) is probably the most important key issue within diffuse contamination, because the contamination is practically irreversible. It focuses on heavy metals accumulating in soil not only from human activities but also from natural sources.

Diffuse contamination by nutrients and biocides focuses on the contamination of soils by agriculture. The input of macro elements and their compounds, as nitrate and phosphate, and pesticides and herbicides are the main issues. This contamination tends to be more concentrated in areas with intensive agricultural production.

Diffuse contamination by persistent organic pollutants results from emissions by industrial, domestic and commercial activities, and transport. The major pathway is atmospheric deposition. Modern pesticides should not contribute to this contamination as their licensing requires that they do not leave significant residues in the soil. However, neither the illegal use of pesticides nor the residues from the historic use of persistent pesticides should not be overlooked,

Diffuse contamination by soil acidifying substances relates mainly to the input of nitrate and sulphate by wet and dry deposition.

Local contamination by point sources such as industrial plants, accidents and waste disposal.

Table 5.2 Overview of key issue selection for Soil Contamination

Contamination type	Key issues selected	Description
Diffuse contamination	heavy metals and other inorganic contaminants (except nutrients)	including trace elements from various origins, other than nutrients, which accumulate in soil
	nutrients and biocides	focusing on the input from agriculture of nutrients e.g. nitrate and phosphate, as well as insecticides, fungicides, herbicides, and other biocides
	persistent organic pollutants	covering emissions by industrial, domestic and commercial activities and transport
	soil acidifying substances	including nitrate and sulphate in wet and dry deposition
Local contamination	point sources	covering inputs from industrial plants, accidents and waste disposals

5.2 Indicators

Firstly, the results of the indicator selection process are described, listing the selected indicators along with their disadvantages and advantages (Section 5.2.1). Secondly, existing and/or proposed baselines and thresholds for the selected indicators are discussed (Section 5.2.2). Thirdly, the data and user requirements for implementing the selected indicators in a European monitoring system are presented (Section 5.2.3). Finally, the three most important indicators (TOP3) according to expert judgement, are proposed (Section 5.2.4).

5.2.1 Indicator selection

The indicators were selected based on a literature search and a standardised ranking procedure using a numerical analysis with weighting of factors. A brief description of the selection process is given in the methodology chapter. Four ENVASSO partner organisations carried out the analysis for diffuse soil contamination and two did so for local contamination. Four qualitative inputs were made by other partners.

It was decided to select two indicators per key issue. To meet this goal, the selection criteria focused on data availability as well as on sensitivity and meaningfulness of the indicators. The short- and medium-term feasibility of using the indicators was considered in the selection process. Indicators that were identified as being of good potential for improved soil management, but for which practical barriers exist to their use at the European scale in the short-term, were included in the analysis. The final list of selected indicators is shown in the diagram in Figure 5.1 (see also Table 5.3).

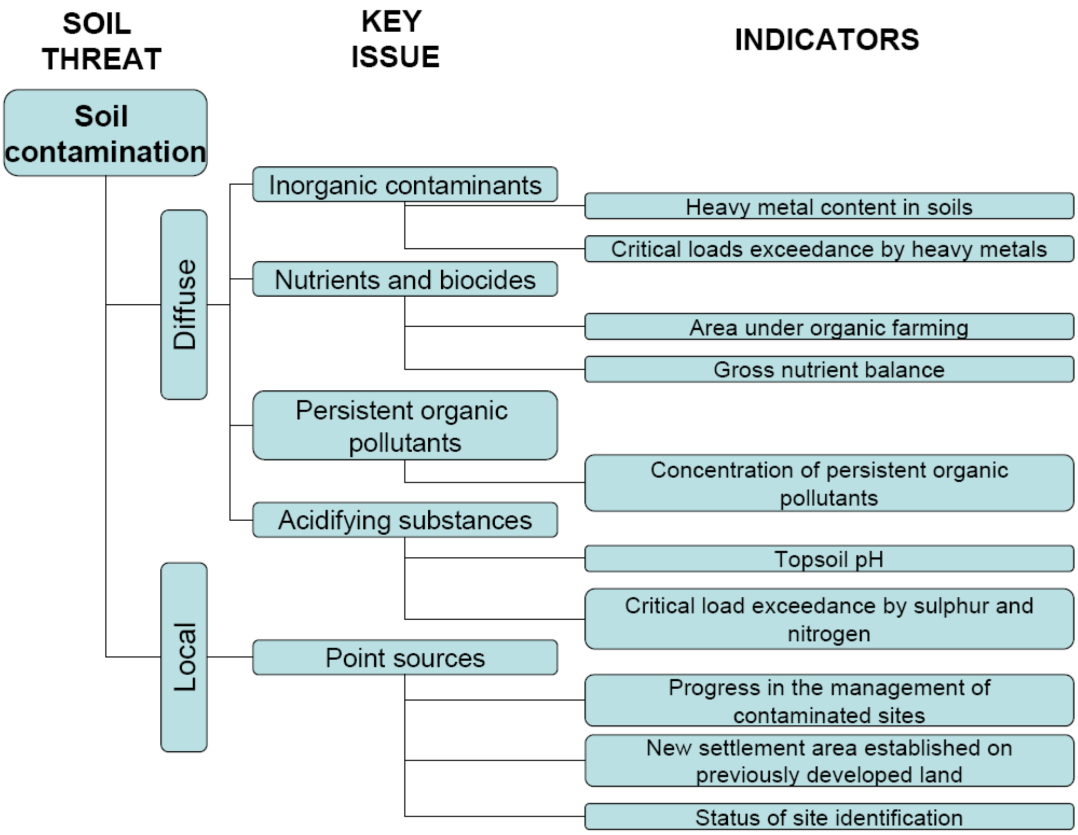

Figure 5.1 Key issue and indicator selection for Soil Contamination

5.2.1.1 Diffuse contamination by heavy metals and other inorganic contaminants

The combination of the two following indicators could provide useful information to identify areas where there is an existing impact from diffuse contamination and areas where the risks from future contamination may justify additional protective measures.

5.2.1.1.1 CO01 Heavy metal contents in soils

Advantages:
- i) The indicator is relatively simple to interpret
- ii) Many relevant data are available throughout Europe

Disadvantages:
- i) Changes in the indicator values are generally slow (> 5 yr)
- ii) The data quality, accessibility and harmonisation are variable throughout Europe

Conclusions:
The indicator is a state indicator which gives basic information on the status of heavy metal contamination and its change in the long term.

5.2.1.1.2 CO02 Critical load exceedance by heavy metals

Advantages:
- i) Changes of the indicator value are relatively fast (< 2 yr)
- ii) Many data and a common methodology are available

Disadvantages:
- i) The current application of the indicator is limited
- ii) In the short-term it precludes its use at the European scale

Conclusions:
Critical loads exceedance by heavy metals provides a measure of the effectiveness of any soil protection measures. In particular, the focus is on cadmium, lead and mercury deposited on soils with different land covers. The methodology for its implementation is described in the ICP Modelling and Mapping manual (2004).

5.2.1.2 Diffuse contamination by nutrients and biocides

5.2.1.2.1 CO03 Area under organic farming

Advantages:
- i) This indicator has been introduced by the EEA (2005a) in its core set of indicators
- ii) Considerable volumes of data are available across Europe (EEA, 2005a)

Disadvantages:
- i) It is a very general indicator giving no precise information on soil contamination from agriculture
- ii) It assumes that organic farming is less polluting than traditional farming

Conclusions:
CO03 is an indicator of change in the extent of organic farming. The indicator reveals a key trend in agriculture and gives a possible indication of the development of soil contamination in agriculture. It might be considered that organic farming eliminates soil contamination. However, organic farming may contaminate soils and/or groundwater with Cu, Zn, and nutrients because of the use of manure or slurry. This indicator is similar to the indicator OM09, but the interpretation is different because another key issue is concerned.

5.2.1.2.2 CO04 Gross nutrient balance

Advantages:
- i) This Indicator has been introduced by the EEA (2005a) in its core set of indicators
- ii) It is relatively easy to interpret

Disadvantages:
i) The calculation of the indicator is quite complex

Conclusions:
The Indicator provides information concerning over-fertilisation and potential leaching of nutrients. In general the indicator is easy to interpret, although the calculation is quite complex (OECD, 2003). The required data should be available, as the indicator has been implemented for many years (e.g. as 'nitrogen balance' of OECD, 2001).

5.2.1.3 Diffuse contamination by persistent organic pollutants

5.2.1.3.1 CO05 Concentration of persistent organic pollutants

Advantages:
i) Persistent organic pollutants are a continuing problem for soil protection

Disadvantages:
i) Only limited monitoring data are available at present
ii) Data coverage of Europe is limited
iii) Measurement costs are high

Conclusions:
CO05 is a state indicator that could be used to identify areas where there is a risk of harm to receptors from contamination by persistent organic pollutants. Only limited data are available at present, due to the large number of organic pollutants and the complexity of their measurement. In the long term, it could be a valuable indicator, as existing initiatives such as those in United Kingdom (e.g. Loveland and Thompson, 2001) and in Germany (UBA, 2002) become more widespread.

5.2.1.4 Diffuse contamination by soil acidifying substances

5.2.1.4.1 CO06 Topsoil pH

Advantages:
i) Topsoil pH is a relatively straightforward measure that is widely used and understood
ii) This indicator is already implemented in the ICP Forest Programme (ICP, 2004)

Disadvantages:
i) Generally, changes in indicator values are slow (> 5 yr)

Conclusions:
CO06 is a state indicator that provides information about soil acidity. It can be used to assess the impacts of aerial deposition, altered land use and soil management on soil acidity. It gives information on the soil pH status and of trends in soil acidification. At the continental scale, the indicator is implemented in the ICP Forest Programme under the Convention of Long Range Transboundary Air Pollution (UN-ECE, 2003). At national scales, statistics are available for several land uses.

5.2.1.4.2 CO07 Critical load exceedance by sulphur and nitrogen

Advantages:
i) This indicator has already been introduced by the EEA (2005a) in its core set of indicators
ii) Data and a common methodology are available across Europe.

Disadvantages:
i) This indicator does not give information on the actual status of soil acidification

Conclusions:
This indicator identifies areas receiving critical loads of acidifying substances, indicating where there is a higher risk of soil acidification. The methodology for the critical loads concept is described in the ICP Forest mapping manual (2004).

5.2.1.5 Local contamination by point sources

Attempts to achieve a pan-European consensus on the definition of 'contaminated site' have been unsuccessful. Two approaches are presented below that circumnavigate the need for a common term, by monitoring responses and measures linked to 'local contamination by point sources'.

This EEA strategy is based on measuring progress within defined management steps against targets. It has four management steps, three of which correspond to the ISO standard 10381-5, 'preliminary investigation', 'exploratory investigation', 'main site investigation', plus an additional management step 'measures completed' (see also CO08 and CO10).

The definition of management phases for sites with local contamination can support future effective monitoring of local soil contamination, by allowing progress to be assessed at the European and Member State levels. The EEA (2002) have tested this approach in selected regions.

5.2.1.5.1 CO08 Progress in the management of contaminated sites.

Advantages:
i) This is an established indicator (EEA 2005a) and provides information on whether or not efforts on the management of contaminated sites are increasing or decreasing over time.
ii) The indicator shows the progress within five logical management steps.

Disadvantages:
i) The indicator provides no quantitative information on the actual area or volume of contaminated soil or the degree of contamination.
ii) A clear quantification of the state of local soil contamination is not possible
iii) The indicator lacks detailed geo-referenced information, since data are aggregated.

Conclusions:
The proposed indicator is the result of extended research and expert consultation carried out by the EEA. One of the key conclusions of this process was agreement that it is not possible to achieve harmonisation of existing national registers on contaminated sites in the short term. However, common agreement was reached on the description of individual management steps and how to measure the progress with these against targets (EEA 2002).

5.2.1.5.2 CO09 - New settlement area established on previously developed land.

Advantages:
i) This indicator is also recommended by the threat 'Soil Sealing' (indicator SE05).
ii) This indicator is already monitored in the United Kingdom (DEFRA 2005).

Disadvantages:
i) Clear quantification of the state of local soil contamination is not possible
ii) The indicator lacks detailed geo-referenced information, since data are agglomerated at national scales.

Conclusions:
This indicator is relevant to both this key issue and 'soil sealing' (e.g. SE05). It measures the area and proportion of new settlements (housing, commercial and industrial sites, infrastructure, etc.) established on previously developed land ('brownfields') in relation to the total area of newly developed land. It quantifies changes in the rate of brownfield re-development, and provides information about how much 'recycling' of brownfields has contributed to reducing consumption of 'greenfield' sites.

5.2.1.5.3 CO10 - Status of site identification.

Advantages:

i) This indicator is part of an established EEA indicator
ii) Some limited quantification of the state of local soil contamination is possible.

Disadvantages:

i) Quantification of the state of local soil contamination is possible but very weak
ii) The indicator lacks detailed geo-referenced information, since data are aggregated at national scales.

Conclusions:

This indicator is part of the EEA core set indicator CSI015 (EEA 2005a). Management of contaminated sites is a tiered process – four management steps are defined according to the EEA definition. This indicator provides information on the number of identified sites for the first management step (preliminary investigation) per reporting area and relative population. Meaningful comparison between reporting areas is very limited. For this reason this indicator is considered of minor significance compared to CO08 and SE05.

Table 5.3 Overview of proposed indicators for Soil Contamination

ID	Key issue	Key question	Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
CO01	**Diffuse contamination by inorganic contaminants**	**Which areas show critical heavy metal contents in excess of national thresholds?**	**Heavy metal contents in soils**	**%**	**S**	**S**	**R**	**20**	**Point data; national**
CO02	Diffuse contamination by inorganic contaminants	Are we protecting the environment effectively against heavy metal contamination?	Critical load exceedance by heavy metals	%	P	M	R	5	EMEP-Grid (50 km x 50km)
CO03	Diffuse contamination by nutrients and biocides	What are the environ-mentally relevant key trends in agricultural production systems?	Area under organic farming	%	R	S	G	1	National
CO04	Diffuse contamination by nutrients and biocides	Is the environmental impact of agriculture developing?	Gross nutrient balance	kg ha^{-1} yr^{-1}	S	S	G	1	National
CO05	Diffuse contamination by persistent organic pollutants	Which areas show critical concentration of organic pollutants?	Concentration of persistent organic pollutants	%	S	M	R	5	Regional, national
CO06	Diffuse contamination by soil acidifying substances	How is the environmental impact of soil acidification developing?	Topsoil pH	-	S	S	G	10	Regional, national

Table 5.3 continued

ID	Key issue	Key question	Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
CO07	**Diffuse contamination by soil acidifying substances**	**Are we protecting the environment effectively against acidification and eutrophication?**	**Critical load exceedance by sulphur and nitrogen**	**%**	**P**	**S**	**R**	**2**	**National; EMEP-Grid (50 km x50 km)**
CO08	**Local soil contamination by point sources**	**How is the management of contaminated sites progressing?**	**Progress in management of contaminated sites**	**% of all sites**	**R**	**S**	**G**	**2**	**National or defined regions**
CO09	Local soil contamination by point sources	Is developed land efficiently used?	New settlement area established on previously developed land	% of new sites	R	S	G	2	National or defined regions
CO10	Local soil contamination by point sources	How many sites exist which might be contaminated?	Status of site identification	Number of sites	S	S	G	2	National or defined regions

Abbreviations: Indicator ID: CO = Soil Contamination, ; DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response; Applicability: S = short-term, M = medium-term;
Monitoring: G = generally, R = in risk areas only; TOP3 indicators in bold letters.

5.2.2 Baseline and threshold values

5.2.2.1 Diffuse contamination by heavy metals and other inorganic contaminants

5.2.2.1.1 CO01 Heavy metal contents in soils

It is proposed that nationally defined thresholds should be used, where these exist and are specific to soil parent material type and land use. Where national thresholds have not been defined, thresholds from other countries or regions with comparable parent material and land use could be used. Most Member States have data available on the heavy metal contents of soil for at least some heavy metals in some areas, that could be useful when identifying baselines.

Baseline

Background values 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 (e.g. calculation of the 85th or 90th percentile of a harmonized data set) (Umweltbundesamt, 2004a). Based on this information guideline values for a further assessment of the soil status can be derived (Österreichisches Normungsinstitut, 2004).

A comprehensive study was conducted by Utermann *et al.* (2004) under contract to DG-JRC, Ispra, leading to an overview of the trace element contents of European topsoils, differentiated according to soil parent material and land use, to soil pH and soil texture. Table 5.4 shows the ranges for heavy metal background contents of soils (according to ISO 19258).

Table 5.4 Range of median values of *aqua regia* extractable heavy metals contents

Heavy metal	Background contents (mg kg^{-1} dry soil) (JRC study)[1]
Cadmium (Cd)	0.07-1.48
Chromium (Cr)	5-68
Copper (Cu)	2-32
Mercury (Hg)	0.02-0.29
Nickel (Ni)	3-48
Lead (Pb)	9-88
Zinc (Zn)	6-130

1 Range of heavy metal contents (median values) in 11 European countries without differentiation according to parent material and with regard to all land uses types (Provisional report, Utermann *et al.* 2004)

The background values given in the JRC report differ according to parent material, land use and differing anthropogenic impacts. Depending on the objective, other stratification models are possible. Table 5.5 shows different stratification criteria used in different legal frameworks

Threshold

Heavy metal thresholds exist in some Member States and should be defined at national, or at larger regional scale, to allow for varying natural conditions. Threshold values have often been defined in the context of regulations for sewage sludge application and food production, but also need to be protective of multifunctional use of soils. Thus, 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 often be inadequate to consider all impacts for different types of soil use. Further research on the impacts of heavy metal contamination on soil biota and studies on heavy metal leaching into water supplies is needed. Some examples of existing threshold values at European and Member State scales are given in Table 5.5. A comprehensive compilation of limit values for soils, in the context of sewage sludge applications, is given by Marmo (2001).

Table 5.5 Heavy metal thresholds for soil in different selected (European) regulations/recommendations

	86/278/ EEC[1]	86/278/ EEC (ENV.E.3/LM) (2000) [2]			BioAbfV (1998) [3] BBodSchV (1999) [4] (BRD)			AbfKlärV (1992) [5] (BRD)	Eikmann/ Kloke (1993)[6]	Leidraad Bodem-sanering (1998) [7]	VBBo (1998) - Richtw. [8] (CH)	Klär [9]
		5<pH<6	6<pH<7	pH>7	T[10]	L[10]	S[10]		BWI	(NL)		(AU)
Cd	1-3	0.5	1	1.5	1.5	1	0.4	(1)-1.5	1	0.8	0.8	0.5–2
Pb	50–300	70	70	100	100	70	40	100	100	85	50	50-100
Cr	---	30	60	100	100	60	30	100	50	100	50	50-100
Cu	50–140	20	50	100	60	40	20	60	50	36	40	40-100
Hg	1–1.5	0.1	0.5	1	1	0.5	0.1	1	0.5	0.3	0.5	0.2–2
Ni	30–75	15	50	70	70	50	15	50	40	35	50	30–70
Zn	150-300	60	150	200	200	150	60	(150)-200	150	140	150	100-300

1 Current “Council Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture”
2 Working document on sludge 3rd draft (04/2000)
3 & 4 German regulations using the same soil (precautionary) threshold values (Organic Waste Directive and Soil Protection Directive)
5 German Sewage Sludge Directive; (in brackets: threshold for soils with < 5% clay or 5<pH<6)
6 Orientation values of the EIKMANN & KLOKE (1993) concept, BWI = threshold for multifunctional utilisation;
7 Netherlands guideline for soil assessment and soil remediation: Soil values according to contents of clay (L) and organic matter (H) (standard soil (25% L, 10% H)
8 Verordnung über Belastungen des Bodens (Schweiz): Target values for the total contents (HNO_3)
9 Austrian guideline and threshold values; ranges according to 6 different directives within Austria (different Federal Provinces) (after Umweltbundesamt, 2004b)
10 German soil texture classes T=clay; L= loam, S=sand

5.2.2.1.2 CO02 Critical load exceedance by heavy metals

Critical loads for heavy metal inputs to soil should be calculated as described in the manual for UNECE-ICP Modelling and Mapping. The exceedance is the difference between the relevant critical loads and the actual deposition. So far the methodology is described only for Pb, Cd, and Hg. Following the request in 2004 for data made by UNECE-ICP, 17 countries delivered data for at least one of Pb, Cd, and Hg.

Baseline

An appropriate baseline could be the critical loads at a point in time (usually the first assessment of the implemented indicator) against which subsequent loadings are compared.

Threshold

According to the definition of critical loads and their exceedances, the threshold of a critical load exceedance must be the critical load itself. As critical loads for heavy metals are calculated in relation to receptors and land use (see Table 5.6; ICP Modelling and Mapping, 2004) thresholds should be differentiated accordingly.

Table 5.6 Types of critical loads of heavy metals, related receptors and land cover

Receptor system	Critical loads related to	Metals of concern	Land cover types to be considered	Indicator addressed by the critical limit
Terrestrial	Human health effects	Cd, Pb, Hg	Arable land	Metal content in food/fodder drops
		Cd, Pb, Hg	Grassland	Metal content in grass, animal, products (cow, sheep)
		Cd, Pb, Hg	Arable land, grassland, non-agricultural land	Total metal concentration in soil water below the rooting zone
	Ecosystem functioning	Pb, Cd	Non-agricultural land, arable land, grassland	Free metal ion concentration in soil solution in view of effects on soil micro-organisms, plants and invertebrates
		Hg	Forests only	Total metal concentration in humus layer in view of effects on soil micro-organisms and invertebrates
Aquatic	Human health effects	Hg	Freshwaters	Metal concentration in fish
	Ecosystem functioning	Pb, Cd, Hg	Freshwaters	Total metal concentration in freshwaters in view of effects on algae, crustacea, worms, fish and top predators

5.2.2.2 Nutrients and biocides

5.2.2.2.1 CO03 Area under organic farming

This indicator identifies the changes in the area under organic farming and is already included in the EEA (2005a) core set of indicators.

Baseline

A baseline could be the area under organic farming in a certain year.

Threshold
The definition of a threshold does not seem to be appropriate for this indicator. Some Member States have set target values of achieving between 10% and 20% organic farming area for the years 2005 or 2010, but these are based on policy objectives rather than scientific evidence.

5.2.2.2.2 CO04 Gross nutrient balance

This indicator has already been included in the EEA (2005a) core set of indicators. It could be assessed regionally or as the mean nutrient surplus of the gross nutrient balance (nitrogen and phosphorous) for the European Union in total. The EEA (2005b) estimated the surplus for nitrogen to be 55 kg ha^{-1} yr^{-1} in 2005.

Baseline
An appropriate baseline could be the nutrient balance at a point in time, such as when the first assessment using the indicator is made against which subsequent balances are compared.

Threshold
A threshold could relate to the maximum surplus of nutrients that ensures adequate protection of water, by taking account of soil type, geology and connected aquifer types should be considered in the assessment.

5.2.2.3 Organic pollutants

5.2.2.3.1 CO05 Concentration of persistent organic pollutants

This indicator describes the concentrations of persistent organic pollutants in soils.

Baseline
Current background concentrations in agricultural soils could be used to set baselines for individual organic pollutants (see ISO 19258 for background values).

Threshold
Some Member States have set national policy targets for concentrations of some persistent organic pollutants. Due to differing natural and other conditions, thresholds should be considered at Member State or regional scales. Table 5.7 presents the German precautionary soil threshold values for organic pollutants (BBodSchV, 1999).

Table 5.7 Precautionary soil threshold values of organic pollutants

Soil organic matter (SOM)	Unit	PCB (DIN 38414 S 21, 2002)	Benzo(a)pyrene	PAH (DIN 38414 S 23, 2002)
> 8 %	mg kg^{-1} (dry matter)	0.1	1	10
≤ 8 %		0.05	0.3	3

Source: German Soil Protection Ordinance, BBodSchV, 1999

5.2.2.4 Soil acidification

5.2.2.4.1 CO06 Topsoil pH

This indicator describes the overall acidity and alkalinity of the soil. It has considerable influence on land use and biodiversity, although, *vice versa*, land use and soil management also affect soil pH.

Baseline
The baseline could be set by reference to background values depending on land use and parent material (an estimation of 'natural' pH value), although the influences of fertilisation and liming have to be taken into account.

Threshold
A threshold could be values that indicate a critical soil pH beyond which sustainable functioning of the soil is limited. For agricultural land pH-target values for good agricultural practice, for example, are given in e.g. the German Soil Mapping Guide (Ad-hoc AG Boden, 2005). Another example for pH threshold values is the German regulation for the recycling of mineral residues (including excavated soil) and wastes, which includes pH. The precautionary pH threshold values for the recycling of excavated soil are given in Table 5.8.

Table 5.8 German precautionary threshold values for pH in excavated soil (topsoil is regulated separately)

	Z0	Z1.1	Z1.2	Z2
Soil	5.5-8	5.5-8	5.5-9	
Eluate (DIN 38414 S5,1981)	6.5-9	6.5-9	6-12	5.5-12

Z0= use not limited
Z1= use limited
Z2= use limited with technical safety measures
Eluate= 1:5 Extract (H_2O)

5.2.2.4.2 CO07 Critical load exceedance by sulphur and nitrogen

Critical loads for acidification should be calculated according to the Mapping Manual of the UNECE-ICP Modelling and Mapping. Exceedance is the difference between the relevant 'critical load' and the actual deposition (SOx, NOx, NHx).

Critical loads for acidification are available for all Member States, in the background-database of the Coordination Centre for Effects (CCE). For each Member State, there is a spatial data set estimating critical loads in different locations.

Baseline
A baseline could be the exceedance in the first year of monitoring.

Threshold
According to the definition of critical loads and their exceedances, the threshold of a critical load exceedance must be the critical load itself. As critical loads for acidification are calculated in relation to land use, thresholds should be differentiated accordingly.

5.2.2.5 Local contamination

5.2.2.5.1 CO08 Progress in management of contaminated sites

Baseline

Recommendations for defining a baseline:

- A baseline for this indicator would ideally correspond to the indicator value in a reference year; i.e. the year when monitoring of this indicator started.
- The definition of a baseline can only be based on policy decision making; there is no scientific basis for defining a baseline.

Threshold
For this indicator a threshold can only be defined by policy decision-making in the sense of a political agreement. Targets have not been established at the European scale at present, although targets exist in most of the EEA area (see Table 5.9).

5.2.2.5.2 CO09 New settlement area built on previously developed land

Baseline

Baselines for this indicator are nonexistent at present at the European level.
Recommendations for defining a baseline:

- A baseline for this indicator would ideally correspond to values of this indicator at a defined reference year; i.e. the year when monitoring of this indicator started.
- The baseline based on actual redevelopment in a given year can be defined without policy input.

Threshold

For this indicator a threshold can only be defined by policy decision-making. In the case of the UK, the Government has set a target of 60% of new development to be built on previously developed land.
Source: http://www.defra.gov.uk/environment/statistics/land/kf/ldkf07.htm

Table 5.9 Example for national targets for the management of contaminated sites according to EIONET priority data flow 2003

Country	Year	Policy or technical target
Austria	2030-2040	Essential part of the contaminated sites problem should be managed.
Belgium (Flanders)	2006 2021 2036	Remediation of the most urgent historical contamination. New contamination to be remediated immediately. Remediation of urgent historical contamination. Remediation of other historical contamination causing risk.
Bulgaria	2003-2009	Plan for implementation of Directive 1999/31/EC on Landfill of waste.
Czech Republic	2010	Eliminate the majority of old ecological damage.
France	2005	To establish an information system on polluted soil (BASIAS) with the objective to provide a complete scope of the sites where soil pollution is to be suspected.
Hungary	2050	To complete measures at all sites with contamination. Government Decision No. 2205/1996 (VIII.24.) adopted National Environmental Remediation Programme (OKKP).
Lithuania	2009	Waste disposal to all landfills not fulfilling special requirements should be stopped. All waste landfills not fulfilling special requirements should be closed according to approved regulations.
Malta	2004	Closure of Maghtab and il-Qortin waste disposal sites.
Netherlands	2030	All historical contaminated sites investigated and under control and remediated when necessary.
Norway	2005	To solve environmental problems on sites with contaminated soil, where investigation and remediation is needed. On sites where further investigation is needed, the environmental state shall be clarified.
Sweden	2020	Environmental quality objective: a non-toxic environment.
Switzerland	2025	The 'dirty' heritage of the past should be dealt with in a sustainable way within one generation.
UK (England and Wales)	2007	The Environment Agency aims to substantially remediate and/or investigate 80 Special Sites identified under Part IIA Regime (Environmental Protection Act 1990).

Source: http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007131746/full_spec

5.2.2.5.3 CO10 Status of site identification

Baseline

Defined baselines do not exist at present.

Recommendations for defining a baseline are:

- A baseline for this indicator would ideally correspond to values of this indicator at a defined reference year; i.e. the year when monitoring of this indicator started.
- The baseline based on actual redevelopment in a given year can be defined without policy input

Threshold
For this indicator the definition of a quantitative threshold is not possible. Only a qualitative threshold can be defined in the sense of an ‘upward trend’. This means that the number of contaminated sites identified should increase with time.

5.2.2.6 Overview of baselines and thresholds for soil contamination

Table 5.10 Information on baselines and threshold values for soil contamination indicators

Key issue	Key question	Indicator	Baseline	Threshold
Diffuse contamination by inorganic contaminants	Which areas show heavy metal contents exceeding national thresholds?	Heavy metal contents in soils	National values available	National values available
Diffuse contamination by inorganic contaminants	Are we protecting the environment effectively against heavy metal contamination?	Critical load exceedance by heavy metals	To be defined	Critical load
Diffuse contamination by nutrients and biocides	Where is diffuse contamination influenced by agricultural production systems?	Area under organic farming	To be defined	Not applicable
Diffuse contamination by nutrients and biocides	How is the nutrient surplus in agriculture developing?	Gross nutrient balance	e.g. 55 kg N ha^{-1} yr^{-1}	To be defined; (e.g. 170 kg N ha^{-1} yr^{-1} for organic fertilizer application)
Diffuse contamination by persistent organic pollutants	Which areas show critical concentration of organic pollutants?	Concentration of organic pollutants	To be defined	To be defined; for selected substances in selected Member States national policy targets exist
Diffuse contamination by soil acidifying substances	What is the status of soil acidification and how is it developing?	Topsoil pH	To be defined	National target values defined
Diffuse contamination by soil acidifying substances	Are we protecting the environment effectively against acidification?	Critical load exceedance by sulphur and nitrogen	To be defined	Critical load
Local soil contamination	How is the management of contaminated sites progressing?	Progress in management of contaminated sites	to be defined; no proposals exist yet	Selected Member States have national policy targets defined
Local soil contamination	Is developed land efficiently used?	New settlement area established on previously developed land	To be defined; no proposals exist yet	Selected Member States have national policy targets defined
Local soil contamination	How many sites exist which might be contaminated?	Status of site identification	To be defined; no proposals exist yet	To be defined

5.2.3 Data and user requirements

Table 5.11 Summary of data and user requirements for Soil Contamination

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
CO01	Heavy metal contents in soils	Site description (coordinates, land use, parent material); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, texture) Analyses (content of heavy metals, method of analyses, detection limits)	national soil data bases; critical limits; background values	depends on the scale required, if EU national	EU-wide	20 Years	comparability of methods should be improved	% of area or plots exceed	approx. 20% relative change
CO01a	Cd contents in soils	Site description (coordinates, land use, parent material); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, texture) Analyses (content of heavy metals, method of analyses, detection limits)	national soil data bases; critical limits; background values	depends on the scale required, if EU national	EU-wide	20 Years	comparability of methods should be improved	% of area or plots exceed	approx. 20% relative change
CO01b	Cu contents in soils	Site description (coordinates, land use, parent material); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, texture) Analyses (content of heavy metals, method of analyses, detection limits)	national soil data bases; critical limits; background values	depends on the scale required, if EU national	EU-wide	20 Years	comparability of methods should be improved	% of area or plots exceed	approx. 20% relative change
CO01c	Hg contents in soils	Site description (coordinates, land use, parent material); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, texture) Analyses (content of heavy metals, method of analyses, detection limits)	national soil data bases; critical limits; background values	depends on the scale required, if EU national	EU-wide	20 Years	comparability of methods should be improved	% of area or plots exceed	approx. 20% relative change
CO01d	Pb contents in soils	Site description (coordinates, land use, parent material); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, texture) Analyses (content of heavy metals, method of analyses, detection limits)	national soil data bases; critical limits; background values	depends on the scale required, if EU national	EU-wide	20 Years	comparability of methods should be improved	% of area or plots exceed	approx. 20% relative change
CO02	Critical load exceedance by heavy metals	HM uptake by plants; critical leaching; actual deposition	better HM-deposition model	EMEP-Grid (50x50 km)	UNECE area, national	5 years	better deposition model; better adjustment of data and methodologies	% of area or plots exceed	50% relative change
CO02a	Critical load exceedance for Cd	Cd uptake by plants; critical leaching; actual deposition	better HM-deposition model	EMEP-Grid (50x50 km)	UNECE area, national	5 years	better deposition model; better adjustment of data and methodologies	% of area or plots exceed	50% relative change

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
CO02b	Critical load exceedance for Hg	Hg uptake by plants; critical leaching; actual deposition	better HM-deposition model	EMEP-Grid (50x50 km)	UNECE area, national	5 years	better deposition model; better adjustment of data and methodologies	% of area or plots exceed	50% relative change
CO02c	Critical load exceedance for Pb	Pb uptake by plants; critical leaching; actual deposition	better HM-deposition model	EMEP-Grid (50x50 km)	UNECE area, national	5 years	better deposition model; better adjustment of data and methodologies	% of area or plots exceed	50% relative change
CO03	Area under organic farming	Percentage of area under organic farming (area under organic farming, total farming area)	to be checked	depends on the scale required, if EU national	EU-wide	Annually	improvement not required	%	20% relative change
CO04	Gross nutrient balance	Input of nitrogen (fertilizers, deposition, N-assimilation by plants) output of nitrogen (plant uptake, leaching, denitrification, volatilization)	to be checked	depends on the scale required, if EU national	EU-wide	Annually	improvement seems not to be required	Kg ha^{-1} yr^{-1}	20% relative change
CO05	Concentration of persistent organic pollutants	Site description (coordinates, land use); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, bulk density, orgC) Analyses (concentration of organic pollutants (µg/kg), method of analyses, detection limits)	to be checked	depends on the scale required, if EU national	EU-wide	5 Years	more research needed	% of area or plots polluted	30% relative change
CO05a	Concentration of PCB(6)	Site description (coordinates, land use); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, bulk density, orgC) Analyses (concentration of organic pollutants (µg/kg), method of analyses, detection limits)	to be checked	depends on the scale required, if EU national	EU-wide	5 Years	more research needed	% of area or plots polluted	30% relative change
CO05b	Concentration of Benzo(a)pyrene	Site description (coordinates, land use); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, bulk density, Corg) Analyses (concentration of organic pollutants (µg/kg), method of analyses, detection limits)	to be checked	depends on the scale required, if EU national	EU-wide	5 Years	more research needed	% of area or plots polluted	30% relative change
CO05c	Concentration of PAK (16)	Site description (coordinates, land use); profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, bulk density, Corg) Analyses (concentration of organic pollutants (µg/kg), method of analyses, detection limits)	to be checked	depends on the scale required, if EU national	EU-wide	5 Years	more research needed	% of area or plots polluted	30% relative change
CO06	Topsoil pH	Site description (coordinates, land use, parent material); profile descriptions (soil type, horizons, horizon depth, sampling depth, Topsoil pH)	to be checked	depends on the scale required, if EU national	EU-wide	10 Years	improvement seems not to be required	pH units	10% relative change

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
CO07	Critical load exceedance by sulphur and nitrogen	Biomass uptake by plants; parent material; critical leaching; actual deposition of nitrogen, sulphur and base cations	to be checked	National; EMEP-Grid (50 km x 50 km)	UNECE area, national	2 years	More accurate data would improve the results; better adjustment of data and methodologies	% of area exceed (eq/ha/a)	30% relative change
CO08	Progress in the management of contaminated sites	no. of identified sites per management step; estimated total no. of sites per management step	to be checked	ideally regional aggregagation to NUTS3	EU, agreement on hot spot regions (highly industrialised and populated) reasonable	2 years	improvement of data consistency, smaller resolution of geographical survey units (regional instead of national)	%	1% relative change
CO09	New buildings built on previously developed land	no. of new housing sites per year on developed and undeveloped land	to be checked	ideally regional aggregagation to NUTS3	EU, agreement on hot spot regions (highly industrialised and populated) reasonable	2 years		%	1% relative change
CO10	Status of site identification	Number of sites included in preliminary study (sites per 1,000 capita)	to be checked	ideally regional aggregagation to NUTS3	EU, agreement on hot spot regions (highly industrialised and populated) reasonable	2 years	improvement of data consistency, smaller resolution of geographical survey units (regional instead of national)	Number of sites	1 site relative change

5.2.4 TOP3 indicators

Table 5.12 TOP3 indicators for Soil Contamination

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 - eavy metal contents in soils (related to national thresholds) was selected as a TOP3 indicator. Diffuse contamination by nutrients and pesticides is strongly related to the impacts of agriculture. While important, this contamination is sector specific and therefore the indicator (CO04) is of less value when evaluating diffuse contamination in general. Diffuse contamination by inorganic contaminants together with diffuse contamination of persistent organic pollutants is an important key issue. Data availability for heavy metal contents in soils is reasonable, but is poor both for estimating exceedance of critical loads by inorganic contaminants and concentration of persistent organic pollutants.

CO07 - Diffuse contamination by soil acidification is judged to be more important than diffuse contamination by inorganic or organic contaminants, because soil acidification is a major problem and more widespread, especially in many countries in northern Europe.

CO08 - It was decided that the third TOP3 indicator should relate to local soil contamination. Out of the three indicators proposed for this issue the following selection was made.

- Indicators CO08 and CO09 were evaluated as most relevant with comparable ratings. Since the indicator CO09 'New settlement area established on previously developed land' is already recommended by the soil threat 'soil sealing' (see SE05), the indicator CO08 'Progress in management of contaminated sites' is recommended.
- Indicator CO10 'Status of site identification' is considered of minor significance compared to CO08 and CO09. The indicator lacks a clear target and can only show a trend.

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6 SOIL SEALING

Soil is sealed when agricultural or other rural land is taken into the built environment (land consumption) and is also a continuing process within existing urban areas, especially where urban population and the density of built structures is increasing and residual inner-city green zones are reduced. 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, i.e. as a result of the wider process of land consumption. Both processes – soil sealing and land consumption – are closely interrelated, usually occur in parallel, and denote different degrees of intensity of human soil consumption. In both cases, natural, semi-natural and rural land is turned to urban and other artificial land covers, which causes adverse effects on, or loss of, soil functions. Therefore, when the term 'Soil Sealing' is used in the context of it representing a soil threat it refers to both processes. Key issues have also been selected for major consequential impacts of soil sealing and land consumption and for related response strategies.

When 'Soil Sealing' is used as a key issue, it is defined by the ENVASSO Glossary of Key Terms as: "The destruction or covering of soil by buildings, constructions and layers or other bodies of artificial material which may be very slowly permeable to water (e.g. asphalt, concrete, etc.), causing a deterioration or loss of one or more soil functions" (based on Burghardt *et al.,* 2004). In contrast, 'land consumption' is a broader concept that – according to the ENVASSO Glossary of Key Terms – "relates to all land development for settlement-related human activities by which previously undeveloped land is urbanised, i.e. agricultural, forest or natural land are turned into built-up areas". Thus, land consumed comprises both sealed and unsealed areas.

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. Soil sealing has most impact in urban and metropolitan areas 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%. Today 75% of the European population live in urban areas. This will increase by 2020 to 80% and in seven countries the proportion will be 90% or more (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 albedo, evaporation and local air temperatures. It increases surface water runoff, which leads to additional flood risk and in some cases catastrophic floods (Burghardt *et al.,* 2004). And it alters and generally reduces the options for biodiversity conservation and restoration. In the most extreme case soil sealing leads to a complete removal of soil.

Most social and economic activities depend on the construction, maintenance and existence of sealed areas and developed land, which therefore have a strong relation to gross national products (Burghardt *et al.,* 2004). Soil consumption has, however, considerable consequences for society and economy. The loss of soil resources caused by soil sealing is effectively irreversible and reduces the availability of soil resources to future generations, whose discretion for action and options for development are thereby narrowed (Lexer *et al.,* 2005; Banko *et al.,* 2004). Urban sprawl, in particular, causes loss of land for agricultural and forest production and high financial burdens for public households due to the low cost-effectiveness of investments (increased costs for establishment, maintenance and operation of housing, technical infrastructures and public services) (UBA Berlin, 2003; Doubek & Hiebl, 2001; Doubek & Zanetti, 1999).

At present, in some Member States soil sealing, land consumption and some response measures (brownfield redevelopment, de-sealing) are monitored in a quantitative way by applying mostly statistical methods or aerial photograph interpretation. There is, however, a lack of European-wide information and much of these data is not comparable since different methodologies are used. At the European level, land consumption is currently assessed by calculating the extent and growth in built-up areas (urban sprawl) from the Corine land cover database (CLC 1990 and 2000) on the basis of satellite images (EC & EEA, 2005). In addition, the MOLAND (Monitoring Land Use Dynamics) database allows assessing change rates in built-up areas at regional and local level for a limited number of urban areas (EEA, 2006). All monitoring approaches mentioned use the extent of built-up area as a proxy indicator to estimate the sealing degree of the land consumed. The Soil Thematic Strategy Technical Working Group on Research, Sealing and Cross-Cutting Issues identified in particular the following high priority research needs for monitoring and assessment of soil sealing: harmonising methods procedures in the European Union; establishing monitoring methods for sealing that include quality parameters of soils (Burghardt *et al.,* 2004).

6.1 Key issues

Four key issues were identified at the start of the selection process:

- Soil sealing
- Land consumption
- Brownfield redevelopment
- Fragmentation

These key issues are defined as follows:

Soil sealing can be defined as the destruction or covering of soil by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.) (Burghardt *et al.,* 2004). It is the most intense form of land consumption and is essentially an irreversible process. Sealed land is a subset of the land consumed by development of settlements, infrastructure, and commercial and industrial areas. An indicator of the intensity of land consumption is the proportion of the total built-up land area which is sealed.

Land consumption occurs where previously undeveloped land is taken in to the built environment, as a result of land development for human settlements and related infrastructure, such as housing, utilities, transport, industry and commercial activities, recreation, etc. It is one of the main pressures causing soil loss. Consumed land is composed of both sealed areas (buildings, road surfaces, car parks, etc.) and unsealed areas (residential gardens, residual space between buildings, unsealed parts of transport corridors, etc.).

Brownfield redevelopment. 'Brownfields' can be defined as land that has previously been developed and brought in to the built environment, but which is not in current active use or is available for re-development. Recycling of Brownfields instead of developing greenfield land outside the built environment reduces land consumption and further soil sealing. Some but not the majority of Brownfield sites are contaminated to differing extents and these require risk assessment and in some cases appropriate clean-up and restoration measures.

Fragmentation. Fragmentation is a process of spatial segregation of entities that need to be together in order to function optimally (Carsjens, 2000). Landscape and habitat fragmentation is caused by land consumption, particularly where this leads to linear artificial landscape structures. Anthropogenic fragmentation of landscapes in industrialized countries has been recognized as a major cause of biodiversity loss. Landscape fragmentation results mainly from expansion and increased densities of transport infrastructure (roads, rail, airports, etc) and by the extension of settlement areas and built-up land. The ecological impacts of habitat fragmentation are diverse and comprise, *inter alia*, dissection, separation and isolation of habitats due to physical barrier effects, reduction of usable habitat size, and disruption of wildlife corridors. Apart from impacts on biodiversity, fragmentation further enhances the dispersion of contaminants to soil and alters water regimes that affect soil functions.

With only minor changes to some wordings, all of the key issues that were proposed initially have been selected (Table 6.1). None was added because due to an aggregated approach to the definition of key issues they were found to be broad enough to cover all candidate indicators that were compiled in the literature review. Also, no key issue was excluded because all of them were rated to be important to monitoring of the soil threat 'Soil Sealing'. The inclusion of 'fragmentation' was to some extent a contentious issue because it is more recognized as a biodiversity threat rather than a soil issue, but it was decided not to omit it because fragmentation is seen as a major consequence of soil sealing on above ground biodiversity. 'Brownfield redevelopment' was originally also pre-selected as an indicator of the key issue 'local contamination' under the soil threat 'Soil Contamination' but is, however, thought to be more relevant to 'Soil Sealing' because by no means are all brownfield sites contaminated, and because it relates to one of the most important response policies for the limitation of sealing.

Table 6.1 Overview of key issue selection for Soil Sealing

Key issue	Key issue selection		Description
	In	Out	
Soil sealing	Soil Sealing		destruction or covering of soil by buildings, constructions and layers or other bodies of artificial material which may be very slowly permeable to water (e.g. asphalt, concrete, etc)
Land consumption	Land consumption		land development for settlement-related human activities by which previously undeveloped land is urbanised, i.e. agricultural, forest or natural land are turned into built-up areas; comprises both sealed and unsealed areas
Brownfield redevelopment	Brownfield redevelopment		re-usage of land that has been used previously for settlement and industrial or commercial purposes, but is currently not used for these purposes; recycling of such derelict land for similar purposes
Fragmentation	Fragmentation		spatial segregation of habitats that need to be together in order to function optimally; consequence of soil sealing by (mainly) linear artificial structures, such as transport corridors; recognized as a main cause of losses in terrestrial (aboveground) biodiversity

6.2 Indicators

This section describes firstly the results of the indicator selection process, listing the selected indicators along with their disadvantages and advantages (Section 6.2.1). Secondly, existing and/or proposed baselines and thresholds for the selected indicators are discussed (Section 6.2.2). Thirdly, the data and user requirements for implementing the selected indicators in a European monitoring system are presented (Section 6.2.3). Finally, the three most important indicators (TOP3), according to expert judgement), are proposed (Section 6.2.4).

6.2.1 Indicator selection

Initial proposals by the subgroup identified 33 indicators for four key issues.

A numerical rating, weighting and ranking system for the evaluation of the proposed indicators was employed. In a first step, a harmonized numerical weighting of the seven defined selection criteria (see chapter 1) was performed among the subgroup members. Relying on expert judgments, the selection criteria were ranked according to their importance in the following order:

1. Significance;
2. Acceptance of methodology or analytical soundness;
3. Practicability or the measurability;
4. Policy relevance and utility for users;
5. Geographical coverage;
6. Availability of baselines and thresholds;
7. Comprehensibility.

For each of the proposed indicators then a weighted numerical analysis of all individual ratings by the subgroup members was carried out and the indicators were ranked according to their overall evaluation performance. This procedure led to a preliminary set of 11 top-ranking indicators for all 4 key issues, with 2 to 4 indicators per key issue. Based on consultations at two subgroup meetings backed up by email exchanges this pre-selection set was then reduced to the final indicator set. On the one hand, that reduction was done by merging overlapping indicators and by combining to one indicator what turned out to actually be different units or output parameters of the same indicator. On the other hand, a few indicators were omitted. Six indicators were selected into the final proposal (see Figure 6.1), none of the four key issues was excluded.

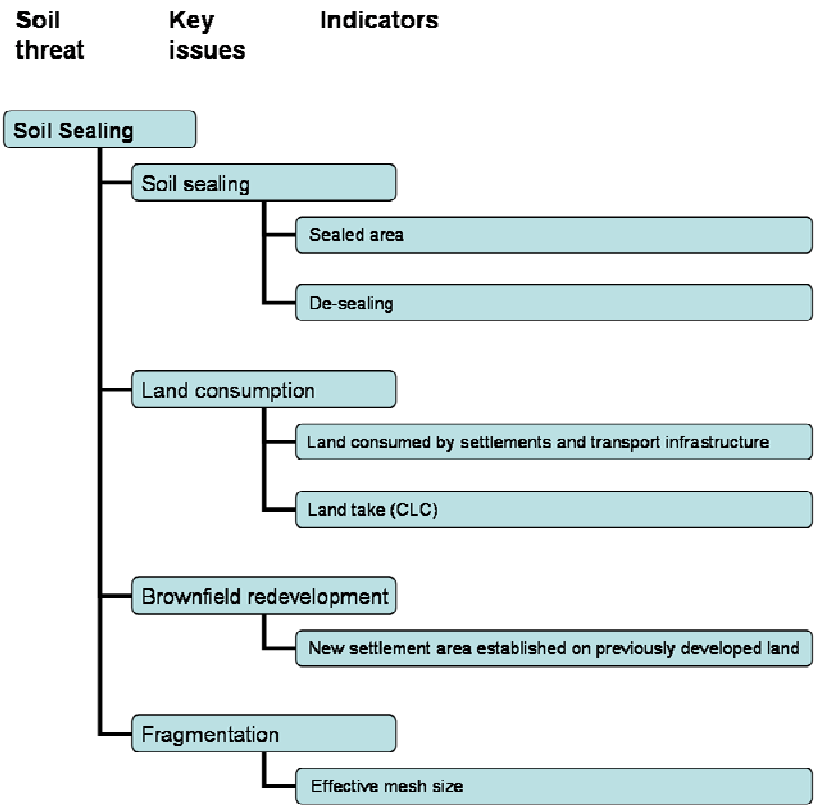

Figure 6.1 Key issue and indicator selection for Soil Sealing

Within the key issue 'Soil Sealing', growth rate and absolute area of sealed soil were combined under indicator SE01 'Sealed area' because they both measure the same phenomenon but provide complementary information on state and trend of sealing. Within the key issue 'land consumption', settlement area per capita was integrated as an additional unit into indicator SE03 'Land consumed by settlements and transport infrastructure' because it can easily be calculated from the same database and only basic demographic data, which are easily available, are required as additional input parameter; yet, it provides added information on a population's spatial efficiency of settlement-related land use. The remaining indicators that were not selected are: i) sealed area per soil quality class, because the proposed methodological approach to combine Corine land cover change data with EUSIS data on soil quality classes is limited by poor spatial resolution and data quality, is neither published nor tested and would be meaningful mainly for issues related to agricultural production; ii) number and percentage of 'undissected low-traffic regions', because indicator SE06 'Effective mesh size', in comparison, represents the more advanced indicator approach to fragmentation and has proven to be well suited for comparing the fragmentation of regions that differ in their total area.

6.2.1.1 Soil sealing

Indicators are proposed for:

- Sealed Area: absolute area and growth rate of area of sealed soil;
- De-sealing: absolute area and growth rate of area of de-sealed soil.

6.2.1.1.1 SE01 Sealed Area (with two different units as below)

1. Absolute area of sealed soil
2. Growth rate of area of sealed soil

Currently, the indicator is mostly calculated from statistical databases that are based on national cadastral maps (land use registers) (e.g. in Austria). In those cases, the initial measurement data are parcel-based. However, these statistical data do not accurately reflect reality. Data reliability concerning growth rates is limited. Alternatively, top-down approaches based on remote sensing data (e.g. GMES-based approaches) can be applied which, despite their lower resolution, are able to increase the accuracy of detection of growth rates, as has been demonstrated by the Spanish Information System for Land Use and Land Cover (SIOSE).

Advantages:

i) Directly related to the key issue;
ii) Straightforward to calculate, provided that the land use categories that are applied in national cadastral systems and that are classified as "sealed" are defined in a transparent and consistent way;
iii) Supported by data that are already gathered in most Member States, so additional effort and costs for data collection are minimised and in addition both the absolute area and its growth rate can be calculated using the same database;
iv) Highly policy-relevant; sealing is a soil threat within the European thematic strategy and reductions in sealing are emerging as targets in some Member States (e.g. Austria, Germany) (BMLFUW, 2004, 2006; UBA Berlin, 2005);
v) Easy to comprehend and communicate i.e. it provides a clear key message;
vi) Possible to aggregate information at different scales relating to political-administrative hierarchies, allowing differentiation of baselines, thresholds and policy targets, and spatial data can be accessed to allow monitoring of specific areas;
vii) Useful for making comparisons between Member States and regions of growth rates and trends, although direct country-to-country data comparability in terms of absolute area may be limited due to the different categories used in national databases;
viii) Currently there is no reasonable alternative to using cadastral map-based, statistical data. However, supported by expected methodological advancements, in the nearby future they are likely to be backed up or replaced by remote sensing-based data: under the joint programme GMES (Global Monitoring for Environment and Security of EC and ESA (European Space Agency) a European wide soil sealing layer with a resolution of 1 ha will be available by early 2008. The current CORINE Land Cover programme will be enhanced by

this high-resolution layer. The sealing product will provide identification of all built-up areas larger than 1 ha in Europe and a discrimination of sealing percentages (1-100% in 10% steps) within urban areas. Linear features will be integrated from a width of 20m upwards.

Disadvantages:

i) Limited data comparability due to differing underlying definitions of land use categories in national databases (national cadastral maps are based on different methodologies);

ii) Due to time lags between actual land use change and updating of cadastral maps data quality may in general be medium (irregular updates of land use registers). Cadastral data therefore should be interpreted as an approximation to reality but can still provide useful information on the dimension of sealing and on overall trends (early warning function). (Lexer *et al.,* 2005; Umweltbundesamt, 2001); outside of urban areas data quality in general tends to decrease;

iii) Data quality for transport infrastructure is less than for settlement areas. For the sealing degree of transport infrastructure estimates of mean values based on literature are used (extrapolated data). These estimates depend on the methodology of national databases (Banko *et al.,* 2004);

iv) Definition of numerical target values for reduction of sealing rates is a policy judgement that can only be informed by scientific inputs;

v) Thresholds should be defined at regional level (regional differentiation of thresholds recommendable).

Conclusion:

For the time being, status and trend of sealed area (SE01) should be monitored by calculating its absolute area extent in hectare and its annual growth rate from statistical cadastral map-based databases. Although this methodological approach has some considerable disadvantages, in particular limitations in data quality and cross-country data comparability, currently no reasonable alternative exists. Many of its disadvantages are likely to be overcome from 2008 onwards, when advanced remote sensing data (including aerial photographs) should be available from the GMES programme and integrated GMES-based land monitoring activities are expected to be implemented in the Member States. Such a future monitoring approach will satisfy better regional information needs and it will employ nomenclature and definitions that are standardized Europe-wide. Current projects from Spain (SIOSE), Germany (De-Cover), Austria (LISA), UK and Sweden have already demonstrated that such an alternative approach to data sampling is feasible and is able to provide improved data on soil sealing. Thus, in the future cadastral map-based monitoring of sealed soil should be replaced by advanced GMES-based monitoring methods.

6.2.1.1.2 SE02 De-sealing (with two different units as below)

1. Absolute area of de-sealed soil
2. Growth rate of area of de-sealed soil

Advantages:

i) Directly related to the key issue;

ii) Illustrative of the effectiveness of response measures to soil sealing;

iii) Policy relevant because de-sealing is an emerging target under some national sustainability strategies (e.g. in some Federal provinces of Germany, and expert recommendations for political target values exist (UBA Berlin, 2003);

iv) Comprehensible and able to communicate a clear message.

Disadvantages:

i) There is little evidence of any accepted measurement methodology

ii) No practical experience is available from operational use

iii) Data availability is unclear; monitoring would require operation of de-sealing registers and/or some kind of reporting system for de-sealed soil, which currently exist only in some regions or municipalities.

iv) Data comparability may be limited by the use of differing national measurement methods

v) Definition of numerical target values for reduction of sealing rates is a policy judgement that can only be informed by scientific inputs.

vi) It is of most use in urbanized areas (risk areas) where a larger potential for de-sealing exists; in rural areas with a relatively small proportion of sealed land it will be difficult to detect meaningful changes

Conclusion:
De-sealing (SE02) is an important response indicator that measures how much sealed soil has been regained and over what area natural soil functions have been at least partly restored by removing completely or partly impermeable artificial soil cover. It informs about the effectiveness of policies to actively minimise the soil threat 'sealing'. Status and trend of de-sealed soil (SE02) should be monitored by measuring its area in hectares and/or in percent of sealed area and its annual growth rate. At present, data availability at national levels appears to be limited because systematic monitoring will require operation of de-sealing registers or some kind of reporting system for de-sealing activities, which do not exist yet. More practical experience exists with implementation of the proposed indicator on brownfield redevelopment (SE05), which is thus proposed as the primary response indicator.

6.2.1.2 Land consumption

6.2.1.2.1 SE03 Land consumed by settlements and transport infrastructure (with four different units as below)

1. Absolute area of land occupied by settlements and transport infrastructure
2. Growth rate of land occupied by settlements and transport infrastructure
3. Share of land occupied by settlements and transport infrastructure in total area suitable for permanent settlement
4. Settlement area (built-up land) per capita

Calculation of the indicator is based on aggregation of parcel-based statistical data that relate to classes of land use and are gathered in national cadastral maps (land registers). The area suitable for permanent settlement (3) quantifies the overall amount of land that is potentially available for settlement purposes; it is usually defined statistically and can be calculated from the same database (total territory minus area unsuitable for permanent settlement activities, which includes alpine unforested area, water area and wastelands). The Settlement area per capita (4) requires the population size as additional input parameter.

Advantages:
i) Directly related to the key issue;
ii) Supported by cadastral map (land register)-based data that are already gathered in most Member States, so additional effort and costs for data collection are minimised;
iii) Comparatively accurate in terms of spatial resolution of initial measurement data because observation units are parcel-based;
iv) Able to provide added information on several complementary aspects of the key issue, i.e. status and trend of land consumption, the proportion of land that is still available for settlement-related activities, and the "spatial efficiency" of land occupation of a population; in addition all indicator units can be calculated using the same database;
v) Straightforward to calculate (simple aggregation of statistical data), provided that an appropriate database exists and that the land use categories are defined in a transparent and consistent way;
vi) Possible to aggregate information at different scales relating to political-administrative hierarchies, allowing differentiation of baselines, thresholds and policy targets, and spatial data can be accessed to allow monitoring of specific areas, including comparison of trends between regions;
vii) Regularly monitored in some Member States; the indicator is applied in established indicator sets on national level (e.g. BMLFUW, 2004, 2006; UBA Berlin, 2005) and has been recommended on supranational level (Alpine Convention, 1994, 2004); the indicator methodology is tested and practical experience with calculation of data and interpretation of indicator results exists (e.g. Austria, Germany);
viii) Highly policy-relevant; sealing is a soil threat within the European thematic strategy, with the concept of ‘soil sealing’ put forward therein addressing many aspects of the broader concept

of 'land consumption'; reductions in land consumption are emerging as targets in sustainability strategies of Member States (e.g. U.K., Austria, Germany) and concrete numerical target values have been set in a number of countries (BMLFUW, 2002, 2005; ÖROK, 2002; Umweltbundesamt, 2004b; Deutsche Bundesregierung, 2002, 2004; BFS, BUWAL & ARE, 2003a, 2003b; Schultz & Dosch, 2005);

ix) Easy to comprehend and communicate i.e. it provides a clear key message;
x) More appropriate to provide assessments at national and smaller scales than indicator SE04 Land take (Corine Land Cover - CLC), which is more suitable for providing an overview at the EU scale;
xi) Useful for making comparisons between Member States of growth rates and trends, although direct country-to-country data comparability in terms of absolute area may be limited due to the different categories used in national databases.

Disadvantages:

i) Cross-country data comparability in terms of absolute area may be limited due to different definitions of land use classes applied in national cadastral maps;
ii) Due to time lags between actual land use changes and updating of cadastral maps data quality may in general be medium, which can cause biased results (possible underestimation of absolute area size, possible overestimation of growth rates) (Lexer *et al.,* 2005; Umweltbundesamt, 2001). Thus, regular updates of the land register are required; larger discontinuities in updating data sets can, however, partly be compensated by longer reporting intervals (appr. 3 years);
iii) If definitions of the land uses classes applied in land registers are changed the detection and tracking of long-term trends gets difficult;
iv) Definition of numerical target values for reduction of land consumption rates is a policy judgement that can only be informed by scientific inputs;
v) It is recommended to differentiate thresholds at regional level in order to allow for consideration of different economic situations and demands for land development in different regions, which makes monitoring a more difficult task;
vi) As regards the indicator variant 3 'Share of land occupied by settlements and transport infrastructure in total area suitable for permanent settlement', the 'potential permanent settlement area' is a concept that may not be established in all countries, or that may require re-definition and adaptation to different national conditions. A common Europe-wide approach to definition according to standardized criteria is desirable, although this will to some extent have to be a policy judgment;
vii) As regards the indicator variant 4 'Settlement area (built-up land) per capita', any threshold based on per capita values for land consumption implies that land consumption targets are dynamic in terms of absolute area, i.e. the overall tolerable amount of consumed land is allowed to change as population size changes. Depending on changes in population size, the same stock of consumed land may be judged as 'sustainable' for a larger population and as 'unsustainable' for a smaller population. Also, moveable thresholds and targets are more difficult to hit (Schultz & Dosch, 2005).

Conclusion:

Despite a number of limitations, land consumed by settlements and transport infrastructure (SE 03) is at present the most suitable indicator to provide reasonably accurate assessments on land consumption at national and smaller scales. Europe-wide assessments should be backed up by monitoring results of the indicator 'land take' (SE 04). All four units proposed above should be calculated from statistical cadastral map-based databases. The area of land consumed (1) should be calculated in hectares and can also be expressed as percentage of total territory; its growth rate (2) should be measured in hectare/year or hectare/day. These two main units should be complemented by the ratio between the land consumed and the potential permanent settlement area (3), expressed as percentage, and by the settlement area per capita (4) in m^2 $inhabitant^{-1}$. In the near future, when advanced remote sensing data (including aerial photographs) will be available from the GMES programme (from 2008 onwards), cadastral map-based monitoring of land consumption may be replaced by advanced GMES-based monitoring methods (see section 7.2.1.1.1).

6.2.1.2.2 SE04 Land take (CLC - Corine Land Cover)

The indicator quantifies how much, in what proportions and at what growth rate soil is lost by converting agricultural, forest, semi-natural and natural land to urban and other artificial land covers. It is an established indicator of the EEA core set (CSI 014). The indicator is mapped from remote sensing data (Landsat satellite images) and is currently calculated from the CORINE Land Cover Change (CLC) database (1990 – 2000). Changes from agriculture, forest and semi-natural/natural land (CLC2 to CLC5) to urban land (CLC1) are grouped according to the land cover accounts (LEAC) methodology. Land cover change values are converted to grid cells which are aggregated by countries. Results are presented as mean annual urban and artificial land take (ha) in percent of artificial land cover of a given reference year, as percentage of the total area of the country, as percentage of EU23, and as percentage of the various land cover types taken by urban and artificial development (EEA, 2005a, 2005b; EC & EEA, 2005; Bossard *et al.,* 2000).

Advantages:

i) Directly related to the key issue;
ii) Able to provide a clear key message;
iii) Applied as an established indicator of the EEA core set (EEA, 2005a, 2005b); baseline data and assessments at the European scale are available for the period from 1990 to 2000, future assessments will possibly be updated every five years. The methodology is tested and – despite some limitations (see below) – generally acknowledged;
iv) Calculated from a homogenous database that is standardised across all Member States, which is up to now lacking for cadastral map-based data on land consumption (indicator SE 03). Thus, land take allows for good cross-country comparison on a pan-European scale (between countries that apply the same interpretation of the ‘island-polygon’ 5-ha rule; (see item (ii) below) and it is very appropriate to provide a general overview at the European scale. Assessments are currently available for 23 European countries, which is the best geographical coverage of all indicators selected under this soil threat;
v) Able to provide assessments for smaller area units (e.g. regions, water catchment areas etc.);
vi) Based on a methodology that also allows analysis of quantitative area changes between individual land cover classes (land cover flows), which provides qualitative added value-information on the relative contributions of land cover categories to land uptake, i.e. on the proportion of land take by different types of human activities. This allows insight into the processes and drivers underlying soil loss due to land use change;
vii) Able to detect significant changes in annual land take on national level, although current data quality in terms of spatial resolution is limited;
viii) Currently improved methodologically; considerable advancements in spatial resolution up to a Minimal Mapping Unit (MMU) of 1 ha can be expected in the short–term to medium-term future (GSE Fast Track Service Land), which will imply strong improvements of the indicator performance;
ix) Highly policy relevant; reduction of land consumption has become a priority issue on many national sustainable development policy agendas (e.g. in Austria, Germany, the U.K. and Switzerland).

Disadvantages:

i) Medium data quality due to limited spatial resolution: the minimal mapping unit (MMU) of the land cover change database is currently set to 5 ha, and the database for the final polygon presentation is 25 ha, i.e. only land cover changes exceeding the threshold of 5 and/or 25 ha can be detected;
ii) Due to methodological inconsistencies between countries the 5 ha MMU is applied differently, depending on the so called ‘island-polygon’ problem. As a consequence, only such countries should be compared directly that use the same interpretation of the ‘island-polygon’ 5 ha rule;
iii) Comparability of data over time requires continuity and consistency of defined land cover classes and mapping methods;
iv) It is less suitable to provide significant and reasonably accurate information on national or regional levels than indicator SE03 Land consumption;

v) Definition of numerical target values for limitation of land take is a policy judgement that can only be informed by scientific inputs.

Conclusion:
At present, land take (SE04) should be applied as a complementary indicator to land consumed by settlements and transport infrastructure (SE03) because it is able to provide fairly robust information on the state and trend of urban and artificial land uptake at a pan-European scale, as it builds on a homogenous database that is harmonized across Europe. In the nearby future, when advanced remote sensing data (including aerial photographs) will be available and combined European and national GMES land monitoring activities will allow for considerable improvements in data quality, making possible analysis on regional level as well, land take (SE04) should become the primary indicator of land consumption.

6.2.1.3 Brownfield redevelopment

6.2.1.3.1 SE05 New settlement area established on previously developed land

This indicator measures how much previously developed land that has been used for settlement and industrial or trade purposes, but is currently not used for these purposes has been re-used as building land. Here, the term ‘settlement area’ includes buildings for housing and for commercial, industrial and settlement-related infrastructural purposes (built-up land).

Advantages:

i) Directly related to the key issue;

ii) Able to provide a clear key message;

iii) A response indicator that measures the effectiveness of policy measures to reduce new land consumption;

iv) Highly policy relevant at the Member States level; a binding political objective with a numerical target value for brownfield redevelopment (60% of new homes to be built on brownfield land by the year 2008) has been set under the national Brownfield Strategy in the U.K. (English Partnerships, 2003); brownfield re-development has been recognized as a key response strategy in order to accomplish reduction of land consumption in a number of national strategy documents (BMLFUW, 2002; RNE, 2004) and its application has been recommended by relevant expert reports (Umweltbundesamt, 2004a, 2004b; UBA Berlin, 2003, 2004a, 2004b; SRU, 2002);

v) Policy relevant at the European scale; although there are, to date, no binding political targets at the European scale, the need to reduce soil sealing and land consumption is addressed in the EU Thematic Soil Strategy and in the Thematic Strategy on the Urban Environment (European Commission, 2005); a policy framework at European scale to reduce greenland consumption and support the re-development of brownfield sites is expected to be defined under the Thematic Strategy and its follow-up legislation;

vi) Regularly and successfully monitored under the national Sustainable Development Strategy (DEFRA, 2005) and the U.K. National Brownfield Strategy (English Partnerships, 2003) since 1989 in England and Wales; methodology has been tested and proven;

vii) Accurate in terms of spatial resolution of measurement data because observation is done on individual parcel scale;

viii) Possible to aggregate information at different scales relating to political-administrative hierarchies, allowing differentiation of baselines, thresholds and policy targets and spatial data can be accessed to allow monitoring of specific areas, including comparison of trends between regions;

ix) Reasonably cost-effective; calculation of the new settlement area is supported by cadastral map (land register)-based data that is already gathered in most Member States; calculation of the area of redeveloped brownfield sites only requires establishment of a reporting system that registers the previous development status of land (previously developed / non-developed land) where construction activities take place; operation of a brownfield cadastre would be supportive with a view to effective implementation of brownfield redevelopment, but it is not necessarily required for monitoring the indicator;

x) Also relevant to the key issue of local soil contamination; some but not the majority of brownfield sites are contaminated and require risk assessment and restoration and clean-up measures.

Disadvantages:

i) Little or no practical experience exists; no systematic monitoring on a national level is known in Member States other than the U.K.;

ii) There is probably a lack of data availability regarding systematic recording of re-developed brownfield sites apart from the U.K.;

iii) Monitoring requires establishment of a recording and reporting system with regard to the preceding status of building land, i.e. it must be known if constructions of buildings occur on brownfield sites or greenfield sites; the respective data has to be provided by the competent local or regional land use authorities; brownfield cadastres (inventories of the stock of brownfield sites), which would be even more supportive, are not known to be operated systematically on national level elsewhere than in the U.K;

iv) The capability of the indicator to detect significant trends on national level might be limited in countries with smaller overall brownfield stocks i.e. with a smaller potential for brownfield redevelopment than in the U.K.;

v) Monitoring is particularly useful in regions with large stocks of brownfields (e.g. urban agglomerations, sub-urban areas, industrialised regions) and higher economic demands for new land development, otherwise change rates may be too low to allow for detection of significant trends;

vi) The ratio between brownfield re-development and entire land consumption depends to some extent on the stock of brownfields that is available for re-usage; in addition, the differing socio-economic framework conditions and differing needs for new economic development in different regions or countries have to be considered when setting thresholds and comparing results for different spatial assessment units (regions, countries); hence, a regionalised approach to the setting of thresholds is recommendable.

Conclusions:

The primary response indicator of the effectiveness of measures to reduce new land consumption and the soil sealing associated with it should be new settlement area established on previously developed land (SE05). It should be measured as the proportion of recycled brownfield land and the entire newly developed land within a reference period and expressed as a percentage. Calculation of the indicator requires two input parameters: i) the area of re-developed brownfield sites and ii) the total area of newly developed land. While the latter is obtained from national land use registers (see indicator SE03), monitoring the area of re-developed brownfield sites (i) requires establishment of a reporting and recording system that registers the previous development status of land where building activities occur (developed land / non-developed land). Brownfield cadastres (inventories of the stock of brownfield sites) would be supportive, but are not required by all means. Monitoring is in particular useful in regions with large stocks of brownfields (e.g. urban agglomerations, industrialized regions) and higher demand for land development; for regions with smaller brownfield stocks it is better to use absolute area values (ha) of re-developed land rather than its proportion (%) in entire newly developed land. Since high spatial resolution is needed to monitor the indicator, future improvements in GMES-based methodologies represent no feasible alternative here.

6.2.1.4 Fragmentation

6.2.1.4.1 SE06 Effective mesh size

The indicator measures the degree and intensity of landscape fragmentation by the high-ranking road network. It is a quantitative measure for the ecological connectivity of landscapes and for the restriction of wildlife mobility and gene flows within and between populations and metapopulations. Thereby, it provides key information on the ecological impacts of soil consumption by linear artificial land use structures on aboveground biodiversity (Esswein *et al.,* 2002, 2003; Jaeger, 2000, 2001a, 2001b, 2002).

The main input parameter is the road network of a topographical area, which is computed with GIS techniques. Effective mesh size (*meff*) is an index value in km^2 that is calculated for a given area with a mathematical algorithm:

$$meff = Fg * \sum_{i=1}^{n} \left(\frac{Fi}{Fg} \right)^2$$

Where:
meff effective mesh size (km^2);
Fg total size of a given surface (km^2) that has been dissected in a number of n areas;
Fi size of area (km^2);
n number of resulting dissected surface areas.

meff reaches a maximum value for a completely undissected area; in this case, *meff* equals the size of that area; *meff* reaches a minimum value of 0 km^2 if an area is completely covered by built-up land.

Advantages:

i) A standardised quantitative indicator that is straight-forward to calculate because a defined mathematical algorithm is used and standard GIS techniques are applied;
ii) An advanced indicator that is based on sound scientific analysis (Esswein *et al.,* 2003; Jaeger, 2000, 2001a, 2001b, 2002) and has been successfully tested and applied in monitoring projects on regional level (Jaeger, 2001b; Esswein *et al.,* 2002);
iii) Highly cost-effective; apart from the transport infrastructure network (vector data in GIS format) no further data inputs are needed; thus, the required data are readily available in all Member States;
iv) Calculated from accurate and reliable data that are annually updated;
v) Applicable to functional spatial assessment units of varying scale (incl. sub-regional and regional scales); methodology allows for up-scaling;
vi) Visualisable in a depictive and demonstrative way;
vii) Directly related to two key parameters that determine the risk of extinction of metapopulations by considering both the size of undissected areas and the accessibility of those areas; this is an advantage compared to the second pre-selected fragmentation indicator ‘Undissected low-traffic regions’;
viii) An important pressure indicator of consequential ecological effects of soil consumption on aboveground biodiversity; it is directly related to one of the most important causes of losses of faunal aboveground biodiversity; according to recent findings, habitat fragmentation has to be ranked among the three largest threats to biodiversity worldwide (MEA, 2005). However, a direct relation to soil issues is lacking.
ix) Recommended as an indicator of the monitoring system of the Alpine Convention (Alpine Convention, 2004); it is also part of some national biodiversity monitoring systems (e.g. MOBI-e, 2006);

Disadvantages:

i) A direct and explicit relation to soil issues is lacking; the indicator is more recognized as a biodiversity pressure indicator; hence, its application in specific soil monitoring systems is disputable;
ii) It has not seen wide-spread practical application in national monitoring systems yet;
iii) The second pre-selected fragmentation indicator ‘Undissected low-traffic regions’ is superior in terms of intuitive understanding;
iv) Compared to the indicator ‘Undissected low-traffic regions’ the influence of traffic densities on the barrier effect of transport corridors is not considered;
v) For the setting of thresholds a regionalised approach would be useful; in addition thresholds might differ for different target or indicator species.

Conclusion:

Monitoring of fragmentation should be part of a European soil monitoring system because it measures an important adverse impact of soil sealing on the habitat function of soils for aboveground biodiversity. Fragmentation should be monitored using effective mesh size (SE06) as an indicator. Scientific soundness of calculation and its ability to compare different regions makes it superior to similar indicators.

Table 6.2 Overview of proposed indicators for Soil Sealing

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
SE01	**Soil sealing**	**What is the share of actually sealed area in the total land consumed by settlements and transport infrastructure?**	**Sealed area**	**ha; % of consumed land or ha y^{-1}; ha d^{-1}**	**P**	**S/M**	**G**	**3 years**	**data gathering: parcels; assessment unit: municipalities (NUTS 5)**
SE02	Soil sealing	How much sealed soil is regained or restored by completely or partly removing artificial soil covers?	De-sealing	m^2; % of sealed area or $m^2 y^{-1}$; $m^2 \cdot d^{-1}$	R	M	R (urban areas)	3 years	data gathering: parcels; assessment unit: municipalities (NUTS 5)
SE03	Land consumption	How much land is occupied at what growth rate for building and infrastructure purposes?	Land consumed by settlements and transport infrastructure (built-up land)	ha; % of territory or ha y^{-1}; ha d^{-1} add. units: % of potential permanent settlement area; m^2 capita^{-1}	P	S	G	3 years	data gathering: parcels; assessment unit: municipalities (NUTS 5)
SE04	**Land consumption**	**How much bio-productive, semi-natural, or natural land has been converted to urban and other artificial land covers?**	**Land take (Corine Land Cover - CLC)**	**% or ha**	**P**	**S (current res.); M (future res.)**	**G**	**5-6 years**	**current MMU: 25 ha; future MMU: 1 ha**
SE05 also see (CO09)	**Brownfield re-development**	**How much previously developed land that is currently unused 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**	**%**	**R**	**M**	**R (brownfield 'hot spots')**	**yearly**	**parcels**
SE06	Fragmentation	What are the impacts of soil sealing (mainly by transport infrastructure corridors) on aboveground biodiversity?	Effective mesh size	km² (index value)	I	S	G	3-5 years	reference area (Fg) = regional level

6.2.2 Baseline and threshold values

While the general definition of baselines has been adopted for the soil threat Soil Sealing without any changes, the concept of thresholds as defined within the project has been applied in a more differentiated way. This is based on the following considerations: numerical threshold values for indicators relating to soil sealing cannot be determined by science alone. How much land consumption and soil sealing is deemed sustainable or unsustainable, and how much response measures are thought to be required, are questions that require policy judgements because they involve value-based normative decisions and societal choices. Normally, such policy-making processes will be based on political negotiations and stakeholder consultation, guided and informed by scientific expertise. Sustainable development itself may be regarded as an implicitly value-based, normative concept that frequently requires trade-offs and value judgements as it is made operational. This cannot be done by science as a substitute for policy-making.

The general approach suggested for most selected indicators is based on the premise that soil sealing and land consumption cause various threats to soil functions and soil services and that there is a need to reduce these threats if overarching objectives of sustainable development shall be met. For the management of non-renewable natural resources, such as soil, the paradigm of sustainability is usually interpreted as imposing a categorical imperative to reduce and limit soil loss and its ecological impacts (including landscape fragmentation) to the extent possible and feasible (Van Dieren, 1995; Huber, 1995). Reciprocally, the effectiveness of response measures (de-sealing, brownfield redevelopment) needs to be increased as much as possible. What exactly ‘possible’ and ‘feasible’ mean is again to some extent a matter of societal choices and value judgements. It is inevitably linked to trade-offs and balancing of ecological sustainability criteria with economic and social aspects of sustainable development.

In the following section, the threshold is in most cases defined as a range of indicator values where there is no increase in the threat level or where the increase in the extent of threat is not accelerating. This means that in most cases the minimum requirement for thresholds is that the rate of change is constant (no increase for pressure / state indicators, no decrease for response indicators). In these cases, the threshold equates to the current baseline.

However, thresholds below the baseline (for pressure / state indicators) or above the baseline (for response indicators) may be regarded as representing more precautionary paths that at some point may even lead to reducing net growth rates of sealing and land consumption to zero, in particular if other paths would end at all soil sealed or occupied by settlement areas and transport infrastructure.

Moreover, for most indicators national, regional and partly also local differentiation of thresholds is recommended. Country-wide thresholds often risk failure in meeting the information needs on regional and local levels, which is where policy measures to control soil threats are mostly implemented.

Definition of policy target values is clearly beyond the scope of any research project. However, since setting of policy targets is expected to be in favour of effective implementation of policy measures for sustainable management of threats to soil functions, some indications of existing or suggested national target values are provided.

6.2.2.1 Soil sealing

6.2.2.1.1 SE01 - Sealed area

- absolute area of sealed soil (ha; as percentage of consumed land); and
- growth rate of area of sealed soil (ha yr^{-1}, ha d^{-1}, change as % of stock of sealed area in baseline year)

If it is accepted that there is a need to limit soil sealing, which is supported by the effective irreversibility of the sealing process, a useful measure is the change in the growth rate of sealing. If this is increasing, then the threat level is also growing, while a reducing rate of sealing would indicate progress towards threat reduction. However, it is clear that any ongoing process of sealing has cumulative effects on the stock of sealed soil and that even a decelerating growth rate of sealing means that its absolute area is increasing, as does the extent of threat to soil functions. The dynamic relationship between both parameters should be considered in decision-making on threshold values and thresholds for both parameters are interrelated.

Baseline
The baseline is defined as the area, and/or growth rate, of sealed soil in a given reference year, such as a year before the first reporting date. This baseline may be higher or lower than the value set as a threshold. It acts as a reference against which progress or lack of progress in managing the extent of soil sealing is assessed.

Threshold
In principle, thresholds for the absolute area of soil sealing could be set by reference to a scientific analysis of the impacts on soil functions caused by soil sealing and the consequent loss of ecological services. In practice, there is insufficient scientific understanding to achieve this, and thresholds have to be based on policy judgement informed by scientific expertise. Even if there was complete scientific knowledge, ecological requirements of sustainable soil management still would have to be balanced with economic and social requirements of sustainable development in the policy-making process. Moreover, such thresholds need to be set differently at national, regional and in some cases local scales to reflect differences in connectivity between soil systems and other environmental compartments (e.g. surface and ground waters) as well as variations in settlement characteristics (e.g. density, anticipated future growth, etc.), biodiversity and existing stocks of sealed area in relation to the unsealed area that is still available for land development.

Thresholds relating to change in the growth rate of sealing can also only be defined by policy judgement. But in this case it is clear that if the rate of soil sealing is accelerating, so is the extent of the threat. It follows that the maximum range for a threshold is where there is no change in the growth rate of sealing i.e. the increase in the extent of the threat is constant, though not the absolute extent of the threat itself. In this case, the threshold equates to the current baseline. However, since the cumulative dynamics of growth rates implies that the absolute area of sealed soil is still increasing, this should be considered in setting threshold values. Thus, with stocks of sealed soil growing and approaching the threshold set for absolute area, acceptable thresholds for growth rates would need to be lowered accordingly. Thresholds below the baseline may be regarded as representing increasingly more precautionary paths that take fuller account of the fact that in the long-term complete soil sealing is impossible to reconcile with sustainable futures and that the net rate of soil sealing must at some point be reduced to zero.

Regional differentiation of baselines and thresholds is highly desirable; policy measures aimed at controlling soil sealing are mostly implemented at regional and local levels. Additionally, (ecologically) sensitive areas should be defined where more restrictive threshold values or a complete prohibition on further soil sealing is required.

Table 6.3 Examples for baselines and policy targets for Soil Sealing

Country (reference year)	Description
Austria (2005)	Sealed area: 181,800 ha or 45% of consumed land; growth rate 2001-2005: appr. 9.8 $ha.d^{-1}$ No explicit policy target for sealing (but policy target for land consumption exists)
Germany (2003)	Sealed area: appr. 50% of settlement area Expert recommendation for policy target (UBA Berlin, 2003): in the long term net growth rate (balance of sealing and de-sealing) shall be reduced to zero.

6.2.2.1.2 SE02 - De-sealing

- absolute area of de-sealed soil (ha; in percent of area of sealed soil) and
- change/growth rate of area of de-sealed soil (ha yr^{-1}, ha d^{-1}, change as % of de-sealed area in baseline year)

As a response measure, de-sealing has considerable potential to reduce the threats to soil functions and services connected to the process of soil sealing and to mitigate the impacts of land consumption on soils. The more sealed soil is de-sealed, the more the existing extent of threat is reduced. With a view to the need to limit sealing rates and – at some point – reduce them to zero net growth, the de-sealing process is able to contribute to maintaining discretion and flexibility for future economic development. Any increase in de-sealing rates would indicate progress in that respect.

Baseline
The baseline is defined as the area, and/or growth rate, of de-sealed soil in a given reference year, such as a year before the first reporting date. This baseline may be higher or lower than the value set as a threshold. It acts as a reference against which progress or lack of progress in managing the extent of soil sealing is assessed.

Threshold
In general, thresholds related to de-sealing have to be based on policy judgements informed by scientific expertise. A useful measure for quantifying effectiveness or lack of effectiveness in the implementation of de-sealing is the change in the growth rate of de-sealed soil. De-sealing policies are effective if de-sealing rates are increasing or constant. It follows that the maximum range for a threshold is where there is no decrease in the growth rate of de-sealed soil. In this case, the threshold equates to the baseline. Provided that present de-sealing rates are mostly either very modest or de-sealing policies have up to date not been initiated at all, which is supported by the fact that hardly any data are available, thresholds above the baseline may be regarded as representing increasingly more precautionary paths that take fuller account of the fact that in the long-term complete soil sealing is impossible to reconcile with sustainable futures and that the net rate of soil sealing must at some point be reduced to zero.

Thresholds need to be determined only in focal areas (risk areas) where a sufficient potential for de-sealing exists. Outside urbanised areas detection of meaningful changes would be difficult. Regional differentiation of thresholds between urbanised areas with different stocks of sealed soil is recommendable (urban areas, per-urban areas, etc.).

Examples for policy targets
Expert recommendations for policy targets have been submitted in Germany (UBA Berlin, 2003):

- de-sealing and re-greening of sealed land within settlement areas in the order of 0.2% of the total area sealed in the year 2000 (per year)
- increasing the share of de-sealed and re-vegetated areas in the developed land within villages in the order of 0.1% per year (in order to improve climatic quality and life quality)

6.2.2.2 Land consumption

6.2.2.2.1 SE03- Land consumed by settlements and transport infrastructure

- absolute area of land occupied by settlements and transport infrastructure (hectare; in % of territory)
- growth rate of land occupied by settlements and transport infrastructure (ha yr^{-1}; ha d^{-1}; change as % of stock of consumed land in baseline year)
- Share of land occupied by settlements and transport infrastructure in total area suitable for permanent settlement (%)
- Settlement area (built-up land) per capita (ha $capita^{-1}$)

Baseline
The baseline is defined as the land consumption (absolute area, growth rate, share in potential permanent settlement area, settlement area/capita) in a given reference year, such as a year before the first reporting date. This baseline may be higher or lower than the value set as a threshold. It acts as a reference against which progress or lack of progress in managing the extent of soil sealing is assessed.

Threshold
All indicator units: In general, the determination of threshold values for all units of the indicator land consumption requires policy judgements that are informed by scientific expertise; this involves balancing of the impacts of land consumption on soil functions against its benefits and against economic and social needs for land development. Thresholds relating to all units need to be differentiated at national, regional and, perhaps, also local scales. In addition, (ecologically) sensitive areas may be defined where more restrictive thresholds have to be met or no further land consumption is allowed.

Absolute area, growth rate: Regarding the growth rate of land consumption, an approach similar to the one described for indicator SE01 Sealed area is recommended: the maximum upper range for a threshold is defined as the current baseline rate of new land consumption; if this value is exceeded, then the stock of greenfield land is degrading faster than before, i.e. the extent of threat is increasing at an accelerating rate. Hence, in this case the threshold equates to the baseline. Since the extent of pressure on soil functions and services depends primarily on the total area occupied, the dynamic relation between growth rates and absolute area needs to be taken into account. The cumulative effects of any rate of new land consumption invariably lead to an increase in the absolute area of land consumed. With a view to the threshold set for absolute area, this reduces the discretion for new land development in the future. Therefore with increasing area occupied by settlements and transport infrastructure the thresholds for land consumption rates need to be lowered if the threshold for absolute area is not be exceeded. Thresholds below the baseline may be regarded as representing increasingly more precautionary paths that take fuller account of the fact that in the long-term complete land consumption is impossible to reconcile with sustainable futures and that the net growth rate of land consumption must at some point be reduced to zero. A zero net growth rate would result from the balance of new land consumption against brownfield redevelopment and de-sealing.

Share of land occupied by settlements and transport infrastructure in the total area suitable for permanent settlement (%): In general, the area suitable for permanent settlement is calculated as total state territory minus the area unsuitable for permanent settlement activities. For example,. in Austria the "potential permanent settlement area" is in practice calculated as state territory minus alpine unforested area, forest area, water area and wastelands (statistically based definition, calculation based on cadastral map). This concept as defined in Austria needs to be adjusted to specific national situations. The area unsuitable for permanent settlement should include all land that is effectively not available for settlement activities, be it because of topographic conditions (as in Austria) or because of restrictive spatial planning legislations, nature protection laws etc. that grant no or strictly limited access for land developers in certain areas (no go-areas).

This indicator unit measures the maximum quantity of land that is potentially still available for future development. If this quantity is shrinking, the extent of threat to soil functions and services is increasing. If the rate of change of this measure is increasing, the increase in threat level is accelerating, while a decreasing rate of change would indicate progress towards relative reduction of threat levels. Therefore it is proposed to define a constant rate of change as the maximum acceptable range for a threshold i.e. the threshold in this case equates to the current baseline. Setting thresholds below the baseline may be regarded as conforming more fully to a precautionary approach that acknowledges that a value of 100% potential permanent settlement area occupied by settlement and infrastructure would not be compatible with sustainable development and intergenerational equity. Moreover, thresholds would need to become increasingly more restrictive if availability of land for development purposes should continues to decrease significantly.

Settlement area per capita: It has to be considered that two dynamic input parameters (population dynamics and growth of settlement area) are used to calculate this indicator and that the dynamics of both need to be put into relation. Any threshold based on per capita values for land consumption implies that the overall tolerable amount of consumed land is allowed to change as population size changes. Depending on changes in population size, the same stock of consumed land may be judged as sustainable for a larger population and as less sustainable for a smaller population. To avoid overshooting pressures on soil functions, threshold values need to be differentiated according to the present and the projected population dynamics of each Member State.

The following general guidance is recommended:

- For stable and decreasing populations, the threshold value should equate, but not exceed the baseline (m^2 $capita^{-1}$ in a given reference year).
- For increasing populations, the threshold value should be lower than the baseline (m^2 $capita^{-1}$ in the reference year).

This has implications for possible definition of policy target values: calculated in terms of absolute area of consumed land, target values are dynamic. They change, as population size changes, or as the growth rate of land consumption changes, or as both change.

Table 6.4 Examples for baselines and policy targets for land consumption

Country (reference year)	Description
Austria (2005)	Absolute area of consumed land: 229,000 ha or appr. 5% of territory Growth rate of land consumption (2001-2005): 18.5 ha d^{-1}; increase compared to baseline in 2001: +27,035 ha or + 6.8% Share of consumed land in the potential permanent settlement area: 13.5% Settlement area $capita^{-1}$: 528 m^2 Policy target: reduction of growth rate in 2001 (25 ha d^{-1}) to a rate of max. 2 ha d^{-1} by 2010
Germany (2003)	Growth rate of land consumption (for several decades until 2000):130 ha day^{-1} Policy target: reduction of growth rate from 130 to 30 ha day^{-1} by 2020
Switzerland (2003)	Policy target: settlement area $capita^{-1}$ shall not exceed 400 m^2 $capita^{-1}$.
Norway (2005)	Growth rate of consumption of agricultural land consumed at national level: appr. 2000 ha yr^{-1} Policy target: reduction of new consumption of land with high soil quality by 50% until 2010 (only 3% of national territory is agricultural land)

6.2.2.2.2 SE04 - Land take (CLC)

- mean annual urban land uptake by urban and artificial land developments in ha
- mean annual land take as % of urban and artificial land of reference year

Land take and land consumption are corresponding concepts. Basically, the indicator SE04 Land take relates to the same empirical phenomenon and measures the same process as does indicator SE03 (Land consumed by settlements and transport infrastructure). Apart from differences in broadness of definition (land take includes additional artificial land cover categories that indicator SE03 does not include), the differences between both indicators lie mainly in data source and methodology. Therefore, the general approach to determination of baselines and thresholds for Land take can be the same as for indicator SE03.

Any reduction of growth rates reflects a further approach in the goal to minimize soil threats.

Baseline
The baseline is defined as the mean annual urban land take in a given reference year, such as a year before the first reporting date. This baseline may be higher or lower than the value set as a threshold. It acts as a reference against which progress or lack of progress in managing the extent of soil sealing is assessed.

Threshold
Thresholds can only be defined by policy judgements informed by scientific expertise. If it is accepted that there is a need to limit the increase in the level of threat to soil functions, the maximum range for a threshold is where no increase in the change rate of mean annual urban land take occurs i.e. the in this case the threshold equates to the baseline. Thresholds below the baseline would indicate that the mean annual urban land take is decelerating, along with the extent of threat. This approach would be in favour of an increasingly more precautionary path towards – eventually and in the long term – zero net growth of land take. Different thresholds need to be set for different countries.

EEA has published an indicator specification and assessments that present the mean annual urban land take (1990-2000) as % of 1990 urban and artificial land per MS (comparison of growth rates), and as % of total EU 23 urban land take 1990-2000 (EEA, 2005a, 2005b). However, no thresholds have been defined yet.

6.2.2.3 Brownfield redevelopment

6.2.2.3.1 SE05 - New settlement area established on previously developed land

- absolute new settlement area established on previously developed land (ha)
- new settlement area established on previously developed land as percentage of total newly developed land (%)

Brownfield redevelopment is an important and potentially powerful response measure to consumption and sealing of greenfield land. By facilitating reduction of growth rates of new land consumption and sealing, additional threats to soil functions and services can be reduced or even avoided. Establishment of new settlement areas on brownfield sites does not necessarily increase the extent of threat on such sites, but redeveloping them rather holds the potential to limit impacts on soil resources compared to previous forms of use (e.g. by minimizing the proportion of sealed soil). By satisfying development needs on previously developed land, growth rates of settlement area can be decoupled from an increase in the level of threat. With a view to accomplishing zero net growth of new land consumption at some point in the future, recycling of brownfield sites contributes to maintaining discretion and flexibility for future economic development. Any increase in rates of brownfield redevelopment would indicate progress on that path.

Baseline
The baseline is defined as the area, and/or growth rate, of new settlements, industrial and trade estates etc. established on brownfield sites in a given reference year, such as a year before the first reporting date. This baseline may be higher or lower than the value set as a threshold. It acts as a reference against which effectiveness or lack of effectiveness in implementing response measures against soil sealing and land consumption is assessed.

Threshold
In general, thresholds related to brownfield redevelopment have to be based on policy judgements informed by scientific expertise. A useful measure for quantifying progress or lack of progress in the implementation of brownfield redevelopment is the change in the growth rate of the area of brownfield sites converted to new settlement areas. Policies are effective if redevelopment rates are increasing or constant. It follows that the maximum range for a threshold is where there is no decrease in the growth rate of redevelopment. In this case, the threshold equates to the baseline. Since the stock of brownfields is expected to grow as new greenfield land is continuing to be consumed, thresholds above the baseline may be regarded as representing increasingly more precautionary paths that take fuller account of the fact that in the long-term complete consumption

of all available land is impossible to reconcile with sustainable futures and that the net rate of land consumption must at some point be reduced to zero.

National, regional and in some cases also local differentiation of thresholds is highly recommendable. Thresholds should be adjusted to differences in existing stocks of brownfields (e.g. due to different historical economic developments) and in economic demands for new land development (different dynamics of settlement growth). The larger the stock of brownfields and the stronger the economic demands for land development, the higher the threshold may be set.

Examples for policy targets

- U.K.: The government has set a national target of 60% of new homes to be built on brownfield land by the year 2008. Monitoring has been practiced in England and Wales since 1989. This target value has been defined entirely by a policy judgement. The current indicator value is above the target value i.e. the target is being achieved. It has to be applied in the context of other controls, such as absolute protection of large areas of rural land, including areas that were industrial. So as a national target it is more or less demanding, depending on local conditions and constraints.
- Germany: An expert proposal by the national environment agency suggests a phased, tiered approach to policy target values: expressed as % of total new settlement area, new settlements should be developed on brownfield sites in the following percentages: 25% immeadiately; 50% until 2010; 75% until 2020 (UBA Berlin, 2003).

6.2.2.4 Fragmentation

6.2.2.4.1 SE06 - Effective mesh size

Landscape fragmentation is major consequence of soil consumption to aboveground biodiversity and is recognized as one of the global main causes of biodiversity losses (MEA, 2005). This is in many cases a hidden process with often decade-long time lags until its pre-determined impacts finally become fully visible i.e. until fragmentation finally results in extinction of species and metapopulations. Conservation of biodiversity is an almost universally accepted international objective, which is supported by a number of 188 countries having signed the Convention on Biological Diversity (CBD, 1992) and all Member States and the European Commission having ratified it and transposed it into domestic/Community legislation (European Commission, 1998). All Parties to the CBD have committed themselves to avoiding or mitigating the impacts of habitat fragmentation. If fragmentation degrees are increasing, then the threat level to biodiversity is also growing, while limiting or avoiding further fragmentation would indicate progress towards limitation of threat. Conserving in particular the landscape connectivity of large contiguous areas that are up to date largely undissected is a key strategy that can contribute most to threat reduction.

Baseline

The baseline is defined as the effective mesh size within a defined assessment unit in a given reference year, such as a year before the first reporting date.

Threshold:

Determining acceptable degrees of fragmentation is difficult because this would depend on selected target species and because sufficient scientific understanding of this issue is missing. To a large extent, policy judgements informed by scientific expertise are required. As Parties to the CBD, Member States and the Commission have committed themselves to applying a precautionary approach that requires taking actions despite the presence of uncertainty.

The general guidance for the setting of thresholds given below takes this into account and suggests a two-step procedure:

- **Step 1 - Protection of large undissected areas (taboo-zones):**
  Large undissected or low-traffic regions (size: appr. 100 km^2) should be identified where no further fragmentation is allowed (taboo zones / no go zones). In these sensitive areas, the threshold equates to the baseline degree of fragmentation (current effective mesh size: more or less the maximum index value).

- **Step 2 - Limitation of small-scale landscape fragmentation:**
  Application of indicator to assessment regions: First, the size of the assessment region has to be defined; regions must not be too small (appr. >5,000 km^2). The measurement unit of the threshold is the change (reduction) of effective mesh size in a given assessment region in percent of the baseline value. If fragmentation is increasing, so does the level of the threat. Therefore the maximum range for a threshold is where the rate of change of effective mesh size does not accelerate i.e. the threshold equates to the baseline. Depending on the current state of effective mesh size within an assessment region, regionally differentiated threshold values should be defined: The higher the existing degree of fragmentation, the more restrictive the threshold value should be (meaning lower reduction percentages in effective mesh size). Additionally, based on selection of certain target animal species, acceptable maximum degrees of fragmentation according to minimum habitat requirements (home ranges etc.) of those species may be defined. Target species may be such species that are representative for the species inventory of a region. Normally, those species with the highest spatial requirements will be chosen.

Examples for policy targets
In Germany, the following combined approach for thresholds is under discussion (UBA Berlin, 2003:

- **Example Step 1 - Protection of large undissected areas (taboo-zones):**
  The number and total area of existing undissected areas larger than 140, 120, 100, 80 and 64 km^2 shall be maintained. In particular undissected areas larger than 100 km^2 shall be preserved at any rate (no further development of settlements and transport infrastructure).

- **Example Step 2 - Limitation of small-scale landscape fragmentation:**
  Within assessment regions with a minimum area of 7,150 km^2 (2% of German territory) the following threshold/target values are suggested for regions with different baseline values:

Table 6.5 Reduction of small-scale landscape fragmentation by applying threshold/target values for effective mesh size.

Current effective mesh size	Reduction of effective mesh size until 2012 not more than:
< 10 km^2	-1.5 %
10-20 km^2	-1.9 %
20-35 km^2	-2.2 %
>35 km^2	-3.0 %

Source: UBA Berlin (2003)

Table 6.6 Baselines and thresholds for Soil Sealing

Key issue	Key question	Candidate Indicators	Units	Baseline	Threshold
Soil Sealing	What is the share and growth rate of actually sealed area in the total land consumed by settlements and transport infrastructure?	SE01: Sealed area	ha; % of consumed land or ha y^{-1}; ha d^{-1}	absolute area / growth rate in reference year	absolute area: policy judgment; growth rate: threshold ≤ baseline, in the long-term zero net growth rate (policy judgment)
	How much sealed soil is regained or restored by completely or partly removing artificial soil covers?	SE02: De-sealing	m^2; % of sealed area or m^2 y^{-1}; m^2 d^{-1}	absolute area / growth rate in reference year	growth rate: thresholds ≥ baseline, only in focal (urbanised) areas (policy judgment)
Land consumption	How much land is occupied at what growth rate for building and infrastructure purposes?	SE03: Land consumed by settlements and transport infrastructure (built-up land)	ha; % of territory or ha y^{-1}; ha d^{-1} add. units: % of pot. permanent settlement area; m^2 $capita^{-1}$	land consumed in reference year (all units)	growth rate, % of pot. permanent settlement area: threshold ≤ baseline, increasingly more restrictive, in the long-term zero net growth rate (policy judgment); m^2 $capita^{-1}$: threshold = baseline if population stable or decreasing, threshold < baseline if population increasing
	How much bio-productive, semi-natural, or natural land has been converted to urban and other artificial land covers?	SE04: Land take (Corine Land Cover - CLC)	% or ha	mean annual land take in reference year	threshold ≤ baseline (no increase in change rate of mean annual land take), in the long-term zero net growth rate (policy judgment)
Brownfield re-development	How much previously developed land that is currently unused has been re-used for settlement purposes in order to reduce new land consumption on greenfield sites?	SE05: New settlement area established on previously developed land	%	absolute area / growth rate of redeveloped brownfield land in reference year	change rate: thresholds ≥ baseline (redevelopment rates constant or increasing) (policy judgment)
Fragment-ation	What are the impacts of soil sealing (mainly by transport infrastructure corridors) on aboveground biodiversity?	SE06: Effective mesh size	km² (index value)	effective mesh size within assessment unit in reference year	general guidance: 1. large undissected areas (no-go zones): threshold = existing fragmentation degree 2. regional assessment units: change rate (reduction) of effective mesh size should not accelerate, the higher existing fragmentation, the more restrictive threshold values should be

6.2.3 Data and user requirements

Table 6.7 Summary of data and user requirements for Soil Sealing

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographic coverage	Frequ-ency	Data quality	Unit	Minimum detectable change
SE01	Sealed area area size of sealed surface area (in absolute area units (ha); in percent of consumed land (ratio)) growth rate of sealed surface area (ha y^{-1}, ha d^{-1})	aggregated statistical area values, based on sub-classes of actual land use according to national cadastral map (land register)	data suitable for national assessment; the origin of data can either be using a bottom-up approach from local and regional information utilities or using a top-down approach from GMES-instruments like the FTS Land monitoring	The spatial resolution required differs for the assessment unit and the observation unit. As the indicator shall provide a regional assessment, the aggregated units should be at NUTS 5 (LAU 2); however data observation should be in the ideal field parcel - based, or at least on a 1 ha base for top-down approach	EU 27	3 years	regular updates of cadastre (land register) needed; larger discontinuities in updating data sets can partly be compensated by longer reporting periods (appr. 3 years); definitions of land use classes should not be changed to allow for detection of long-term trends	sealed area in ha: area size: ha; percent of consumed land. growth rate: ha y^{-1}, ha d^{-1}, absolute change compared to reference year.	area size: no limit; growth rate: no limit
SE02	De-sealing area size of de-sealed area (ha; in percent of sealed area) growth rate of de-sealed area (ha y^{-1}, ha d^{-1})	aggregated area sizes of de-sealed parcels within built-up land; based on national cadastral map (land register)	as desealing is a quite sensitive are, information from data sources from SE01 will mostly not be accurate enough; therefore the de-sealing cadastres will be the solution on hand	De-sealing information has to be parcel-based as the error would be too large if the spatial resolution is more aggregated (e.g. 1 ha)	urban agglomeration zones (centres of settlement activities) in EU 25, based on municipalities (NUTS 5)	3 years	regular updates of cadastre (land register) needed; larger discontinuities in updating data sets can partly be compensated by longer reporting periods (appr. 3 years); definitions of land use classes should not be changed to allow for detection of long-term trends	de-sealed area in m^2.	all changes >10 m^2 (?)
SE03	Land consumption by settlements and transport infrastructure Area size (ha; in % of territory) Growth rate (ha y^{-1}, ha d^{-1}) Percentage of potential permanent settlement area (%) Settlement area per capita (ha.$person^{-1}$)	aggregated statistical area values, based on classes of land cover / land use in national cadastral map (land register)	data suitable for national assessment; the origin of data can either be using a bottom-up approach from local and regional information utilities or using a top-down approach from GMES-instruments like the FTS Land monitoring	the spatial resolution required differs for the assessment unit and the observation unit. As the indicator shall provide a regional assessment, the aggregated units should be at NUTS 5 (LAU 2); however data observation should be in the ideal field parcel - based, or at least on a 1 ha base for top-down approach	EU 27	3 years	regular updates of cadastre (land register) needed; larger discontinuities in updating data sets can partly be compensated by longer reporting periods (appr. 3 years); definitions of land use classes should not be changed to allow for detection of long-term trends	Area size: ha; percentage of territory; Growth rate: ha y^{-1}, ha d^{-1}; Percentage of potential permanent settlement area: % Settlement area per capita: ha $capita^{-1}$	no limit

Table 6.7 Summary of data and user requirements for Soil Sealing (continued)

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographic coverage	Frequ-ency	Data quality	Unit	Minimum detectable change
SE04	Land take (CLC)	changes in area size of land cover classes larger than 5 and/or 25 ha, based on remote sensing data	data suitable for national assessment; the origin of data can either be using a bottom-up approach from local and regional information utilities or using a top-down approach from GMES-instruments like the FTS Land monitoring	country-to-country comparison currently possible; future resolution of MMU > 1 ha holds even more promising potential.	EU 27	5-6 years	current data quality sufficient to allow for detection of changes in annual land take and for country-to-country comparison; future resolution of MMU > 1 ha holds even more promising potential.	ha, expressed in percent annual urban land take	currently: changes > 25 ha; future: changes > 1 ha
SE05	New settlement area established on previously developed land (in percent of total new settlement area)	area percentage of re-developed brownfields; calculation based on reporting system	reporting system: reporting of area size and previous development status (developed / undeveloped land) of the land where building activities have occurred by competent authorities	municipalities (regional differentiation of thresholds useful because regional availability of brownfields (stock) is different	EU 27, with focus on regions with large stock of brownfields	Annually	high	ha (parcels), expressed in % of total new built-up land	no limit
SE06	Effective mesh size	total size of given surface area, sizes of segregated surface areas, number of segregated surface areas	road network (using teleatlas, NAVTECH) and in addition land cover layers like CORINE Land Cover or the advanced FTS Land monitoring products; in addition to geometric data (road-vector data) also information on traffic density is mandatory	assessment regions approx. >5.000 km2, level of spatial detail has to be defined for the underlying data (roads) as well, inclusive traffic density	EU 27 plus functional linked areas (e.g. Russia)	3-5 years	high	km^2 differentiated according to total area and functional areas (forest and natural areas vs. settlement area and agriculture)	no limit

6.2.4 TOP3 indicators

Table 6.8 TOP3 indicators

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 y^{-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 - Sealed area is the most direct and a largely self-explaining indicator for the process of soil sealing, i.e. it is highly representative to the key issue under consideration and it is easy to comprehend and to communicate. To some extent sealing can also be regarded as a proxy indicator for the broader process of land consumption, because both processes are closely interlinked and usually occur in parallel. If desired, both indicators, SE01 and SE03, can be applied in conjunction with each other without any mentionable additional effort and cost, as appropriate.

SE04 - Land uptake by urban and other artificial land developments (settlement activities, including housing, supply and disposal infrastructure, roads, industrial and commercial estates, recreational facilities etc.) is the main cause of soil loss by human-induced land consumption. By the process of land take, previously undeveloped land (natural and semi-natural land, agricultural land, forest land) is turned into built-up areas. Land take is the cause of many other pressures on soil ecosystems, including change of relief features, compaction, contamination, and depletion of soil organic matter. Thus, land take is highly meaningful and representative to the given soil threat and relates directly to the key issue of land consumption. Urban and artificial land cover classes according to the CORINE database consist of both sealed and unsealed portions of land; sealed areas are a subset of the land taken. Land take is to be seen as the key driver causing soil sealing and is able to answer the question to what extent different land use/land cover classes contribute to the increase in urban land take.

SE05 - Recycling of previously built-up land rather than designating and developing new building land can contribute much to the reduction of new land consumption and soil sealing. Brownfield redevelopment is one of the most important response measures to direct soil losses. This indicator measures the effectiveness of responding to the soil threat Soil Sealing. In principle, the methodology is well developed and its applicability has been proven, in particular in the U.K. where monitoring is successfully practiced under the U.K. Sustainability Strategy. However, application will require establishment of reporting systems, which at present are not in operation in all Member States.

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7 SOIL COMPACTION

The ENVASSO Glossary of Key Terms defines 'soil compaction' as: "The densification and distortion of soil by which total and air-filled porosity are reduced, causing a deterioration or loss of one or more soil functions".

The main soil functions (Blum, 1993) affected by soil compaction are:

- Food and biomass production (soil productivity for agricultural and forest cropping);
- Environmental interaction (water filtration and storage capacity);
- Physical and cultural heritage (compaction, and its alleviation by subsoiling, have been shown to destroy cultural artefacts in soil).

Soil compaction is a form of physical degradation in which soil biological activity and soil productivity for agricultural and forest cropping are reduced, resulting in decreased water infiltration capacity and increased erosion risk. The compaction process can be initiated by wheels, tracks or rollers of agricultural and construction machinery, and from the passage or draft of grazing animals.

Soil compaction is an ancient phenomenon. The formation of plough pans started with the use of horses walking in the open furrow during ploughing many centuries ago. A later step was the use of tractors for ploughing. This caused a considerable additional compaction of the subsoil because two wheels of the tractor run in the open furrow during ploughing, and tractors are heavier than horses. Increased mechanisation and the increased weight of tractors over time have caused the widespread formation of plough pans (Van den Akker, 1999).

Structural degradation of subsoil is a well-known problem in modern agriculture, caused by increased ground pressure of tyres and axle loads that are not always compensated for by reductions in ground contact pressures. The major part of the decrease in pore volume, as a result of compaction, is the reduction in macro pores, and the resulting soil deformation strongly affects pore continuity. Both these conditions reduce the ability of the soil to conduct water and air, causing anaerobic conditions and reduced infiltration rates and capacity. The reduced infiltration increases surface runoff and leads to more erosion.

Tyre equipment and flexibility have improved and tyre inflation pressures have been lowered to reduce compaction, but these improvements have been insufficient to reduce the overall problem of compaction. From about 1960 onwards labour became increasing expensive and mechanisation of agriculture using heavy machinery started in many countries in Europe that had previously relied on significant inputs of manual labour. Very large axle loads, during harvesting and transport of agricultural produce across the land, cause high stresses in the subsoil that can even compact the plough pan and result in deep subsoil compaction (Van den Akker, 2004; Van den Akker and Schjønning, 2004).

Topsoil compaction considers the compaction of the upper 20 - 35 cm of the soil profile. In most cases the topsoil has greater organic matter content, contains many more roots and supports a much greater biological activity than the subsoil. Also, physical processes such as wetting, drying, freezing and thawing are more intense in the topsoil than in the subsoil. Consequently, natural loosening processes are much more active and stronger in the topsoil than in the subsoil. This makes topsoil more resilient to compaction than the subsoil.

The subsoil can be defined as the soil below the A horizon normally about 20 - 35 cm thick (the ploughed layer under arable and the humus enriched horizon under other land uses), and can include a plough pan in the upper part of the subsoil. Such a pan layer is caused by tractor tyres driving directly on the subsoil during ploughing or by heavy wheel loads that transmit the pressure through the topsoil into the subsoil. The pan layer is characterised by greatly reduced rootability, and permeability for water and oxygen than in the topsoil above and subsoil below. It acts as a 'bottleneck' for the functioning of the subsoil. Heavy loads on the soil surface, that cause compaction in the subsoil immediately below the topsoil, are cumulative and in time the bulk density of the subsoil will increase significantly.

In land that is ploughed annually, compacted topsoil is broken down but subsoil compaction will persist because the subsoil is not loosened by annual cultivation and the cumulative compaction eventually becomes too severe to restore the soil structure to its original condition. Subsoil compaction is a hidden problem in European agriculture and, because the size and weight of agricultural machinery continues to increase, the degree and extent of compaction are also increasing (Van den Akker *et al.,* 2003). The introduction of irrigation on a large scale in some countries is exacerbating subsoil compaction, because wet soil cannot bare the same loads as dry soil.

In the wider context of ENVASSO and its scientific support to the policy process, the report of Le Bas *et al.* (2006) on identifying risk areas for soil degradation by compaction in Europe is relevant. It identifies factors that cause compaction and summarises minimum data requirements to identify areas most at risk.

7.1 Key issues

At the start of the selection process five key issues were identified:

- Topsoil compaction
- Subsoil compaction
- Soil structure degradation
- Soil water infiltration
- Intentional compaction (to reduce volume or hydraulic conductivity; to increase strength).

Subsequently by expert consultations within the ENVASSO consortium, the key issues 1 to 5 were combined into ‘compaction and structural degradation’, and two complementary key issues were introduced: ’vulnerability to compaction’, and ‘causes of compaction’.

Table 7.1 Overview of key issue selection for Soil Compaction

Compaction type	Key issue selection		Description
	In	Out	
Soil compaction	Compaction and structural degradation		densification and distortion of soil
		Topsoil compaction	densification and distortion of topsoil
		Subsoil compaction	densification and distortion of subsoil
		Soil structure degradation	structural degradation of the soil as a result of compaction
		Soil water infiltration	inability of water to percolate through the soil because of reduced permeability
		Intentional compaction	to reduce volume or hydraulic conductivity, or to increase strength
Potential compaction	Vulnerability to compaction		likelihood of the soil to compact
Compaction by management	Causes of compaction		soil management, tillage practice, tyre pressure, density of grazing animals

7.2 Indicators

The selected indicators must give a comprehensive insight into the key question: 'Where and to what extent is soil quality degraded by compaction and structural degradation in such a way that the soil cannot fulfil its functions?'.

The indicators are listed below, together with the advantages and disadvantages identified during the selection process. It is important to note that a soil survey is the minimum requirement to identify the soil and its properties. The soil is usually identified from a profile pit excavated during the survey.

7.2.1 Indicator selection

Following initial proposals by the subgroup, 12 indicators were identified. Two indicators, 'land use' and 'climate', were later dropped as these were considered to be cross-cutting indicators relevant to other threats such as soil erosion and soil organic matter decline. No proxy-indicators, such as the production or licensing of agricultural machines, were proposed for compaction.

A numerical ranking system for the proposed indicators was employed, similar to the system adopted for the other threats to soil. Expert judgement was applied at the final stage because several of the selection criteria essentially relied on expert judgement in the first place. Following consultations at two subgroup meetings, backed up by email exchanges and several versions of an indicator report, three key issues (see Figure 7.1) and ten indicators were finally selected.

The highest ranking selection criteria (by expert judgement) were:

1. Acceptability or the extent to which the indicator is based on 'sound science';
2. Practicability or the measurability of the indicator;
3. Policy relevance and utility for users;
4. Geographical coverage.

The first three criteria are similar to those proposed by the OECD (2003). Geographical coverage, though not an intrinsic property, is an important consideration for ENVASSO because of the need to identify gaps in geographical coverage to fulfil the project's aim of developing recommendations to harmonise soil monitoring in Europe.
Figure 7.1 (page 110) shows the key issues. The advantages and disadvantages of the selected indicators are described below and the full list is presented in Table 7.2 on page 114.

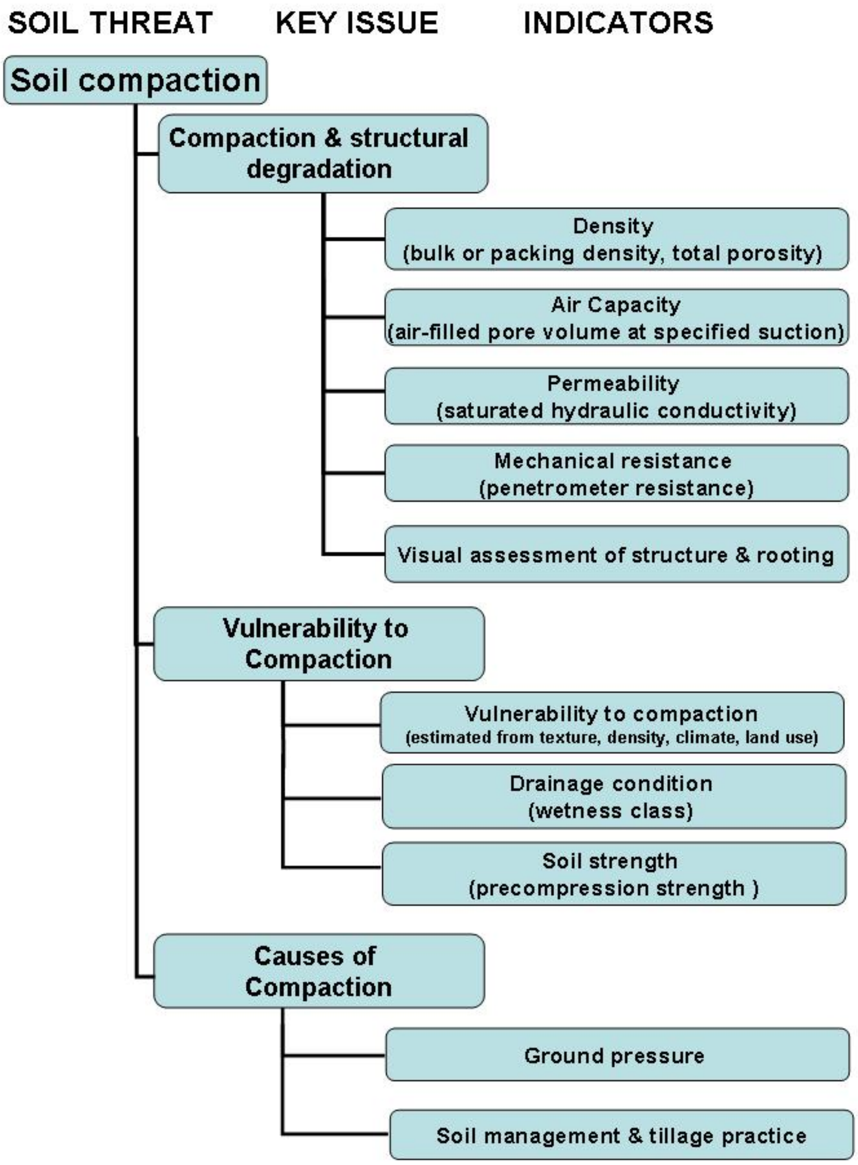

Figure 7.1 Key issue and indicator selection for Soil Compaction

7.2.1.1 Compaction and structural degradation

7.2.1.1.1 CP01 Density (bulk density, packing density, total porosity)

Advantages:

i) Bulk density is a direct measure of soil compaction.
ii) Packing density, calculated from bulk density and clay content, is a good measure of the apparent compactness of soil.

Disadvantages:

i) This indicator can change over relatively small distances and short timescales, although compaction in the subsoil is subject to smaller changes than in the topsoil over these timescales.
ii) Bulk density is normally determined from undisturbed cores of soil sampled in the field, which can be time consuming and difficult under dry conditions.

Conclusion:
The primary indicator of compaction is bulk density which can be measured directly in the field. The upper part of the subsoil (in general the plough pan layer) is the zone of most importance for identifying compaction.

7.2.1.1.2 CP02 Air capacity (air-filled pore volume at a specified suction - e.g. 3, 5 or 6 kPa)

Advantages:
i) Indicates oxygen diffusion capacity and rootability of the soil in wet conditions.
ii) Easier to measure than the saturated hydraulic conductivity.
iii) Good indicator of the amount of macro pores.

Disadvantages:
i) Standardisation is needed – some soil scientists measure air capacity at 5 kPa, others at 3 or 6 kPa.
ii) Does not necessarily provide information about the continuity of pores.

Conclusion:
This is a good indicator which is appropriate because the direct measurement of porosity or air capacity defines the air space or capacity for roots and biota, which controls the soil's air and water regimes. Soil compaction always reduces the air-filled pore volume.

7.2.1.1.3 CP03 Permeability (saturated hydraulic conductivity)

Advantages:
i) An integrated indicator of soil structure, oxygen diffusion capacity, rootability and conditions for biota.
ii) In case of topsoils, the measurement of the infiltration capacity can be considered.

Disadvantages:
i) Measurement of saturated hydraulic conductivity is laborious and time consuming, thus it is sometimes prohibitively expensive to obtain a statistically significant series of measurements.
ii) The diameter of the samples must be in agreement with the structural elements, which normally necessitates large diameter cores (e.g. 20 cm).
iii) The method of sampling and measurement can significantly affect the results and standardisation is required.
iv) Saturated hydraulic conductivity in the topsoil can change over short time intervals.
v) Infiltration capacity of topsoils measures unsaturated hydraulic conductivity, which is a less well defined measurement than saturated hydraulic conductivity.

Conclusion:
This indicator is a direct measure of one of the key functions of the soil, the infiltration capacity and filtering capability. The priority area is the upper part of the subsoil (including any pan or compacted layer). Topsoil compaction can be important for land that is not in arable agriculture, in which the soil is not loosened annually.

7.2.1.1.4 CP04 Mechanical resistance

Advantages:
i) Measurements are rapid and easy, making it possible to obtain large quantities of data over relatively short time intervals.
ii) This enables statistical analyses on frequency and distribution of compaction within a field.

Disadvantages:
i) There is a strong relationship between penetrometer resistance and soil moisture, which makes the interpretation of the measurements difficult unless the field moisture content is also measured.
ii) Ideally, the penetrometer resistance should be measured when the soil is at or near 'field-capacity', which restricts considerably the opportunities for data collection.

iii) There is a strong relationship between penetration resistance and the shape and size of the penetrometer cone, therefore standardisation will be needed if this indicator is to be used in any future European soil monitoring system.

Conclusion:
Mechanical resistance is closely related to the rootability of a soil and a penetrometer is a useful instrument to identify compacted layers. However, a well structured soil can have a high resistance to penetration whilst rootability remains good.

7.2.1.1.5 CP05 Visual assessment (of structure and rooting)

Advantages:
i) The results can reveal previous compaction.
ii) Additional profile information can be determined during the assessment.

Disadvantages:
i) Assessment is subjective and can be laborious.
ii) Expertise is needed to assure meaningful and standardised determinations and even highly skilled field scientists need regular calibration checks on their assessments.
iii) Interpretation is difficult because seasonal, climatic and drainage conditions can have a large impact on rooting and other visible aspects of compaction.

Conclusion:
This is a direct and complete determination of compaction and structural degradation and the effect on rooting, biota, structure, and air and water regime in the whole profile, but consistent data is difficult to obtain because of standardisation and calibration issues.

7.2.1.2 Vulnerability to compaction

7.2.1.2.1 CP06 Estimated vulnerability to compaction (based on texture, density, climate, land use)

Advantages:
i) Combines several controlling factors into a single vulnerability assessment.
ii) Has been shown to produce reasonable results for Europe.

Disadvantages:
i) Application of the model at 1:1,000,000 scale may be questionable; it may be more appropriate at 1:50,000 scale or larger, where real crop performance in specific fields, or where detailed management interventions, are being evaluated (Jones *et al.,* 2003);
ii) There is a lack of detailed data at scales larger than 1:1,000,000

Conclusion:
This is a directly useable indicator for soil compaction in Europe. Modifications can be incorporated as knowledge and data (availability and quality) improve in the medium to long term.

7.2.1.2.2 CP07 Drainage condition (wetness condition, groundwater levels)

Advantages:
i) Drainage status is needed for identification and classification of the soil and is a routine assessment in any soil survey.
ii) Natural drainage conditions are closely related to soil type.

Disadvantages:
i) Skilled ‘field soil scientists’ are needed for the estimation of soil drainage conditions.
ii) Monitoring of groundwater levels is time consuming and expensive, especially when the levels fluctuates over short timescales.

Conclusion:
Soil drainage class defines the length of time that soils are wet or dry. Soil moisture content is crucially important when studying compaction. Wet soil deforms much more easily than dry soil and machinery (or stock) degrades soil structure to a much greater extent when heavy loads are applied under wet conditions. Soil drainage class is assessed routinely during soil surveys and on experimental sites, thus data are readily available.

7.2.1.2.3 CP08 Soil strength (precompression strength, e.g. determined with uni-axial test)

Advantages:

i) Soil strength is very useful for further evaluating and extrapolating the threat of compaction and in developing guidelines for its prevention.
ii) Soil strength is a direct measure of the capacity of the soil to bear loads.

Disadvantages:

i) Measurement is moderately laborious and not standardised in agricultural research.
ii) Soil strength also depends on soil moisture and speed of loading.

Conclusion:
Soil strength relates directly to the likelihood of the soil to compact, and thus the vulnerability of soil to compaction.

7.2.1.3 Causes of compaction

7.2.1.3.1 CP09 Ground pressure (weight and type of machinery - wheeled or tracked vehicle and density and type of stock - animals)

Advantages:

i) Enables evaluation and extrapolation of the results of monitoring compaction.
ii) In the case of wheeled vehicles, the size, number and type of tyres can be varied to reduce the applied ground pressures.
iii) This indicator provides a means for the policy process to mitigate soil compaction.

Disadvantages:

i) An inventory of mechanisation at administrative unit level (NUTS) in Europe is required but data of this type are scarce.
ii) The situation on any monitoring site will be strongly dependent on the equipment type and its use.

Conclusion:
The ground pressure exerted by wheeled or tracked vehicles is a direct cause of compaction and structural degradation. This indicator has additional value for policy purposes, but data are scarce and usually only available at local scale.

7.2.1.3.2 CP10 Soil management & tillage practice

Advantages:

i) Soil management practices are the basis for determining the vulnerability and/or the resilience of the soil to compaction.
ii) The results of monitoring soil compaction can be interpreted better if good soil management (especially tillage) data are available.
iii) This indicator provides a link to policy for mitigating soil compaction.

Disadvantages:

i) Data on soil management practices are rarely georeferenced and/or extensive enough for determining the vulnerability and/or the resilience of the soil to compaction.

Conclusion:
Soil management practices are useful for identifying the pressures on soil.

Table 7.2 Overview of proposed indicators for Soil Compaction

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
CP01	**Compaction and structural degradation**	**Where and to what extent are soil functions impaired by compaction**	**Density (bulk density, packing density, total porosity)**	**$g\ cm^{-3}$ or $t\ m^{-3}$ % ($v\ v^{-1}$)**	**S**	**S**	**G**	**5 – 10 yr**	**National and European scale**
CP02	**Compaction and structural degradation**	**Where and to what extent are soil functions impaired by compaction**	**Air capacity (volume of air-filled pores, e.g. at 3, 5 or 6 kPa)**	**% ($v\ v^{-1}$)**	**S**	**S**	**G**	**5 – 10 yr**	**National and European scale**
CP03	Compaction and structural degradation	Where and to what extent are soil functions impaired by compaction	Permeability (saturated hydraulic conductivity)	$M\ d^{-1}$	S	S	G	5 – 10 yr	Local and regional scale
CP04	Compaction and structural degradation	Where and to what extent are soil functions impaired by compaction	Mechanical resistance (penetrometer resistance)	MPa	S	S	G	5 – 10 yr	Local and regional scale
CP05	Compaction and structural degradation	Where and to what extent are soil functions impaired by compaction	Visual assessment (of structure and rooting)	classes	S	S	G	5 – 10 yr	Local and regional scale

Table 7.2 Overview of proposed indicators for Soil Compaction continues on the next page

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring-type	Frequency (years)	Spatial resolution
CP06	**Vulnerability to compaction**	**What are the causes and circumstances that result in persistent compaction?**	**Vulnerability to compaction (estimated)**	**class**	**S**	**S**	**G**	**5 – 10 yr**	**National and European scale**
CP07	Vulnerability to compaction	What are the causes and circumstances that result in persistent compaction?	Drainage condition; (wetness condition, groundwater levels)	class (d yr^{-1})	S	S	G	5 – 10 yr	National and European scale
CP08	Vulnerability to compaction	What are the causes and circumstances that result in persistent compaction?	Soil strength (precompression strength e.g. determined with uni-axial test)	MPa	S	S	G	5 – 10 yr	local scale
CP09	Causes of compaction	What are the causes and circumstances that result in persistent compaction?	Ground pressure - weight of machinery and tyre/track equipment or density and type of stock	Mg, kN, cm, kPa	P	S	G	5 – 10 yr	Local and regional scale
CP10	Causes of compaction	What are the causes and circumstances that result in persistent compaction?	Soil management and tillage practice	class code	P/S	S	G	5 – 10 years	Local and regional scale

Abbreviations: DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response
Applicability: S = short-term, M = medium-term
Monitoring: G = generally, R = in risk areas only
TOP3 indicators in bold letters

7.2.2 Baseline and threshold values

One way to derive baseline values for soil compaction is to determine the start of the period when heavy machines, that force compaction deeper into the subsoil, began to be used. An evaluation of measured data in databases prior to that period can provide baseline values for the structural state of specific soils. Another option is to search for fields that have never been trafficked by heavy farm machinery. This has been successfully done by Håkansson *et al.* (1996), who measured penetration resistances that were 40% higher in fields trafficked with heavy slurry manure tankers, in intensive potato and sugar beet production systems, than in fields never trafficked by farm machinery.

Threshold values are presented 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. In fact, packing density, dry bulk density and total pore volume (porosity) are directly related and therefore combined in one indicator (CP01). Pore volume and packing density can be calculated from the dry bulk density if the specific weight of the particles, organic matter content and clay content are known.

7.2.2.1 Compaction and structural degradation

7.2.2.1.1 CP01 Density

Packing Density (PD) has proved to be a very useful parameter for spatial interpretations that require a measure of the compactive state of soils (Jones *et al.,* 2003). In situations where the actual bulk density is known, packing density can be readily determined from Equation 1.

$$PD = Db + 0.009C \quad \text{Equation 1}$$

Where: *Db* is the bulk density (g cm^{-3} or t m^{-3})
PD is the packing density (g cm^{-3} or t m^{-3})
C is the clay content (%, w w^{-1})

Three classes of packing density are recognized: low < 1.40, medium 1.40 to 1.75 and high > 1.75 g cm^{-3}. Soils with high packing density can be regarded as compact and almost always have an air capacity (air-filled pores at 5kPa) less than 10% and often less than 5%.

Most plant roots have problems to penetrate soils with a total pore volume (n) less than 40% (Hidding and van den Berg, 1961). Roots of bulbous plants and maize are thicker and more vulnerable than roots of other plants, and require higher pore volumes than 40%. Not only is the penetration resistance of a soil with a pore volume < 40% too high, but also there are problems with the oxygen supply to the roots (Bakker *et al.,* 1987; Tacket and Pearson, 1964). Pore volumes of 40% are associated with sandy and sandy loam soils (clay content < 17.5%). In the Netherlands, clay soils always have pore volumes larger than 40%.

The packing density threshold of 1.75 g cm^{-3} can easily be converted into a dry bulk density value using Equation 1. For soils low in organic matter, for example sands and sandy loams, the pore volume of 40% is equivalent to a bulk density value of about 1.6 g cm^{-3}. As with the pore volume threshold of 40%, the bulk density criterion of 1.6 g cm^{-3} is only relevant for sandy and sandy loam soils. It should be noted that this limit of 1.6 g cm^{-3} is lower than the limit computed based on the packing density threshold of 1.75 g cm^{-3} in case of coarse textured soils (with clay content < 17.5%).

7.2.2.1.2 CP02 Air capacity (air-filled pore volume at specified suction)

Bakker *et al.* (1987) determined the relation between the diffusion coefficient Ds and the air-filled pore volume (ng) for a series of Dutch soils in arable land use. These relations depend strongly on the quality of the soil structure. According to Bakker *et al.* (1987) plant roots will never have aeration problems if Ds > 30 10^{-8} m^2 s^{-1} but will have severe aeration problems if Ds < 1.5 10^{-8}

$m^2 s^{-1}$. We used the relationships devised by Bakker *et al.* (1987) to convert these limits into thresholds for the air-filled pore volume in Table 7.3. It should be noted that this air-filled pore volume is not coupled to any specified soil water suction. The values in Table 1.3 tell us that a soil with an excellent soil structure can be almost saturated before anaerobic conditions occur whereas a soil with a poor structure must be rather dry and have a higher air-filled pore volume than a better structured soil to avoid anaerobic conditions.

Table 7.3 Determined minimum and preferred air-filled pore volumes to avoid (severe) anaerobic conditions for plant root growth

Soil structure	Air-filled pore volume (ng) should be:	
	At least	Preferably
Excellent	> 2 %	> 14%
Good	> 5 %	> 15%
Moderate	> 8 %	> 17%
Poor or structureless	> 12 %	> 21%

According to Grable and Siemer (1968) an air capacity of at least 10% (air-filled pore volume at a specified suction) is required for a satisfactory medium for plant growth. This value (10%) is widely recognised and also used in the Least Limiting Water Range (LLWR) concept of Da Silva *et al.* (1994), which is based on Letey (1985) and demonstrated by, amongst others, Betz *et al.* (1998). In general, the quality of the subsoil structure is only moderate to poor according to the classes in Table 7.3, so a threshold value of about 10 % is needed for a subsoil. According to Lebert *et al.* (2004), the air capacity in subsoils should be larger than 5%, based on German research on redox potential values and root growth. In Table 7.3 a required air-filled pore volume > 5% agrees with a well-structured soil.

The next question is which soil water suction should be used to measure the water content to determine air capacity. We propose a soil water suction that agrees with a condition of a wet but well drained soil in early spring. According to Hall *et al.* (1977) this agrees with a soil water suction of 5 kPa. Our conclusion is that a threshold value of 10% for an air capacity (air-filled pores) at a soil water suction of 5 kPa is a reasonable threshold.

7.2.2.1.3 CP03 Permeability

According to Lebert *et al.* (2003, 2004), a saturated hydraulic conductivity of 10 cm d^{-1} is a suitable threshold for permeability in the subsoil, which is the same value used for classifying a soil as 'bad' in the Netherlands (Cultuurtechnische Vereniging, 1988). In the UK, soils with air capacities (air-filled pores at 5kPa) < 5% are considered to be very slightly porous (Hodgson, 1997, p.50); very slight porosity is normally associated with a saturated hydraulic conductivity of < 10 cm d^{-1} and is indicative of poor soil structure (Thomasson, 1975).

The saturated conductivity (K_{sat}) of a soil can be considered as one of the best indicators of its physical quality because K_{sat} has a direct relationship with the quality of the soil structure and the existence of continuous macro-pores (Wösten *et al.*, 2001). The major part of the decrease in pore volume caused by compaction is at the expense of the macro-pores and soil deformation strongly affects pore continuity. Both macro-pores and pore-continuity affect the ability of the soil to conduct water and air and any reduction in either results in slow saturated hydraulic conductivity, that increases surface runoff and erosion.

The Technical Working Group on Soil Erosion', established under the Thematic Strategy for Soil Protection of the European Union, identified saturated hydraulic conductivity (K_{sat}) as an indicator for the physical quality of a soil (Van Camp *et al.,* 2004b). (K_{sat}) is a commonly measured property and is also an important soil property needed in calculations and modelling of water infiltration, runoff, erosion, trafficability, and transport of nutrients and subsequent pollution. However, K_{sat} data are not widely available in Europe although hopefully this will change with implementation of the forthcoming Soil Framework Directive.

7.2.2.1.4 CP04 Mechanical resistance (penetrometer resistance)

The mechanical resistance of a soil is related to its rootability and there is a strong inverse relationship between resistance to penetration and soil moisture condition. The resistance to penetration is best measured using a penetrometer and measurements should be taken when the soil at 'field capacity'. There is also a strong relationship between mechanical resistance and the shape and size of the penetrometer cone used. The 'small' ASAE(B) cone, which has a top angle of 30° and a base area of 1.3 cm^2 , is recommended. Greacen *et al.* (1969), Gooderham (1977a, b), Ehlers *et al.* (1983) and Dexter (1986), and Håkansson *et al.* (1988) concluded that limiting values of penetrometer resistance (Pr) for root growth range between 2 and 5 MPa. Brussaard *et al.* (2004) suggested a threshold value of Pr < 3 MPa. However, in well-structured subsoils a higher threshold value Pr < 4 or 5 MPa may be acceptable. Nevertheless, it must be appreciated that in certain circumstances a well-structured soil can have a high penetration resistance whilst rootability still remains good.

7.2.2.2 Vulnerability to compaction

7.2.2.2.1 CP06 Vulnerability to compaction

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, if the resilience of a soil is high and the compacted and structurally degraded soil material recovers in a few years by natural processes and/or artificial loosening, a temporary degradation in soil quality and functioning may be acceptable.

7.2.2.2.2 CP08 Soil strength

Three soil strength properties, i.e. cohesion, angle of internal friction and the pre-compaction stress, should be considered. The measurement of the cohesion and angle of internal friction are laborious and expensive and data for these properties are not common in agricultural research. Cohesion and angle of internal friction are needed to determine the shear strength of soils. In agriculture, shear strength failure of subsoils by wheel loads occurs when the cohesion is low. This means that sandy subsoils can be vulnerable to shear strength failure and can be deformed and compacted in this way (Van den Akker, 2004; Van den Akker and Schjønning, 2004).

The high cohesion of clay soils results in a high shear strength which prevents shear failure of clayey subsoils. Compaction by failure of the pre-compaction stress plays an important role in both sandy and clay soils. The pre-compaction stress can be measured with a uni-axial test. This test is moderately laborious but not very expensive. Measurement of the pre-compaction stress can be a good option for a systematic assessment and monitoring of the vulnerability of subsoils to compaction.

In the European SIDASS project (Horn and Fleige, 2005), a classification of pre-compaction stress is defined (Horn *et al.,* 2005).

Table 7.4 Classification of pre-compaction stress

very low<	30 kPa;
low	30–60 kPa;
medium	60–90 kPa;
high	90–120 kPa;
very high	120–150 kPa

Source: Horn *et al.,* 2005

This classification is a measure of compactability, the higher the pre-compression stress the lower the vulnerability of the soil to compaction.

7.2.3 Data and user requirements

Table 7.5 Summary of data and user requirements for Soil Compaction

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
CP01	**Density (bulk density, packing density, total porosity)**	**Dry bulk density Organic Matter content Clay content**	**Monitoring network to be developed**	**National and European scale**	**National and EU**	**Spring sampling when soil is at field capacity; every 5 years**	**medium to high**	**g cm^{-3} or porosity in % (v v^{-1})**	**0.01 g cm^{-3} or 1% porosity These changes are meaningful around the threshold values**
CP02	**Air capacity (air-filled pore volume at a specified suction)**	**Dry bulk density Organic Matter content Soil water content at a certain suction (e.g. 3, 5, 6 kPa)**	**Monitoring network to be developed**	**National and European scale**	**National and EU**	**Spring sampling when soil is at field capacity; every 5 years**	**medium to high**	**% (v v^{-1})**	**1%**
CP03	Permeability (saturated hydraulic conductivity)	soil infiltration, soil permeability	Monitoring network to be developed	Local and regional scale	National and EU	Spring sampling when soil is at field capacity; every 5 years	medium to high	cm d^{-1}	100% logarithmic scale should be used: 1 cm d^{-1} = very bad; 10 cm d^{-1} = bad; 100 cm d^{-1} = reasonable; etc
CP04	Mechanical resistance (penetrometer resistance)	penetrometer resistance at field capacity	Monitoring network to be developed	Local and regional scale	National and EU	Spring sampling when soil is at field capacity; every 5 years	medium, standardization required, ASAE(B) cone should be used (top angle 30 degrees, base area 1.3 cm^{2})	MPa	0.2 MPa

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
CP05	Visual assessment (of structure and rooting)	Root penetration depths, soil structure taxonomy Soil survey, measurements and estimations texture, height groundwater table	Monitoring network to be developed	Local and regional scale	National and EU	Spring sampling when soil is at field capacity; every 5 years	Medium-High, standardization of classification required	classes	no limit
CP06	**Vulnerability to compaction (estimated)**	**Texture (& SOC), density, land use, climate**	**European Soil Database; MARS agroclimatic database**	**National and European scale**	**National and EU**	**every 5 years**	**Medium**	**Classes**	
CP07	Drainage condition (wetness condition, groundwater levels)	Mean highest ground water table Mean lowest ground water table Drainage classes	Monitoring network to be developed	National and European scale	National and EU	Spring sampling when soil is at field capacity; every 5 years	medium	classes	no limit
CP08	Soil strength (e.g. precompression strength determined with uni-axial test)	precompression strength determined with uni-axial test	Monitoring network to be developed	local scale	National and EU	Spring sampling when soil is at field capacity; every 5 years	medium to high	MPa	5 kPa
CP09	Ground pressure; weight of machinery and tyre/track equipment or density and type of stock	Land use, crop, used machinery	To be specified	Local and regional scale	National and EU	Every 5 years	medium	Load in Mg or kN per wheel, tyre width (cm) and inflation pressure (kPa), description of machine and tyre equipment.	5 kN in wheel load
CP10	Soil management and soil tillage	Land use, crop, soil management and tillage	To be specified	Local and regional scale	National and EU	Every 5 years	medium	ploughing, depth of ploughing, conservation tillage etc	no limit

7.2.4 TOP3 indicators

Table 7.6 TOP3 Indicators for Soil Compaction

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 - 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, but 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). Density data can be used across Europe because bulk density is already measured in some of the monitoring programmes and data also exist from national inventories (soil surveys).

CP02 - selected as a quantitative measurement of soil structure, 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 rootability of plants. However, at the present time, air-filled porosity has not generally been included in national soil databases.

CP06 - selected as a TOP3 indicator because it is applicable at European scale to estimate the vulnerability of soils to compaction. The vulnerability scheme categorises the inherent susceptibility of the soil to compaction according to soil texture (taking soil organic matter content into account) and soil density. This susceptibility is then converted into the vulnerability that expresses the likelihood of the soil compacting under different soil moisture and climatic conditions.

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8 DECLINE IN SOIL BIODIVERSITY

The soil biota play many fundamental roles in delivering key ecosystem goods and services, and are both directly and indirectly responsible for delivering many important functions such as releasing nutrients from soil organic matter, forming and maintaining soil structure and contributing to water storage and transfer in soil (Lavelle and Spain, 2005).

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.,* 2005). 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" (see 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 of soil functions. As it is known that many of the soil threats will affect soil biodiversity monitoring, its decline is crucial to maintain soil sustainability.

8.1 Key issues

For soil biodiversity two key issues were considered:

- Species diversity.
- Biological functions (e.g. organic matter decomposition and mineralization or release of nutrients in mineral form).

These related aspects of biodiversity need to be understood and monitored. Species diversity (e.g. total number of species, species richness, genetic diversity within species, distribution of individuals among those species) and biological function (e.g. organic matter decomposition and mineralization or release of nutrients in mineral form) complement one another. For example, assessing biological functionality does not describe species' diversity while on the other hand, the number and abundance of species does not directly assess functionality. When monitoring the decline of soil biodiversity both aspects should be considered (Table 8.1).

Table 8.1 Overview of key issue selection for Decline in Soil Biodiversity

	Key issue selection		Description
	In	Out	
Decline in soil Biodiversity	**Species diversity**		**Diversity within species, between species and of ecosystems**
	Biological functions		**Maintenance and functioning of specific ecosystems or habitats**

8.2 Indicators

This section describes the results of the indicator selection process, listing the selected indicators along with their advantages and disadvantages (Section 8.2.1). Secondly, as neither baselines nor thresholds for the selected indicators were proposed, a common approach to their derivation is discussed (Section 8.2.2). Thirdly, the data and user requirements for implementing the selected indicators in a European monitoring system are presented (Section 8.2.3), and finally, the three most important indicators (TOP3) are proposed (Section 8.2.4).

8.2.1 Indicator selection

The literature review underlined the diversity of methods and indicators used mostly by research teams to assess and sometimes monitor soil biodiversity (Andren *et al.,* 2004). As a summary the following indicators were included in the selection:

- Microflora (bacteria and fungi): diversity of species based on different methods (e.g. DNA or PLFA fingerprints), microbial activities, general parameters such as soil respiration or total biomass. (Fierer and Jackson, 2006; Nielsen and Winding, 2002; Ibekwe *et al.,* 2002, Kubat J., 2003)
- Microfauna: protozoan (Foissner, 1997) and nematodes (Ekschmitt *et al.,* 2001),
- Mesofauna: Collembola, Acari and Enchytraeids (Sousa *et al.,* 2005; Ruf, 1998; Jänsch *et al.,* 2005)
- Macrofauna: earthworms are mainly used (Römbke *et al.,* 2005) but also total macrofauna (at family level for all groups and at species level for ecosystem engineers like earthworms and ants). The activity of soil macrofauna is used as an index for soil diversity (Pérès *et al.,* 1998).
- Soil organic matter is also used as an indicator for biodiversity and soil functioning (Ponge, 2003)

Mathematical indices have also been developed to simplify field data and to improve communication of the results to non-scientists (e.g. maturity index (Bongers & Ferris, 1999), soil macrofauna index (Ruiz-Camacho, 2004), QBS index (Parisi *et al.,* 2005), PLFA index (Puglisi, 2005).

There are no reported monitoring networks which fully include biodiversity, except in the Netherlands where the monitoring system includes both diversity of species and soil biological functioning (Rutgers *et al.,* 2005). The Dutch soil monitoring network is a stratified grid according to land use (about 160 locations are sampled for biological determinations every 6 years). Nevertheless in other EU countries (e.g. Austria, Czech Republic and Hungary) biodiversity indicators (e.g. soil respiration, Gamasid mites, earthworms) are already included or experimental studies are starting in order to complement soil monitoring networks (France, Germany).

Within the scope of this work it was not possible to review all possible indicators (more than 90 were identified) and it was decided to regroup them according to classical soil ecology definitions under two identified key issues, to give the following scheme (see Figure 8.1).

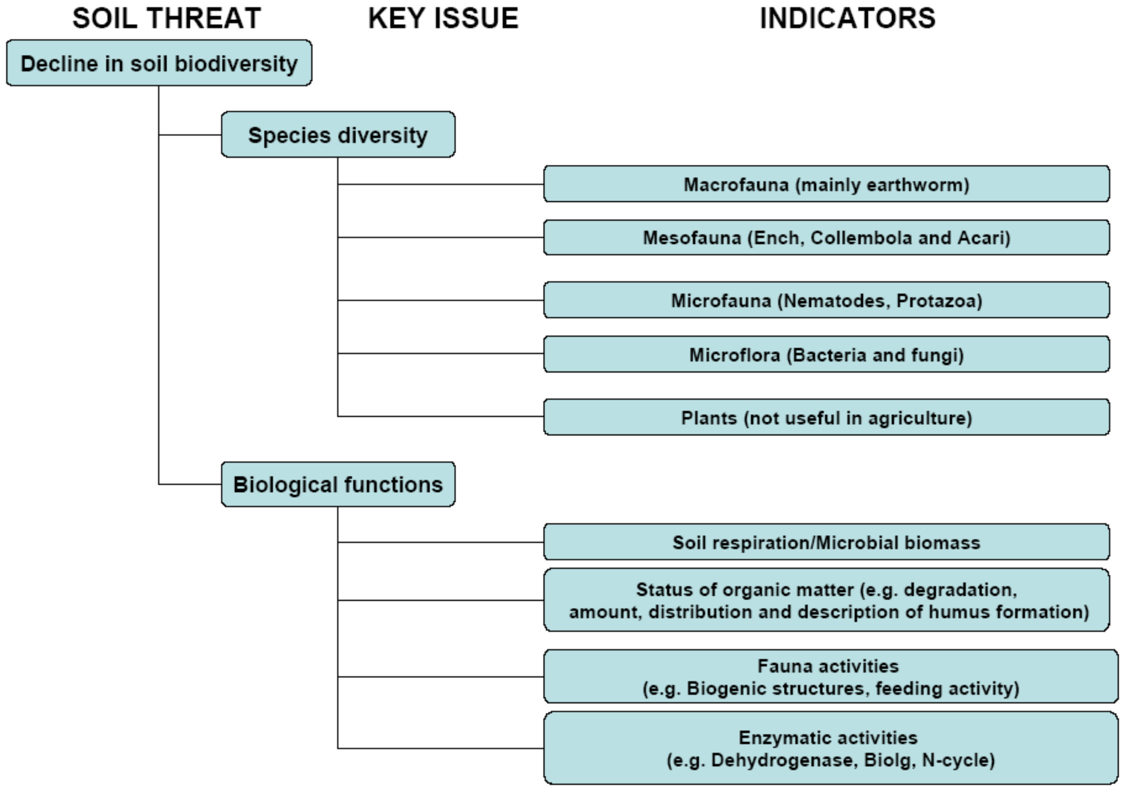

Figure 8.1 Key issues and indicators for Decline in Soil Biodiversity

A numerical ranking system for the proposed indicators was employed. Each indicator was ranked during 2 meetings involving 6 to 10 experts on soil biodiversity. The highest ranking selection criteria were:

1. **Significance of the indicator** (indicator based on 'sound science') - all candidates were considered as significant except plants since their natural abundance is meaningless in agriculture
2. **Acceptance of the methodology** - indicators with standardized methods were favoured
3. **Measurability and costs** - all available indicators for assessing soil biodiversity are both time-consuming and expensive, requiring labour intensive sampling, identification and quantification but nonetheless those that are more straightforward and relatively cheaper were preferred. (Research is progressing to develop software and/or technical guides allowing easier identification. Furthermore identification of soil species from DNA extracts is being developed)

Based on such criteria, the following indicators were selected: soil macrofauna, soil mesofauna, soil microflora for the first key issue (species diversity) and soil respiration as well as the status of organic matter for the second key issue (biological functions). Indicators identifying the status of organic matter are included in the TOP3 indicators chosen in the chapter covering the threat 'Decline in soil organic matter' (Chapter 4).

The species indicators belong to ecological groups which reflect the size of organisms. As an example, soil macrofauna integrates all organisms that can be seen visually (from 2 to 10 mm), including ants, earthworms, spiders and insect larvae. In principle all soil organisms and the biological functions which they provide are important and should be assessed. However, for reasons of practicability it was decided to select a minimum set of representative ecological groups (priority level I, Table 8.2) to act as surrogates measures for overall decline in biodiversity. (It should be noted that an increase in biodiversity may also be the sign of a disturbed ecosystem). Depending on the availability of resources and any specific requirements, this minimum set of indicators could be extended in some regions (priority level II and III, Table 8.2). The minimum recommended set of indicators (priority level I, Table 8.2) is to be based on:

i) For species diversity, earthworm diversity and biomass (or Enchytraeids if earthworms are not present) and Collembola diversity.
ii) For biological functions, microbial respiration.

Table 8.2 Priority level of indicators for Decline in Soil Biodiversity

Key issue	Groups of species	Level I (all core points of the monitoring network)	Level II (all core points or selected points depending on relevance to specific issues and availability of resources)	Level III (optional)
Species diversity	Macrofauna	Earthworm Species	All macrofauna	
	Mesofauna	Collembola species Enchytraeids (if no earthworms)	Acari sub-orders	Activity based on litter bags or on bait lamina
	Microfauna		Nematode diversity based on trophic guilds	Proctista
	Microflora		Bacterial and fungal diversity based on DNA / PLFA extraction	
	Plants			For grassland and pastures
Biological functions	Macrofauna			Macrofauna activity (e.g. biogenic structures, feeding activity)
	Mesofauna			Mesofauna activity
	Microflora	Soil respiration	Bacterial and fungal activity	

8.2.1.1 Species diversity

8.2.1.1.1 BI01 Earthworm diversity (identified at species level) and biomass

Advantages:

i) This measure of the diversity of earthworm species is directly relevant to the soil threat Decline In Biodiversity and the key issue 1.
ii) Earthworms are regarded as the main soil engineers and changes in their abundance and community structure modifies several soil properties such porosity and density, as well as functionalities, for example recycling and distribution of organic matter.
iii) Earthworms are the largest soil invertebrates, which makes them easier to sample and to identify with minimum knowledge.
iv) There are existing national datasets from which baselines and other criteria may be interpreted.
v) They are already measured in some soil monitoring networks.
vi) Easily understood and communicated to non-experts.

Disadvantages:

i) Sampling, identification and enumeration of earthworms is time-consuming and expensive.
ii) Earthworms cannot be used as the only surrogate for the decline in biodiversity
iii) They are not included in all soil monitoring networks.

Conclusion:
The primary indicator for species diversity is earthworm diversity (or Enchytraeids if earthworms are not present) identified at species level and fresh biomass. Sampling should be performed according to the ISO method 23611-1 (2006). For Enchytraeids the sampling method is ISO DIS method 23611-3 (2006). This indicator should be combined with the second one (BI02) in order to estimate the diversity of soil invertebrates.

8.2.1.1.2 BI02 Collembola diversity (identified at species level)

Advantages:

i) A measure of the diversity of Collembola species is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) Collembola are primary agents in the soil organic matter decomposition process, acting as dispersal agents for fungal spores and bacteria and promoting fungal succession during decomposition, while changes in their abundance and community structure modify the kinetics of litter degradation.
iii) When performing soil ecological assessments, Collembola are one of the most frequently used ecological groups as they are sensitive to changes in land-use practices and landscape composition and structure.
iv) There are existing national datasets from which baselines and other criteria may be interpreted.
v) There is some evidence that it may be possible to simplify Collembola identification since good correlations have been observed between species level and family level.
vi) They are already measured in some soil monitoring networks.

Disadvantages:

i) Collembola determination will require soil sampling followed by species identification and thus will be time-consuming and expensive.
ii) Collembola can not be used as the single surrogate for decline in below ground biodiversity.
iii) They are not included in all soil monitoring networks.
iv) Requires relative expertise

Conclusion:
The secondary indicator for species diversity is Collembola diversity identified at species level and sampled according to the ISO 23611-2 method (2006). Together with BI01 it will give a picture of the status of soil organisms.

8.2.1.2 Biological functions

8.2.1.2.1 BI03 Microbial respiration

Advantages:

i) Microbial respiration is relevant to the soil threat Decline in Soil Biodiversity and the key issue ‘biological functions’.
ii) Microbial respiration is considered to be a critical process in the soil system; it is correlated with degradable organic matter and soil microbial biomass.
iii) Microbial respiration of soils is easy to measure and standard protocols are already available.
iv) There are existing national datasets to support interpretation of baselines and thresholds.
v) It is already measured in some soil monitoring networks.
vi) It is relatively easily understood and communicated to non-experts.

Disadvantages:
i) Microbial respiration is a broad measure of soil system activity and provides little information about the activity of specific communities of soil micro organisms.
ii) Microbial respiration can not be used as the single surrogate for decline in below ground biodiversity.

Conclusion:
The indicator for species diversity is based on the measurement of microbial respiration (basal and induced) according to ISO methods 16072 and 17155 (2002). This method is widely used to characterize the status and activity of soil microbes as well as the available pool of organic carbon.

8.2.1.3 Supplementary indicators for species diversity and biological functions

This minimum set can be then be supplemented by additional measurements depending on specific issues that need investigation and availability of resources. The following groups of organisms or functions are proposed (priority level II, Table 8.2), reflecting those included in existing monitoring networks. Other additional indicators (not described here) may be usefully included in monitoring which is directed to specific issues and research investigations (priority level III, Table 8.2).

8.2.1.3.1 BI00 Microflora diversity

This indicator is based on PLFA and DNA extraction.

Advantages:
i) Diversity of bacteria and fungi is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) Microflora have many critical roles in soil functions; they support biogeochemical cycles and the growth of plants.
iii) This is already measured in some soil monitoring networks
iv) There are some national datasets which can be used for interpretation of baselines and thresholds.

Disadvantages:
i) Microflora diversity determination is much less labour-intensive than others which rely on identification and enumeration of organisms but will require expensive equipments.
ii) The sampling and extraction methods are not yet standardized.
iii) Interpretation of the results can be difficult in terms of effect on soil function.

8.2.1.3.2 BI01-1 Macrofauna diversity

This indicator is identified at family level. Soil macrofauna contain Lumbricidae (usually the most important taxon), followed in decreasing order by Formicidae, larvae (Coleoptera + Diptera), Coleoptera, Arachnidae, Gastropoda and Myriapoda. Some other groups may be present but in very low numbers, such as Hemiptera, Isopoda, Dictyoptera, Orthoptera, Isoptera and Dermaptera.

The assessment of soil macrofauna can be done by the species richness of earthworms (Lumbricidae) and ants (Formicidae), together with the number of other families present (a strong correlation with species diversity exists). Since many macrofauna species tend to have rather restricted areas of distributions and/or low densities that make their discovery rather infrequent, families appeared to be the best indicator of diversity, especially when comparisons have to be made over large geographical areas. Ants and earthworms, however, may be identified at species level because there are fewer species than other families and because their grouping into a single unit ignores their functional diversity. In addition, practical keys exist for the identification of these invertebrates.

Advantages:

i) The diversity of macrofauna families is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) Soil macrofauna play a major role in different soil functions, including microbial activation, nutrient cycling, soil aggregation, humus formation and organic matter recycling.
iii) As the different group of organisms integrated in this indicator have different feeding habits and exploit all resources available in the litter and soil it is anticipated that each group will react differently to soil pressures making this indicator sensitive to a range of soil changes.
iv) As organisms are identified at family level instead of species level, their identification and enumeration will be more straightforward for the non-specialists.
v) It is relatively easily understood and communicated to non-experts.

Disadvantages:

i) Macrofauna determination will require soil sampling followed by species/families identification and thus will be time-consuming and expensive.
ii) Standard sampling methods do not exist.
iii) This has not been included in existing soil monitoring networks and only a few national dataset are currently available or are being acquired. Consequently, there is a lack of data for interpreting baselines and thresholds.

8.2.1.3.3 BI02-1 Acari diversity

This indicator is not identified at species but at higher levels and sampled according to the ISO 23611-2 method (2006).

Advantages:

i) The diversity of Acari is directly relevant to the soil threat Decline in Soil Biodiversity and key issue 1.
ii) Organisms within different sub-orders (e.g. Gamasida, Oribatida) have different feeding habits and exploit all resources available in the litter and soil. It is anticipated that each sub-order will react differently to soil pressures making this indicator sensitive to a range of soil changes.
iii) As organisms are identified at a higher level (not species level) their identification and enumerations will be more straightforward for non-specialists.
iv) It is already measured in some soil monitoring networks.

Disadvantages:

i) Acari determination requires soil sampling followed by identification and enumeration and is time-consuming and expensive.
ii) The determination is relatively difficult compared, for example, to that of Collembola. Furthermore it seems that the taxonomy of the sub-orders is still being developed.
iii) Requires specialist expertise

8.2.1.3.4 BI02-2 Nematode diversity

This indicator is based on trophic guilds (e.g. fungivore, bacterivore, phytophage) and sampled according to the ISO DIS 23611-4 method.

Advantages:

i) Diversity of nematodes is directly relevant to the soil threat Decline in Soil Biodiversity and the key issue 1.
ii) As nematodes have different feeding habits it is anticipated that they will react differently to soil pressures making this indicator sensitive to a range of soil changes.
iii) This is already measured in some soil monitoring networks.

Disadvantages:

i) Nematode determination requires soil sampling followed by trophic guilds identification and is time-consuming and expensive.
ii) Even if based on the trophic habits and not on species identification, determination requires specialist expertise.

8.2.1.3.5 BI03-1 Microflora activity

This indicator is based on enzymatic reactions.

Advantages:

i) Diversity of enzyme activities is relevant to the soil threat Decline in Soil Biodiversity and the key issue 2.
ii) Microflora have many critical roles in soil functions; they support biogeochemical cycles and the growth of plants.
iii) This is already measured in some soil monitoring networks.
iv) There are some national datasets which can be used for interpretation of baselines and thresholds.
v) It can be explained relatively easily to the non-expert.

Disadvantages:

i) Microflora activity determination will require soil sampling followed by the analysis of several activities (it seems that an automation of the measurement is feasible).
ii) The measurement method is not yet standardized (except for the dehydrogenase activity).
iii) Interpretation of the results can be difficult.

8.2.1.4 Conclusion

This minimum set of TOP3 indicators (BI01, BI02 and BI03) should be measured at least at core sites within a monitoring network. Sampling must be done in the same season, preferably in spring or autumn, to allow temporal comparisons. The time between two measurements should preferably be 3 years, but not longer than 5 years as soil biota will react quickly to soil pressures (Table 8.3).

Supplementary indicators were added in Table 8.3 (BI00, BI01-1, BI02-1, BI02-2 and BI03-1) as these are already performed in some EU monitoring systems or because, depending on available resources, they will increase knowledge on the decline in soil biodiversity.

Table 8.3 Overview of proposed indicators for Decline in Soil Biodiversity

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability (S or M)	Monitoring type (gen or risk)	Frequency (years)	Spatial resolution
BI00	Species diversity	Are there changes in the diversity of soil micro organisms?	Microbial and fungal diversity	Number of genotypes kg^{-1} soil (DM)	Impact	M	G or R	3 to 5 years	EU or National based on a grid or a stratified system Point data
BI01	Species diversity	**Are there changes in the diversity of soil macrofauna?**	**Earthworms diversity and fresh biomass**	**Number m^{-2}, g fresh weight m^{-2}**	**Impact**	**M**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI01-1	Species diversity	as above	Macrofauna diversity at family and/or specie levels	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI02	**Species diversity**	**Are there changes in the diversity of soil mesofauna?**	**Collembola diversity (Enchytraeids diversity if no earthworms)**	**Number m^{-2}**	**Impact**	**M**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI02-1	Species diversity	as above	Acari diversity	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI02-2	Species diversity	as above	Nematode diversity	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI03	**Biological functions**	**Are there changes in soil functioning?**	**Microbial respiration**	**g CO_2 kg^{-1} soil (DM)**	**Impact**	**S**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI03-1	as above	as above	Microbial activity based on enzymatic reactions	g substrate metabolized kg^{-1} soil (DM)	Impact	M	G or R	3 to 5 years	As above or point data

DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response / Applicability: S = short-term, M = medium-term / Monitoring: G = generally, R = in risk areas only
TOP3 indicators in bold letters

8.2.2 Baseline and threshold values

For Decline in Soil Biodiversity a minimum set of 3 indicators has been chosen including measurements of species diversity (key issue 1) and of biological functions (key issue 2). However, if no earthworms are expected or measured due to soil conditions, e.g. pH, then Enchytraeids should be measured. Whatever the indicator, it is not possible to define single baseline or threshold values 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 thresholds.

Baseline 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 taken with caution, as different soil conditions as well as a lack of harmonised measurements is likely to lead to misleading estimates of temporal change.

Another way to define baseline values is to use the procedure developed in the Netherlands monitoring network where reference situations have to be selected (depending on land use, soil type, climatic conditions, biogeographical region) according to expert judgement. Such reference situations are calculated as the minimum, or the maximum or the mean values for selected indicators. As an example it is possible to select a certain number of organic farms as a reference situation for all organic farms. Various endpoints, e.g. the mean value of earthworm abundance, can be calculated for the selected farms. Subsequently, any measurement made on other organic farms may then be compared with this reference/baseline.

The key to being able to discern with a given confidence whether any indicator is showing improvement, decline or no change, is to adopt a sufficient spatial and temporal sampling density. This depends on being able to define in advance acceptable detection limits for temporal change (such work is already in discussion and will be included in an ISO standard dedicated to field sampling designs for soil organisms).

Threshold values

The simplest threshold will 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, e.g. earthworms in very acidic soils). Another approach could be to define a threshold as an unacceptable deviation from the baseline value or from the 1st (t_0) measurement. In the latter case, natural variations have to be taken into account.

Defining natural variations

Depending on various factors, setting of acceptable/unacceptable deviations may need information about the natural variations in the diversity and activity of an organism. This can be assisted by combining existing data sets that are available at the national level. Although there is a lack of data from true monitoring networks, there is substantial data from national transect or monitoring plots (e.g. UK, D, F, DK) and some at European level (e.g. from European research projects such as BIOASSESS). Further data may also be useful from the many field experiments made on the effect of various soil threats on soil biodiversity (e.g. contamination). The following data sets have been identified but others may be available from the following sources:

- The Dutch soil monitoring network which includes the diversity of microbes, nematodes, potworms, earthworms, mites, springtails and measurement of soil processes at about 160 locations within cropped land and grassland
- The EU BIOASSESS project which covers the diversity of macrofauna, of Collembola, and of carabids in 8 EU countries within a gradient of land use change at landscape level (from semi-natural forest to mixed cropping)
- German monitoring plots which include the diversity of earthworms and Enchytraeids within three main land uses (forest, grassland, crops) plus measurements of soil respiration and microbial biomass, mainly at permanent plots at crop sites

- The Hungarian soil monitoring network which covers measurement of respiration, cellulose activity and deshydrogenase activity on 1236 points (865 in arable land and grassland, 183 forest and 188 special points).
- The Danish farm survey which covers the diversity of soil invertebrates within 4 farming systems (organic farming, integrated forage / grain farming, conventional farming)
- A French land use/land practice survey which includes the diversity of soil earthworms within different land uses (e.g. vineyard, mixed farming/breeding and pasture), land practices (e.g. with and without ploughing, rotation crop), land managements (organic farming, integrated agriculture, conventional agriculture) and under different climatic conditions (from the western to the eastern part of France and also in the south of that country).
- A Portuguese study of the diversity of Collembola in several forest stands representing the dominant tree species in Portugal, and for some forest types, different management practices.

When using data from these and other sources, it should be remembered that data with different origins may not be completely comparable due to differences in sampling methods, bearing in mind that ISO sampling standards have only been published quite recently (2005; 2006). Nevertheless it seems that data sets of some organism groups from different countries may be comparable (e.g. endogeic earthworms). These datasets should be collated according to soil type, land use and climate.

Interpretation of measurements of species diversity and activity to a indicator values
Estimation of indicator values can be achieved straightforwardly from the area, or the number, of monitoring sites where the threshold is exceeded and reporting this in terms of a % of monitored land where a significant change in soil biodiversity has been observed. Clearly interpretation of indicator values requires definition of a baseline.

8.2.2.1 Conclusion

Within the timeframe of the project and due to the lack of data it was impossible to define baseline or threshold values. Nevertheless an approach was proposed but will require further work as follows:

- collecting existing national or EU data on soil biodiversity in order to identify already covered situations (e.g. soil type, climate, land uses),
- new measurements based on the proposed standardized methods on locations where no data already exits,
- data treatment to select baseline or threshold values. This will also require the definition of natural variations at the European level which means that the selection of reference sites (representing land use, soil type, climatic conditions, bio-geographical region) should be done according to expert judgement.

8.2.3 Data and user requirements

As soil diversity and biological functioning are related to soil type and associated properties (e.g. pH, SOM), climate (e.g. dryness), land use (e.g. forest, grassland, crops) and land practices (e.g. tillage, use of pesticide and of fertilizers), the following information is needed for data interpretation:

1. General habitat characterization:
   i) Detailed geographical characterization (including georeferencing of monitoring sites),
   ii) Land use (e.g. forest, grassland, crop sites, urban sites) and land practices (including vegetation),
   iii) Climate data (annual means and minimum and maximum of temperature and precipitation),
   iv) Groundwater level and, if appropriate, distance to nearest surface water.

2. Soil properties, differentiated by soil horizon:
   i) pH-Value (CaCl2),
   ii) Soil organic carbon content,
   iii) Total nitrogen, C/N-ratio,
   iv) Texture (sand, silt, clay),
   v) Cation-Exchange Capacity (CEC),
   vi) Assessment of the usable field capacity of the root layer.

3. Contamination and anthropogenic stresses:
   i) Concentration of heavy metals and organics (e.g. persistent organic pollutants and pesticides),
   ii) Any other kind of anthropogenic stress like soil compaction

Based on the discussion above, it is concluded that it will be difficult to compare the biodiversity data from different countries. Nevertheless comparisons of data between different land uses within the same climate/soil region may be usefully made as well as the comparison of relative results (expressed as a % deviation from the initial measurement) between countries.

Table 8.4 Summary of data and users requirements for Decline in Soil Biodiversity

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
BI01	Earthworms diversity, abundance and biomass of species (Note: species composition of Enchytraeids and abundance of species may substitute this indicator if no earthworm is expected)	EU data needed to further define baseline and threshold values	Many more sites measuring the status of soil biodiversity in EU Member States	To be discussed and evaluated if a grid or a stratified network is needed	EU27	3 years	high	Species name Number individuals m^{-2} g fresh weight m^{-2}	15-25% relative change
BI02	Species composition of Collembola, abundance of species	EU data needed to further define baseline and threshold values	Many more sites measuring the status of soil biodiversity in EU Member States	To be discussed and evaluated if a grid or a stratified network is needed	EU27	3 years	high	Species name Number individuals m^{-2}	15-25% relative change
BI03	Soil microbial biomass Soil microbial respiration	EU data needed to further define baseline and threshold values	Many more sites measuring the status of soil biodiversity in EU Member States	To be discussed and evaluated if a grid or a stratified network is needed	EU27	3 years	high	Resp: g CO_2-C h^{-1} kg^{-1} soil (DM); Cmic: g Cmic kg^{-1} soil	Resp: 0.05; Cmic-SIR: 2.0; Cmik-CFE: 10.0

8.2.4 TOP3 indicators

Table 8.5 TOP3 indicators for Decline in Soil Biodiversity

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 – selected for estimating the species diversity in soils because earthworms are known to be the main soil engineers. Changes in their abundance and community structure modifies several soil properties such porosity and density, as well as functionalities, for example recycling and distribution of organic matter. Their sampling is already standardized and many soil studies include the measurement of their abundance and diversity.

BI02 – selected for estimating the species diversity in soils because Collembola are primary agents in the soil organic matter decomposition process. Changes in their abundance and community structure modify the kinetics of litter degradation. Their sampling is already standardized and many soil studies include the measurement of their abundance and diversity.

BI03 – selected for estimating the biological functioning of soils because microflora is involved in all catabolic reactions in soils. Microbial respiration is considered to be a critical process, correlated with degradable organic matter and soil microbial biomass. Microbial respiration is easy to measure and standard protocols are already available.

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

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

With such diversity it is anticipated that each indicator may react differently to soil pressures making this set sensitive to a range of soil changes (e.g. compaction, contamination, loss of organic matter, erosion).

Due to lack of standardization, but also to lack of interest, soil biodiversity has up to now been poorly explored whereas its contribution to soil functions is known and recognized. Thus it has not been possible to propose baseline and threshold values for the selected indicators at European scale. This will become possible if the TOP3 indicators are measured with the already standardized sampling protocols on all cores points of existing EU monitoring networks and/or if existing data on the TOP3 indicators across the EU are collected, harmonized and treated in order to propose baseline/threshold values and increase knowledge on the Decline in Soil Biodiversity.

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9 SOIL SALINISATION

Salt affected soils cover extensive areas on each continent of the Earth. Salinity, alkalinity and sodicity are among the most important and widespread soil degradation processes and environmental/ecological stresses in the biosphere. They limit agro-ecological potential and represent a considerable ecological and socio-economical risk for sustainable development. According to the latest estimations, the total area of salt-affected soils is about one billion (10^9) hectares. They occur mainly in the arid and semi-arid regions of Asia, Australia and South America, and cover fewer territories on other continents, e.g. in Europe (Table 9.1). European salt affected soils occur south of a line from Portugal to the Upper Volga including the Iberian Peninsula, the Carpathian Basin, the Ukraine, and the Caspian Lowland.

Table 9.1 Distribution and extent of salt affected soils

Country	Affected area (1000 ha)					
	Saline soil	Alkali soil			Potential salt affected soil	Total area (1000 ha)
		without	with			
		Structural B-horizon				
			non-calc.	calc.		
Austria	0.5				2.5	3.0
Bulgaria	5.0		20.0			25.0
Czech &Slovak Republics	6.2	7.5	2.7	4.3	85.0	105.7
France	175.0		75.0			250.0
Greece						3.5
Hungary	1.6	58.6	294.0	31.9	885. 2	1271.3
Italy	50.0				400.0	450.0
Portugal	75				25	100.0
Romania	40.0	100.0		110.0		250.0
Spain						840.0
Russia	7546.0	1616.0	20382.0		17781.0	47325.0
Former Yugoslavia	20.0	50.0	110.0	75.0		255.0

(After Szabolcs, 1974, 1989)

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 inappropriate irrigation practices, use of salt-rich irrigation water 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 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 erosion potential, desertification, soil structure, aggregate failure, compaction); the hydrological cycle (moisture regime, increasing hazard – frequency, duration, severity – of extreme moisture events as flood, water logging, and drought); and biogeochemical cycles (plant nutrients, pollutants, potentially harmful elements and compounds).

9.1 Key issues

Factors linked to salt accumulation are:

i) Salt source (primary: weathering, volcanic activities; secondary: parent material, surface- and subsurface waters)
ii) Transporting agents (wind, surface water, subsurface water) that cause an accumulation of salts (e.g. flow from a large water catchment area to a relatively small accumulation territory; or flow from a thick geological deposit to a relatively thin accumulation horizon)
iii) Transport potential (e.g. a landform within which surface water-runoff accumulates, suction gradient in the unsaturated zone, groundwater hydraulic gradient, concentration gradient)
iv) Negative water balance (at least for certain periods of the year) and vertical and horizontal drainage limitations.

Environmental (natural) factors resulting in soil salinisation are:

i) Transgression and regressions of marine waters that in some particular geological conditions increase salt concentration in groundwater and consequently in soils;
ii) Salt-rich groundwater rising to the surface or near to the surface due to natural factors or human interventions (see below);
iii) Groundwater seepage into areas below sea level, microdepressions with no or limited drainage;
iv) Floods of fluvial waters coming from areas with geological substrates that release high amounts of salts;
v) Wind activities that, in coastal areas, introduce moderate amounts of salts to soils.

Human-induced factors which may lead to soil salinisation are:

i) Irrigation of waters rich in salts;
ii) Rising water tables due to human activities (filtration from unlined canals and reservoirs; Uneven distribution of irrigation water;
iii) Poor irrigation practice, improper drainage;
iv) Use of fertilizers and amendments, especially in situations of intensive agriculture with low permeability and limited net-leaching;
v) Irrigation with wastewaters rich in salts;
vi) Salt-rich wastewater disposal on soils.

Table 9.2 shows that one key issue – the impact of salinisation/sodification – was excluded from the final selection.

Consequently, the key issues for the threat of ‘Soil Salinisation’ are as follows:

- *Salinisation:* accumulation of salts in the upper soil horizons resulting in physiological or physical deterioration and extreme moisture regime.
- *Sodification:* accumulation of exchangeable sodium in the upper soil horizons resulting in physiological or physical deterioration and extreme moisture regime.
- *Potential salinisation:* risk of salt accumulation from either a rising saline water table or one with an unfavourable ion composition, or salt movement from lower to upper horizons and the active root zone, or salt water intrusion from the sea, or the incorrect use of saline or brackish irrigation water.

Table 9.2 Overview of key issue selection for Soil Salinisation

Key issue		Description
In	**Out**	
Salinisation		Accumulation of salts in the upper soil horizons resulting in physiological or physical deterioration and extreme moisture regime
Sodification		Accumulation of exchangeable sodium in the upper soil horizons resulting in physiological or physical deterioration and extreme moisture regime
Potential salinisation/ sodification		Risk of salt accumulation from either a rising saline water table or one with an unfavourable ion composition, or salt movement from lower to upper horizons and the active root zone, or salt water intrusion from the sea, or the incorrect use of saline or brackish irrigation water.
	Impact of salinisation/ sodification	Physiological deterioration of the natural vegetation or cultivated crops due to high salt content, specific ion effect, high pH and high amount of exchangeable sodium. Unfavourable impact of sodium accumulation in the liquid or solid phase of soil, resulting in the increase in swelling/shrinkage/cracking characteristics, sometimes radical decrease in infiltration rate, hydraulic conductivity and water retention, which lead to extreme moisture regime, increasing frequency of waterlogging, floods, or droughts.

9.2 Indicators

Only the most important characteristic indicators of a high threat potential were selected. More detailed investigation is advised where these indicators indicate a higher threat level, to inform appropriate soil management. Generic practical land management solutions may present serious and unintended environmental hazards. The selected indicators are intended to reveal information on both existing salt-affected areas and areas that may be under threat in the future.

9.2.1 Indicator selection

Initial proposals by the subgroup identified 11 indicators for four key issues. It is necessary to emphasize that even this longer list of indicators was considered too general to express the specific character of saline and sodic soils and features of their formation and development, as soil salinisation/sodification are complex processes under the influence of various geographical factors and/or human activities. Key issues, key questions and indicators must be specific to environmental conditions and land use practices. Any over-simplification may lead to incorrect conclusions and thus to the misuse of salt-affected lands.

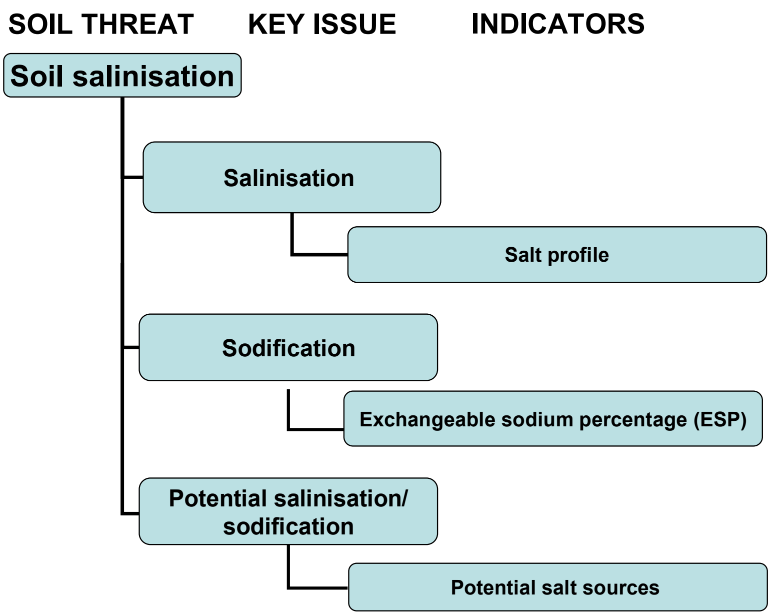
During the past few years, land use in salt affected soils, has undergone a change from reclamation for agricultural production to preservation for nature conservation and biodiversity. The emphasis now is to keep these salt affected lands as protected areas, maintaining the original biota, flora, fauna and rural life. The approach focuses on completely different parameters to be observed and evaluated in a specific e.g. saline lakes, saline fields with special – sometimes unique – flora and fauna). This is also valid for the salty wetland and salty marsh reconstruction programmes in national parks and protected areas.

The selection of key issues and indicators was made on the basis of a numerical ranking system based mostly on expert judgement, according to the following selection criteria:

1. The clear, exact and quantitative scientific definition of the indicator.
2. Practical applicabiltiy of the indicator for the rational use of salt affected lands (agricultural production, environment protection, gene reservoir).
3. The importance and measurability of the indicator.
4. The existing data sources.
5. Geographical coverage (This needs a special approach for saline and sodic soils due to their limited extent in Europe and their sporadic appearance).

The selected indicators (Figure 9.1) call attention to the actual or potential state of salinisation/sodification and serve as guidelines for the identification of hot spots where these environmental hazards are important and need further study to clarify the details.

Figure 9.1 Key issue and indicator selection for Soil Salinisation



9.2.1.1 Salinisation

9.2.1.1.1 SL01 Salt profile

The indicator 'salt profile' was selected because it gives a complete picture on the salinity state of the soil, or more exactly the salt-affected area.

Advantages:

i) Salt *profiles give a vertical picture of the distribution of water soluble salts (content, vertical distribution; salt composition, quantity and ion composition of salts).*
ii) *Salt profiles reflect the actual state of salt accumulation processes due to natural factors or human* activities. These profiles are sensitive indicators and important diagnostic criteria for soil classification, serving as the basis for hot spot regionalisation for further investigation.

Disadvantages:

i) Does not give information on salt profile changes in time or the main source of salts.
ii) The limited availability of measured data, which can only be partly substituted by models, even after careful and precise field validation. Pedotransfer functions can be applied only after careful validation.
iii) Does not give any information on the impact of salinisation/sodification on

iv) soil physical properties (soil structure, pore size distribution; swelling/shrinkage/cracking properties)
v) soil moisture regime
vi) salinity/sodicity induced extreme moisture regime (waterlogging and over-moistening hazard and drought sensitivity)

Conclusion:
In the critical areas the total salt content of the profile (3-dimensional spatial distribution) has to be complemented with detailed chemical analysis of the salts (cation and anion composition) and pH, and a comprehensive analysis of soil physical and hydrophysical properties related to salinity.

9.2.1.2 Sodification

9.2.1.2.1 SL02 Exchangeable sodium percentage (ESP)

ESP was chosen as main indicator, as ESP and SAR (Sodium Absorption Ratio) are the best characteristics for solonetz formation.

Advantages:
i) Expresses the vertical distribution of ESP in the soil profile.
ii) Serves as the basis for 'hot spot' regionalization for further investigation.

Disadvantages:
i) Does not give information on ESP changes in time or the main source of exchangeable sodium (solonetz process)
ii) The limited availability of measured data. ESP can be estimated by calculation from the SAR value of the saturation extract and saturation percentage (SP).
iii) Does not give any information on the impact of salinisation/sodification on
iv) soil physical properties (soil structure, pore size distribution; swelling/shrinkage/cracking properties)
v) soil moisture regime
vi) salinity/sodicity induced extreme moisture regime (waterlogging and over-moistening hazard and drought sensitivity)

Conclusion:
In critical areas, the soil absorption complex and exchangeable sodium percentage of the profile (3-dimensional spatial distribution) has to be complemented with detailed chemical analysis of the soil (pH and exchangeable cations, CEC) and a comprehensive analysis of soil physical and hydrophysical properties related to sodicity.

9.2.1.3 Potential salinisation/sodification

9.2.1.3.1 SL03 Potential salt sources and vulnerability of soils to salinisation/sodification

The indicator 'potential salt sources' gives a good picture of the characteristics of the potential salt source (irrigation water or groundwater) as well as the vulnerability of soils to salinisation/sodification.

Advantages:

i) Expresses the main potential salt sources (groundwater, saline seep, irrigation water).
ii) Expresses the vulnerability of soils to salinisation/sodification.
iii) Serves as a real basis for risk assessment.

Disadvantages:

i) Does not specify the impact of various human activities on salinisation/sodification (land use practices, agro-techniques).
ii) Does not clarify the conditions that may lead to salinisation/sodification from various salt sources.
iii) Does not give specifications on the salt and sodium tolerance of various plants, consequently, on their adaptability to the changed chemical and physical soil characteristics and extreme moisture regime.

Conclusion:

For efficient salinity/sodicity control, comprehensive prognosis is necessary rather than focussing on individual components of salinity. This indicator offers the possibility of preventing further salinisation/sodification (Kovda & Szabolcs, 1979; FAO, 1975).

The proposed indicators are listed in Table 9.3.

Table 9.3 Overview of proposed indicators for Soil Salinisation

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
SL01	Soil Salinisation	What is the vertical distribution of water soluble salts in the profiles of European salt-affected soils?	Salt profile	Total salt content: %; electrical conductivity: dS m^{-1}	S	S	G	1 - 3 yr	national, 1:25,000, in salt- affected areas
SL02	Sodification	What is the chemical reaction and exchangeable sodium percentage (ESP) in the soil profile: the depth of the sodium accumulation horizon?	Exchangeable sodium percentage (ESP)	ESP: %	S I	S	G	1 - 3 yr	national, 1:25,000, in salt- affected areas
SL03	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	P	S	R	1 yr	national, 1:100,000

SL =Soil Salinisation, DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response / Applicability: S = short-term, M = medium-term / Monitoring: G = generally, R = in risk areas only

9.2.2 Baseline and threshold values

Baselines

The characteristics of a soil without any specific influence of salts and sodium are 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 in the saturated soil paste is less than 0.05% or the electrical conductivity (EC) is less than 2 dS m^{-1}. The baseline for the exchangeable sodium percentage (ESP) is 5%; for the sodium adsorption ratio (SAR) a value less than 4, and for pH a range of 5 to 8. These values can be taken as background values.

Thresholds

Thresholds are highly specific for various salts, because their impacts are different and depend on various land use practices and cropping patterns. The thresholds 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.

Thresholds have to be set on a soil and land use specific basis, depending on soil characteristics and the particular unfavourable physical and hydrophysical consequences of salinisation/sodification. This specificity is reflected in the different classification systems of salt-affected soils.

9.2.2.1.1 SL01 Salt profile

- 0.10% total salt content or 4 dS m^{-1} EC in the 0–30/50 cm soil layer (depending greatly on ion composition and pH).

9.2.2.1.2 SL02 Exchangeable sodium percentage (ESP)

- ESP > 15
- SAR > 10
- pH more than 8.5 in the accumulation horizon

9.2.2.1.3 SL03 Potential salt sources

(irrigation water, groundwater, seepage water) and vulnerability of soils to salinisation/sodification.

The baseline for irrigation waters is < 500 mg l^{-1} salt content or 0.5 dS m^{-1} EC, < 4 SAR.

The salt quantity threshold for irrigation water greatly depends on:

- Chemical composition of salts (cation and anion composition, SAR, soda equivalent) and pH;
- Salt tolerance of vegetation and cultivated crops;
- Method and practice of irrigation (less quantity of applied water than the leaching requirement or leaching fraction, e.g. water-saving irrigation practices such as drip irrigation).

The baselines can be taken as thresholds because, in the case of a baseline exceedance, the water cannot be used for irrigation without special precautionary measures, e.g. dilution or chemical improvement technologies. For example, such criteria are formulated precisely in the Hungarian irrigation water quality norm (based on Darab and Ferencz, 1969), which is a national standard as set by Ministerial Decree. The water must fit these quality norms even in irrigated fields, because the salt content may increase during the water transport in unlined earth canals.

For the quantification of salt accumulation from groundwater, the following factors must be considered:

- depth and seasonal dynamics of the groundwater table;
- chemistry of the groundwater (ion composition and concentration)
- capillary transport from the groundwater to overlying horizons.

On this basis, the critical depth or critical regime of groundwater can be quantified (Kovda *et al*. 1967; FAO, 1975). The critical depth of groundwater depends on the chemistry of groundwater (salt concentration and ion composition), the salinity status of the soil profile and the character of the salt balance. As a general threshold 1000 mg l^{-1} salt concentration and 10 SAR can be used. A proper early warning system is necessary for successful prediction, and this is the key to successful prevention of soil salinisation/sodification in areas at higher risk.

Table 9.4, Table 9.5 and Table 9.6 summarise the baseline and threshold values for the indicators selected for Soil Salinisation.

Additional remarks
During the evaluation and interpretation of the baselines and thresholds above, special attention should be paid to the land use concept of salt affected areas.

The approach described above has evolved for application to agricultural land, although it is a useful starting point where other land uses such as amenity and conservation of biodiversity are more prevalent. In the protected salt affected areas (saline lakes, saline fields with special – sometimes unique – flora and fauna), different measures should be observed and evaluated. This is also valid for the salty wetland and salty marsh reconstruction programmes (national parks, protected areas etc.).

Table 9.4 Baseline and threshold values for Soil Salinisation

	Indicator	Input	Units	Baseline	Threshold
Soil Salinisation	SL01 Salt Profile	Salt content (total) [1]	%	<0.05	>0.10
		EC [2]	$dS\ m^{-1}$	<2	<4
		Depth	cm	0-150	0-30→50
Sodification	SL02 Exchangeable Sodium percentage	pH		5-8	>8.5
		ESP [3]	%	<5	>15
		SAR [4]		<4	>10
Potential soil salinisation/ sodification	SL03 Potential salt sources and vulnerability [7] of soils to salinisation/ sodification	Salt conc. (irrigation water)	$Mg\ l^{-1}$	<500	500-2000 [5]
		EC (irrigation water)	$dS\ m^{-1}$	<0.5	0.5-5
		SAR (irrigation water)		<4	
		Salt conc. (groundwater)	$Mg\ l^{-1}$	<500	1000 [6]
		EC (groundwater)	$dS\ m^{-1}$	<0.5	
		SAR (groundwater)		<4	>10

[1] Electrical conductivity

[2] Comment: pH, ion composition and plant-specific

[3] Exchangeable sodium percentage: $ESP = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \cdot 100$

[4] Sodium absorption ration : $SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$

[5] Comment: depending on soil vulnerability, salt tolerance of the crop and irrigation practice (e.g. Hungarian water quality norm)

[6] Comment: depending on groundwater chemistry (pH, ion composition)

[7] Comment: no overall baseline or threshold values are given for the vulnerability of soils to salinisation/ sodification because these depend on specific conditions

For sodium hazard prediction the following empirical relation between SAR and ESP is used:

Table 9.5 Thresholds for crop tolerance rating

Crop tolerance category	75% yield reduction (EC, $dS\ m^{-1}$)	50% yield reduction (EC, $dS\ m^{-1}$)
Sensitive	< 3	3–6
Moderately sensitive	3–6	6–9
Moderately tolerant	6–9	9–15
Tolerant	9–15	15–21

Table 9.6 Thresholds for the relative fertility of soil

Relative fertility of soil (%)	ESP (%)	Remark
100	< 5	non-sodic soil
60–75	10–15	moderately sodic soil
20–30	25–30	sodic soil
0	> 50	strongly sodic soil

9.2.3 Data and user requirements

Soil salinisation/sodification is a substantial environmental problem all over the world, and particularly in Asia, Africa, South America and other arid and semi-arid regions. In Europe, there is significant environmental deterioration only in limited areas and, in general, natural conditions are not favourable for salinisation/sodification processes. Consequently, the evaluation of the problem must focus on the actual salt affected lands and on the endangered areas (potential salt affected regions.

In the Soil Thematic Strategy of the European Commission, the environmental threat of salinisation/sodification is approached in two steps:

1. Delineation of actual salt affected areas as ‘hot spots’ and identification of potential salt affected areas due to the influence of changing environmental conditions or various human activities (agricultural and non-agricultural land use, irrigation, drainage, application of chemicals, waste and waste water management, etc.).
2. More detailed studies on the delineated hot spots for the precise characterization and quantification of salinisation/sodification. This has to be purpose-specific (production – environment conservation – rural development etc.).

These goals will determine the necessary resolution and scale of the study:

- spatial and time resolution;
- number and character of indicators;
- baselines and thresholds (preferably defined by numerical values).

The detailed observations in pilot territories can be extended for larger areas by similarity analysis and can be used for risk identification. The character of salinisation/sodification requires a specific approach by comparison with other soil threats in Europe. The required data are included in Table 9.7, including spatial and time resolution, and in the text that follows. To fully satisfy the user requirements, more comprehensive observations are needed on ‘hot spots’ (present salt affected land) and threatened areas.

Table 9.7 Data and user requirements for Soil Salinisation

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
SL01	Salt profile	Total salt content or electrical conductivity (EC) of the saturated soil paste or saturation extract	EU and national field measurements and laboratory analysis for salt-affected areas	1:25,000 for salt-affected areas	Salt-affected regions in Europe	1 to 3 yr	High for salt affected areas	total salt content: percentage; electrical conductivity: dS m^{-1}	total salt content: 0.1%; EC: 4 dS m^{-1}; Rate of change of salinisation processes (S $m^{-1}yr^{-1}$): none to slight: < 2; moderate: 2-3; high 3-5; very high: > 5
SL02	Exchangeable sodium percentage (ESP)	pH and exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) in the saturated soil extract	EU and national field measurements and laboratory analysis for salt-affected areas	1:25,000 for salt-affected areas	Salt-affected regions in Europe	1 to 3 yr	High for salt affected areas	pH unit; ESP: %	pH: 0.5 unit; ESP: 10% relative percentage; Rating of sodification (ESP: % yr^{-1}): none to slight: <1; moderate: 1-2; high: 2-3; very high: <3
SL03	Potential salt sources (groundwater or irrigation water)and the vulnerability of soils to salinisation/sodification	For waters: total salt content, electrical conductivity (EC), SAR, pH; for soils: as above	EU and national field measurements and laboratory analysis for threatened (potential salt-affected) areas	1:100,000 for threatened (potential) salt-affected areas	Potential salt-affected regions: areas where there is a potential risk of soil salinisation/sodification processes from irrigation water or from the rising saline water table (approx. 1.4 Million ha in Europe)	yearly, for early warning	High for threatened areas	For waters: Salt content: mg l^{-1}; SAR: calculated ratio; for soils: as above	Salt content: 15% relative percentage; SAR: 10-15% relative percentage

9.2.4 TOP3 indicators

Table 9.8 TOP3 indicators for Soil Salinisation

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 – This 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 – ESP and SAR (Sodium Absorption Ratio) are diagnostic of increasing sodicity (solonetz formation). The most important indicative parameters are pH and ESP or SAR in a saturated soil extract.

SL03 – Groundwater: Secondary salinisation may be caused where a rising water table has a high salt content and unfavourable ion composition. This may be due to natural fluctuation in groundwater levels or a consequence of 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. Irrigation water: Human-induced secondary salt accumulation from poor-quality irrigation water may take place where: the water source (rivers, lakes, reservoirs, groundwater) has a high salt content and an unfavourable ion composition; irrigation water collects salts while flowing in unlined earth canals. The most important indicative parameters for waters 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.

9.3 References

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10 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), which 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, i.e.

$$F = \frac{\text{Resistance of the soil mass to shear along a potential slip plane}}{\text{Shear force acting on that plane}}$$

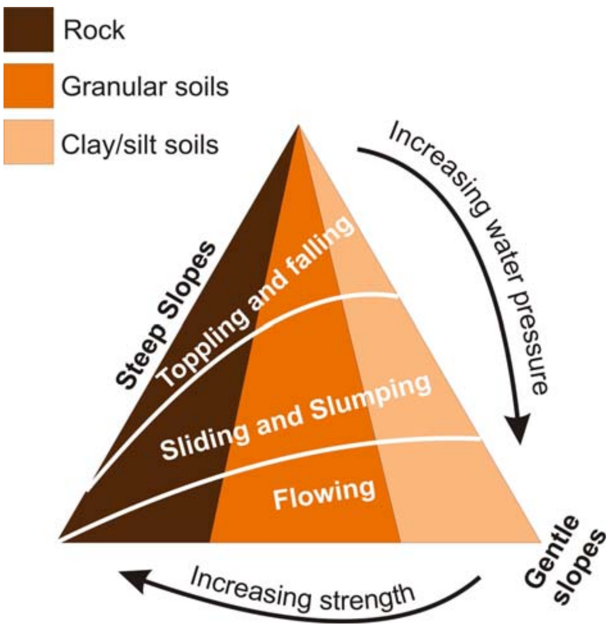
A landslide as a 'threat to soil' can be defined as: 'the movement of a mass of rock, debris, artificial fill or earth down a slope, under the force of gravity, causing a deterioration or loss of one or more soil functions' (see the ENVASSO Glossary of Key Terms). Clearly, landslides sometimes form more dramatic hazards in populated areas, threatening human lives and properties, but in the context of ENVASSO we focus 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 hundreds if not 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 (see ENVASSO Glossary of Key Terms) 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 ENVASSO Glossary of Key Terms) 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.

At the start of the ENVASSO Project, landslides were considered as a key issue under the threat 'Soil Erosion' because the units are essentially the same, i.e. 'soil loss' in t ha^{-1} yr^{-1}. However, landslides, and methods of detecting and monitoring them, were considered sufficiently different to the other key issues for soil erosion to warrant their separate treatment in this chapter.

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) as follows:

i) *slides* - rotational or translational mass displacements with limited internal deformation, and relatively uniform velocity profiles;
ii) *flows* – associated with relatively high moisture contents, and with non-uniform velocity profiles, reflecting frictional effects between the base of the flow and the in-situ ground;
iii) *falls* – slope displacement that are principally vertical in nature;
iv) *topples* – slope displacements with both lateral and vertical components;
v) *lateral spreads* – slope displacements that are primarily horizontal;
vi) *ground or frost-heave* – associated with expansion/contraction of individual constituents of the slope material, which destabilises the slope e.g. freeze/thaw; exfoliation (Carson & Kirkby, 1972).



(after Carson and Kirkby, 1972)

Figure 10.1 Failure of slopes

The diagram in above illustrates how the failure of slopes is directly related to the type of soil/rock, its strength, the water conditions in the slope and its geometry. These modes of failure can be subdivided further, depending on whether the material is propagated mainly as individual particles, e.g. rockfall, rock avalanche, or as a reworked mass, e.g. mudslides, earthflows, and debris flows. Other classifications are based on the velocity of failure, e.g. very rapid, rapid, moderate, slow, very slow (Varnes, 1978). The latter approach is useful as it expresses indirectly the level of risk, as the velocity at which the displaced material moves at the onset of the event determines the amount of damage caused. This includes early warning systems and organisation of evacuation away from the failing slope.

A simpler classification could be based on whether or not the landslides are a consequence of natural or anthropomorphic factors. In terms of environmental protection, it could be argued that natural factors can rarely (or should not) be controlled, whereas anthropomorphic factors can be prevented altogether. In reality, individual landslide events usually result from a complex, unique combination of natural and human factors acting simultaneously.

In terms of protecting soil, consideration must be given to three critical areas in the landscape where the soil resource is under threat:

vii) site of the slope failure where topsoil and or substrate have been removed;
viii) failed mass itself (assuming it remains relatively intact), and
ix) temporary or permanent destination of the failed mass.

As this is true for all types of mass movement (slides, flows, falls, topples, lateral spreads and ground/frost heave), further discussion will combine all types of slope failure under the generic term ‘landslides’.

Often the economic losses from landslides are difficult to determine as they usually occur as a consequence of other natural hazards such as seismic activity or flooding. It has been estimated that in terms of costs to society, landslides can cost up to €1.2 billion per event (http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/06/341&format=HTML&aged=0&language=EN&guiLanguage=en).

It is increasingly clear that landslide hazard assessment forms an important part of land use planning, especially in hilly, mountainous and coastal environments, which are most prone to landslide activity. In densely populated/industrialised areas, landslide hazards may be exacerbated by soil sealing (and compaction), thereby further increasing the socio-economic impacts of landslides.

10.1 Key issues

Six key issues were identified:

1. Mechanisms causing landslides
2. Landslide activity
3. Assessing impacts of landslides
4. Vulnerability to landsliding
5. Mitigating the impacts of landslides
6. Landslide control

All these key issues apply to some extent to all types of landslide (slides, flows, falls, topples, lateral spreads and ground/frost heave).

Mechanisms causing landslides
The general theory of slope stability has been well researched by a number of scientific disciplines, such as geotechnical and civil engineering, physical geography and geology. For example, geomorphology has valuable application in both predicting areas of potential landsliding and controlling the cause of landslides. However, in practice the mechanisms operating in any given slope failure are site- and time- specific. Often a unique combination of interactions between the intrinsic and extrinsic factors causes failure at a certain time and place.

Landslide activity
The recent EU Research programme titled ‘Concerted action on forecasting, prevention and reduction of landslides and avalanche risk’ (CALAR, 1999) concluded that the first step in any landslide risk management programme should be to develop an inventory map of previous landslide activity.

All types of landslides leave a topographical signature when they occur, and are driven largely by topographical effects. Thus mapping the spatial distribution of landslides is relatively straightforward, although uncommon in the EU. Improved sources of high-resolution topographic information have the potential to increase greatly the accuracy of landslide hazard maps. Geomorphological mapping can be used to identify active, relict, dormant and stabilised areas. Areas prone to landsliding in the past have a high risk of further failure taking place, unless substrate material has been removed completely. Topographical maps and remote sensing can be used to recognize different kinds of active or recently active landslides by detailed examination of the land form, micro-relief and surface composition of predefined sets of geomorphological units for both ‘stable parts surrounding the slide’ and ‘parts that have moved’. In addition, automatic recording systems connected to different sensors can be installed to closely monitor a specific area under threat of landsliding (Angeli *et al.,* 2000).

Assessing the impacts of landslides
Potentially, the environmental and economic impacts of landslides cover a significant geographical area (off-site), well beyond the origin of the slope failure (on-site). There may also be impacts associated with the failed mass itself (assuming it remains relatively intact) and the resting place of the failed mass, which may only be temporary until the mass fails again. Little is known and even less is quantified regarding the actual impacts of landslides in terms of either the environment or society, or whether these impacts are always detrimental.

Vulnerability to landsliding
The simplest approach to predicting the occurrence of landslides is to identify where, and how frequently, failure has taken place in the past. More complex approaches consider slope stability models that can be used to predict the short and long term occurrence of mass slope failure. The

simplest examples are based on the 'Method of Slices', which analyses the stability of a slope in two dimensions (Fellenius, 1936). The slope is plotted and an assumed failure surface is drawn. The failure surface is divided into vertical slices, and the forces acting on each slice are analysed. One classic example for calculating the stability of slopes is the Modified (or Simplified) Bishop's Method (Bishop, 1955)- an extension of the Method of Slices.

By making some simple assumptions, the problem becomes statistically determinate and suitable for simple calculations:

- shear forces on the sides of each slice are equal
- normal forces on the sides of each slice are collinear

The method has been shown to produce 'factor of safety' values that differ only slightly from the 'correct' values.

$$F = \frac{\sum \left[\frac{mc' + ((W/b) - \upsilon m)\tan\phi'}{\psi} \right]}{\sum \left[(W/b)\sin\alpha \right]}$$

Where:

$$\psi = \cos\alpha + \frac{\sin|\alpha|\tan\phi}{F}$$

and:
c' is the effective cohesion.
θ' is the effective internal angle of friction.

Many of these models allow for changes to circumstances at a site, such as the role of vegetation on slope stability (Wu, 1995; Greenway, 1987). The impact of climate change on slope stability in terms of rainfall patterns, snow and ice loading and melting, freeze-thaw cycles and evaporation can also be taken into account by many of these models. A number of other landslide hazard assessment tools have been developed in more recent years (Huabin *et al.,* 2005, Dikau *et al.,* 1996, Guzzetti *et al.,* 1999).

Mitigating the impacts of landslides
As natural phenomena, landslides are unavoidable, but their detrimental impacts can be minimised by civil authorities or even by individuals using various strategies. It should be remembered that mitigating impacts may be necessary at the origin of the landslide, on the failed mass itself, and where the failed mass has come to rest. If areas affected by landsliding can be identified, then land use planning should restrict or even prohibit development or economic activity taking place there.

Techniques such as land suitability classification can assess actual or potential landsliding, and identify areas best suited to land uses such as wildlife conservation or watershed protection, e.g. afforestation. This approach has limitations in areas subjected to landsliding due to extensive seismic activity, or where the landslide risks are outweighed by economic benefits of using the land, e.g. agricultural production on slopes prone to mass movements, or road construction through unstable areas in order to open up economic hinterlands.

Landslide control
Knowing the intrinsic and extrinsic factors affecting the incidence of landslides is the first step in developing control measures. The combination of factors causing landslides is unique to each slope in space and time. It follows that any control measures will also be site and time specific, which makes the design of control strategies challenging. The preferred approach should be one of preventing landsliding rather than dealing with their aftermath.

Landslide control strategies can be aimed at prevention, or stabilisation of slopes that have already failed. Methods can be categorised into engineering or biological approaches. Most deal with removing water from the slope, so increasing cohesion and reducing loading and lubrication. Surface and sub-drainage methods, borrowed from agricultural and civil engineering, can be used. Re-vegetation is also commonly used, although this is a longer term strategy. Established vegetation can remove water from a slope through evapo-transpiration, as well as adding tensile strength and cohesion to the slope through root networks. Experience has shown that preventing landsliding is always more cost-effective than trying to restore already failed slope masses.

Table 10.1 Overview of key issue selection for Landslides

Landslide type	Key issue selection		Description
	In	Out	
Slides / flows / falls / topples / lateral spreads / ground/frost heave		Mechanisms causing Landslides	Mechanisms operating when landslides occur are complex but detailed knowledge and understanding are needed to aid policy design and appropriate responses
	Landslide activity		Spatial distribution of landslides shows: (i) the severity and extent of the threat to soil; (ii) likely vulnerability of areas to slope failure in future; and (iii) potential impacts of landslides
		Assessing the impacts of Landslides	Impacts of landslides (physical, economic, social) are most accurately assessed at the local, rather than European scale
	Vulnerability to landsliding		Identifying areas at risk of landsliding is important to assess the threat to soil resources. Indicators should reflect the vulnerability of an area to slope failure.
		Mitigating the impacts of Landslides	Reducing the impacts of damage by landslides is best determined by local planning procedures and regulations.
	Landslide control		Control strategies are best devised at the local scale but implementation will often have a European dimension.

10.2 Indicators

There are many indicators of the threat to soil resources posed by landslides. The relative importance of each causative factor will also vary with each event at each site. Rather than having all the factors affecting landslide as indicators, only those that relate directly to the key issues identified in Section 10.1 and Table 10.1 (i.e. the spatial distribution of landslides and the vulnerability of slopes to landslides) were selected. Figure 10.2 lists the indicators proposed for the selected key issues. The advantages and disadvantages of these selected indicators are described also listed below.

10.2.1 Indicator selection

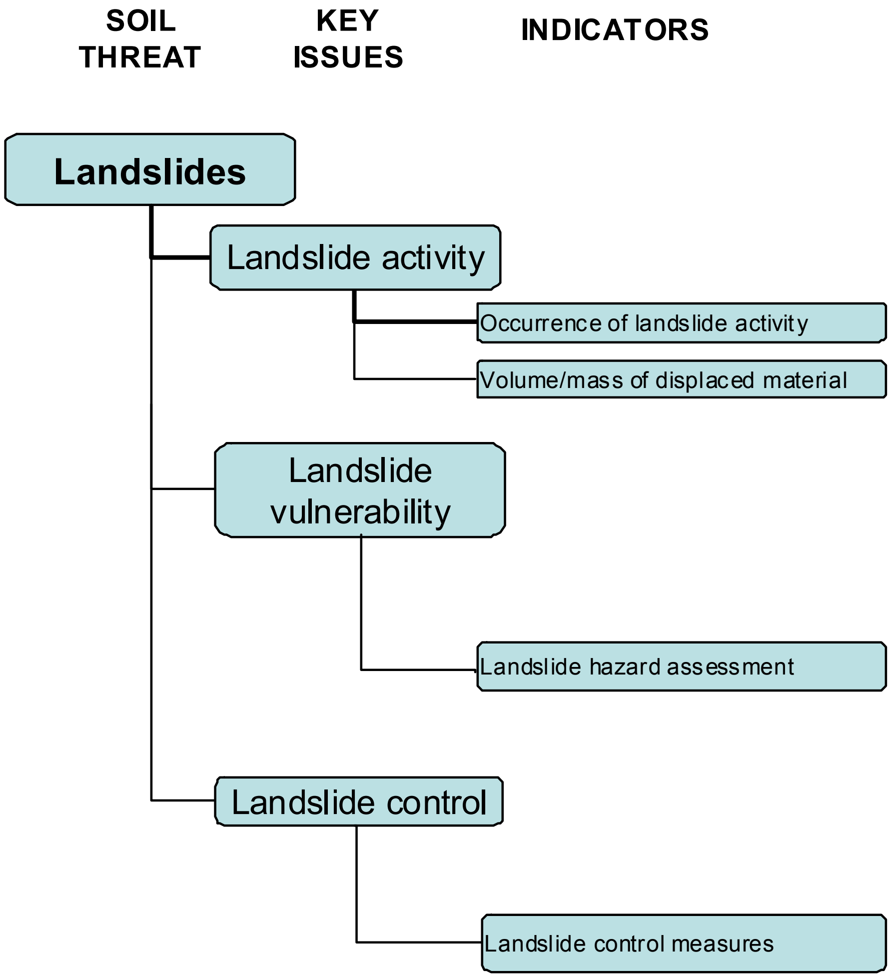


Figure 10.2 Key issue and indicator selection for Landslides

10.2.1.1 Landslide activity

The spatial distribution of landslides (slides, flows, falls, topples, lateral spreads and ground/frost heave) is a key issue because it indicates the:

- severity and extent of the threat to soil in Europe;
- future vulnerability of areas to slope failure;
- potential impacts of landslides

Indicators showing the spatial distribution of landslides are:

i) Location/site of landslide activity
ii) Spatial extent of landslide activity
iii) Density of landslide activity
iv) Volume/mass of material displaced

10.2.1.1.1 LS01 Occurrence of landslide activity

This indicator quantifies the location and area affected by landslides and can be expressed as a ratio of the total area considered.

Advantages

i) Incidence of landslides can be easily identified on aerial photographs or satellite imagery, especially in inaccessible areas (e.g. mountain and coastal environments)
ii) Sequential imagery can show changes in landslide form and frequency over time and these changes can be further quantified by spatial analysis (GIS).
iii) Different types of landslide (slides, flows, falls, topples, lateral spreads and ground/frost heave) and present status (active, stabilised, dormant, relic etc.) can be identified.
iv) The methodology of geomorphological mapping of landslides is well established

Disadvantages

i) Detailed survey of landsliding in Europe is incomplete at present;
ii) Survey techniques can be costly and technically complex (Van Westen *et al.,* 1999, van Westen *et al.,* 2006);
iii) Spatial resolution of remotely sensed data and/or imagery may be too coarse to identify many smaller slope failures
iv) Present location of landslide activity may be a poor indicator of future risk where land use and climate change are prevalent

Conclusion

Mapping the density of landslides, for example the area affected by landslides expressed as a ratio of total area, will highlight areas where the threat to soil resources by slope instability is greatest. This indicator will also identify areas potentially at greatest risk of further slope failure in the future, and where impacts may be significant. This is the first step in quantifying landslide activity.

10.2.1.1.2 LS02 Volume or mass of displaced material

The location and areal extent of landslide activity (determined by LS01) can be used to estimate the volume (or mass) of material displaced by a landslide event. This indicator will quantify the amount of slope forming material which is degraded by landslide activity.

Advantages

i) LS01 can be used to estimate volume or mass of material displaced by a landslide event;
ii) This indicator (LS02) effectively reflects the amount of material moved and thus the potential damage done by different types of landslide, e.g. small vs. large events; shallow vs. deeper seated failures;
iii) Identifies areas most prone to landsliding and the areas with highest volume or mass of displaced material have highest risk in the future

Disadvantages

i) Requires detailed survey techniques and high resolution of remotely sensed imagery;
ii) Relies on accurate measures or estimates of the bulk density of the displaced material;
iii) Does not necessarily reflect damage done to environmental, social or economic resources;
iv) Estimating volume or mass of displaced material will be very time consuming, and prone to measurement error.

Conclusion

Whilst this indicator will help quantify the amount of damage done to soil resources by landslide events, it will be difficult to apply at the European scale because: a) it requires a detailed resolution of landslide survey and imagery; b) past events may be obscured by subsequent re-working of displaced material; c) estimating the volume/mass of displaced material may not indicate high risk areas in the future and d) estimating the volume/mass of displaced material may not be directly related the damage done to soil resources landslide events.

10.2.1.2 Vulnerability to landsliding

Identifying areas which are vulnerable to landslide activity is important because:

- the threat to soil resources is greatest in these areas;
- risk assessment identifies the causes of landslide activity;

- preventative measures, which are more cost-effective than remediation techniques, can be applied in the most vulnerable areas.

Indicators should represent the vulnerability of an area to slope failure. The indicators of the vulnerability of an area to landsliding are summarised as:

i) Slope materials (texture, lithology, stratigraphy, angle of internal friction, cohesion);
ii) Slope steepness;
iii) Moisture content of slope materials (including pore water pressure);
iv) Rainfall and snowmelt contribute to most slope instabilities, except some 'dry' slope failures e.g. rock falls and topples);
v) Temperature fluctuations (applies to snow melt, freeze/thaw processes, exfoliation);
vi) Seismic activity;
vii) Land use change (e.g. deforestation);
viii) Land management practices (e.g. over-grazing)
ix) Evidence of previous landsliding

However in reality, whether or not a slope actually fails will be determined by a number of these indicators occurring simultaneously. There may be inter-dependency of some of these indicators too e.g. annual rainfall and moisture content of the slope.

10.2.1.2.1 LS03 Landslide hazard assessment

Assessing the likelihood of landsliding depends on the factors mentioned above. Any evidence of previous landslide activity is valuable for refining hazard assessments. Methods used to assess landslide hazard based on GIS technology may be heuristic (qualitative map combination), statistical (bivariate and multivariate) and deterministic (probability of failure).

Advantages

i) Identifies the threat prior to landsliding;
ii) Properties can be deduced from existing soil, geomorphological and geological maps;
iii) Rainfall, snowfall and temperature data are available from existing climatic databases Land use change can be deduced from current and historical land use maps and databases.

Disadvantages

i) Relative contribution of each property (texture, lithology, stratigraphy, angle of internal friction and cohesion) to 'vulnerability to landsliding' is site-specific;
ii) Measurement of all the relevant properties is time consuming and costly;
iii) Properties are dynamic in space and time, making quantification difficult.

Conclusion

Although the type of slope material is directly related to 'vulnerability to landsliding', there are many properties to consider and the relative importance of each is site and time specific. Hence a simple, generic indicator of how slope materials affect vulnerability to landsliding is impossible to identify.

10.2.1.3 Landslide control

Monitoring where structures to control landslides occurrence are placed is important because:

- It reflects actions on the ground in response to previous landsliding and the perceived risk of future events
- Maintenance of control measures provides insight into their efficacy and rates of landsliding

10.2.1.3.1 LS04 Landslide control measures

Measures to control or prevent landslides are important considerations in vulnerable areas. Geo-textiles, concrete and stone barriers, afforestation and planning other stabilising vegetation are good examples.

Advantages

i) Construction of slope stabilisation structures, afforestation and laying of geo-textiles can be monitored by remote sensing.
ii) Installation of landslide control measures are installed only where there is a high risk of mass movement or there has been significant such activity previously.

Disadvantages

i) Detailed monitoring by remote sensing is costly and analysis of the data is time-consuming;
ii) Control measures can be completely obscured by dense vegetation and/or clouds;
iii) As a response indicator it is sensitive to skewed distribution of data values.

Conclusion

Although control measures are a good indicator of landslide activity, this indicator (LS04) would be difficult to implement at European scale because of the resources needed to procure and analyse remotely sensed data. It is better suited to guiding local responses.

Table 10.2 Overview of proposed indicators for Landslides

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applic-ability)	Monitoring type)	Frequency (years)	Spatial resolution
LS01	**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)**	**S**	**S**	**G**	**1**	**1 km × 1 km**
LS02	**Landslide activity**	**What is the status of displaced material by landslide activity?**	**Volume or mass of displaced material (estimated)**	**m^3 (or km^3) (or tonnes) of displaced material**	**S**	**S**	**G**	**1**	**1 km × 1 km**
LS03	**Vulnerability to landsliding**	**What is the susceptibility of slope materials to landslide processes?**	**Landslide hazard assessment**	**Variable**	**S**	**M**	**R**	**5**	**1 km × 1 km**
LS04	Landslide control	What is the susceptibility of slope materials to landslide processes?	Landslide control measures	ha affected per km^2	S	S	G	1	1 km × 1 km

Abbreviations: Indicator ID: LS = Landslides; DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response; Applicability: S = short-term, M = medium-term; Monitoring: G = generally, R = in risk areas only; TOP3 indicators in bold letters.

10.2.2 Baseline and threshold values

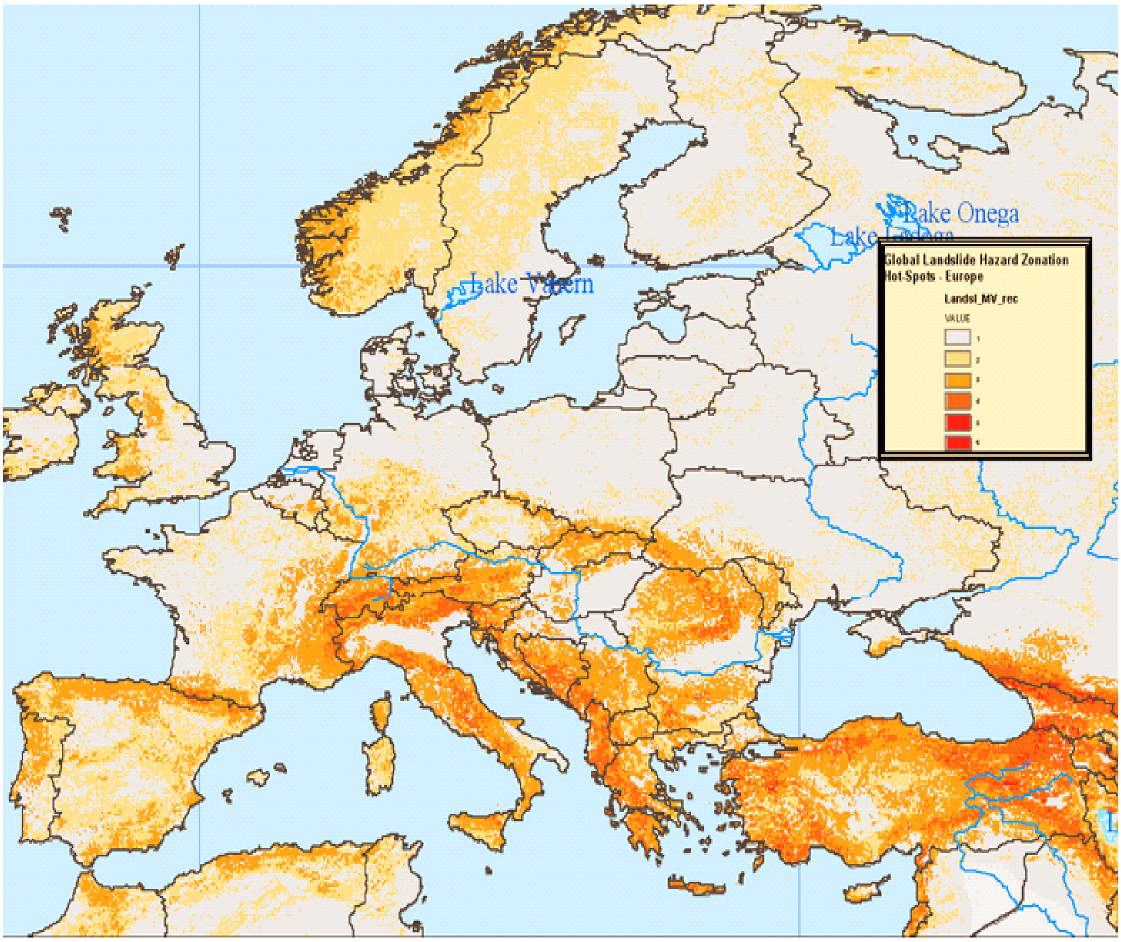
To define a baseline in a particular area, a detailed inventory is required. In areas of Europe where no landslide activity is present, the baseline in these areas is 0 unit area affected per unit area. The remaining land is subject to varying degrees of landslide activity where baselines are greater than zero.

An indicator threshold is defined as the value at which a critical soil status is reached, which limits or threatens sustainable functioning of the soil. It is argued that any landslide activity will exceed this threshold value, 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 mudflows.

Table 10.3 Baselines and thresholds for Landslides
(TOP3 indicators are in bold)

Key issue	Key question	Candidate Indicator	Units	Baseline status	Threshold status
Landslide activity	**What is the status of landslide activity in Europe?**	**LS01 Occurrence of landslide activity**	**ha (or km^2) affected per ha (or km^2)**	**0 ha ha^{-1} or (km^2 km^{-2})**	**≥ 0.1 ha.ha^{-1} or (km^2.km^{-2})**
Landslide activity	**What is the status of displaced material by landslide activity?**	**LS02 Volume or mass of displaced material**	**m^3 (or km^3) (or tonnes) of displaced material**	**0 m^3 (or 0 km^3); tonnes**	**≥ 0 m^3 (or 0 km^3)**
Vulnerability to landsliding	**What is the susceptibility of slope materials to landslide processes?**	**LS03 Landslide hazard assessment**	**variable**	**No hazard**	**Dependent on model used**
Vulnerability to landsliding	What measures have been installed to control or prevent landsliding?	LS04 Landslide control measures	ha (or km^2) affected per ha (or km^2)	0 ha ha^{-1} (or km^2 km^{-2})	≥ 0.1 ha ha^{-1} or (km^2 km^{-2})

Landslides occur naturally and landsliding is, in combination with erosion, responsible for the geomorphology of the landscape we see around us today. For some regions, e.g. volcanic areas such as the Canary Islands, landsliding may be the main contributing factor to landscape evolution (Cendrero and Dramis, 1996).



Prediction is based on a GIS approach where major attributes, which govern stability of slopes, are accounted for. Relative landslide hazard triggered by rainfall/and or earthquakes is marked in a scale with six classes, 6 being high, 1 negligible.(source: NGI)

Figure 10.3 Predicted landslide hazard zonation map for Europe.

10.2.3 Data and user requirements

Table 10.4 Data and user requirements for Landslides

Indicator ID	Indicator	Input parameter	Data sources	Spatial resolution	Geographical coverage	Frequency (years)	Data quality	Unit	Minimum detection of meaningful change
LS01	Occurrence of landslide activity	Visual identification of slides, flows, falls, topples, lateral spreads and ground/frost heave.	Aerial photos; satellite imagery; ground truth sample surveys. Geomorphological maps.	1 km × 1km	EU at higher resolution than presently available	Annual	High	ha (or km^2) affected per ha (or km^2)	5%
LS02	Volume or mass of displaced material	Volume or mass of material displaced by landslide activity (i.e. area extent × depth of failure)	Aerial photos; satellite imagery (stereo pairs required for depth estimation); ground truth sample surveys. Geomorphological maps.	1 km × 1km	EU at higher resolution than presently available	Annual	High	m^3 (or km^3) (or tonnes)	5%
LS03	Landslide hazard assessment	texture, lithology, stratigraphy, angle of internal friction and cohesion, slope gradient; moisture content, rainfall - mean monthly and annual rainfall. storm data (daily); temperature data; seismic activity; visual identification of slides, flows, falls, topples, lateral spreads and ground/frost heave	Global and National Soil and Terrain Digital Database (SOTER) has data on lithology. Samples of slope material – in-situ and lab tests of properties DEM; Samples of slope material – in-situ and lab tests of properties; Climate data; Seismograph outputs; land use (e.g. CORINE); aerial photos	1 km × 1km	Soil data at scale 1:250k for European soils, some countries have better detail (1:50k, 1:25k); DEM available for whole of Europe; Climatic data from MARS and other small-scale climatic databases	3-5	High	Texture: particle-size; deg; %v/v ; moisture content	10%
LS04	Landslide control measures	Observed structures and treatments	Remotely sensed data	1 km × 1km	National and European	Annual	High	ha	10%

10.2.4 TOP3 indicators

The selection criteria used to identify the top 3 indicators (TOP3 - see below) were:

1. Relevance for assessing the soil threat posed by landslides
2. Acceptability or the extent to which the indicator is based on 'sound science';
3. Practicability or the measurability of the indicator (ease of application);
4. Policy relevance and utility for users;
5. Geographical coverage - applicability in a pan-European context.

The first three criteria are similar to those proposed by the OECD (2003). Geographical coverage, though not an intrinsic property, is an important consideration for ENVASSO because of the need to identify gaps in geographical coverage to fulfil the project's aim of developing recommendations to harmonise soil monitoring in Europe.

Table 10.5 TOP3 Indicators for Landslides

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 or mass 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

Justification of selected indicators

LS01 - the occurrence of landslides in the past 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 to be included in the TOP3 because the data on past landsliding is available in some parts of Europe and the techniques exist to extend this kind of information across Europe.

LS02 – This indicator will quantify 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 exist for some parts of Europe, or at the advanced stage of development, making this indicator a good choice for inclusion in the TOP3.

LS03 - 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. The inclusion of this indicator in the TOP3 stems from the need for a predictive indicator.

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11 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. Desertification was considered initially as key issue within the threat Soil Erosion (See chapter 3).

Desertification is a consequence of a set of important processes which are active in arid and semi-arid environments, i.e. where water availability is the main limiting factor in ecosystems (Kirkby and Kosmas, 1999). A number of factors control the process of desertification and Kirkby *et al.* (1996) have defined the different feedback mechanisms that control it. 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.

In the context of the EC Project MEDALUS (Mediterranean Desertification and Land Use), the focus was primarily on European Mediterranean environments where physical loss of soil by water erosion, and the associated loss of soil nutrients, was identified as the dominant problem. In more arid areas, there is greater concern with wind erosion and salinisation problems, but these are considered to be less significant than water erosion for the northern Mediterranean area (Kirkby and Kosmas, 1999).

Kirkby and Kosmas (1999) summarise the process thus: “desertification of an area will proceed if certain land components degrade beyond specific thresholds, beyond which further change is irreversible. For example, soils may eventually become so stony that they can only degrade towards scree or bare bedrock. Climate change cannot bring a piece of land to a desertified state by itself, but it may modify the critical thresholds, so that the system can no longer maintain its dynamic equilibrium. 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.”

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). Gully erosion is probably the most significant erosion process in the arid areas of southern Europe, by contrast to the north where rill and sheet erosion predominate. There is a need to differentiate a gully from a rill or a stream channel, although all three forms are part of the fluvial network. It is matter of the depth and permanency of water that dictate which feature falls into each particular class. Various definitions of gullies have been proposed, for example by Schumm *et al*. (1984, p.8) and Knighton (1998, p.30), but in general a gully is expected to have steep sides and a depth of at least 0.5m (Prosser and Winchester, 1996, p.92).

The most effective method of estimating soil loss by gully erosion is by directly measuring the amount of suspended sediment transported to a receiving stream (Imeson and Kwaad, 1980) but realistic results can only be achieved over a relatively long time span, typically longer than 10 years. Alternatively, periodic measurement of the dimensions of a gully have been employed (Seginer, 1966; Crouch, 1987; Sneddon *et al.,* 1988; Daba *et al.,* 2003), these ranging from photogrammetry to the use of erosion pins. Sequential aerial photos or Digital Elevation Models (DEMs) have been used to remotely determine the change in gully dimensions in both time and space (Martinez-Casasnovas *et al*. 2003, 2004), but considerable differences were found between the results obtained by remotely sensed methods and those from conventional (direct) methods. Models have been developed estimate the amount of gully erosion taking place (e.g. Sidorchuk, 1999); Flugel *et al.,* 2003; Instanbulluoglu *et al.,* 2005) and other models have looked at the processes of how gullies are distributed in the landscape (e.g. Willgoose *et al.,* 1991; De Vente *et al.,* 2005). However, there appears to be no model for predicting or estimating soil loss by gully erosion that could be applied at the European scale that compares with the PESERA model (Kirkby *et al.,* 2004) for rill and inter-rill erosion (ER01).

However, at the European scale, desertification is also closely associated with other degradation processes (Brandt and Thornes, 1996) including soil organic matter decline, 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.

11.1 Key issues

As desertification is a cosequence of a set of different processes which cannot be separated only one key issue was identified:

- Desertification

11.2 Indicators

11.2.1 Indicator selection

Although initially identified as a key issue under erosion in the ENVASSO project, desertification is now considered separately from the other threats to soil because of its cross-cutting nature and the increasing link with global warming. Some indicators proposed in previous projects demonstrated that desertification may have proceeded to a state where soils are infertile, or highly sodic, or the land has become a rock desert. Kirkby and Kosmas (1999) concluded that the most useful indicators are those that predict the potential risk of desertification while there is still time and scope for remedial action. With this in mind, six indicators are proposed.

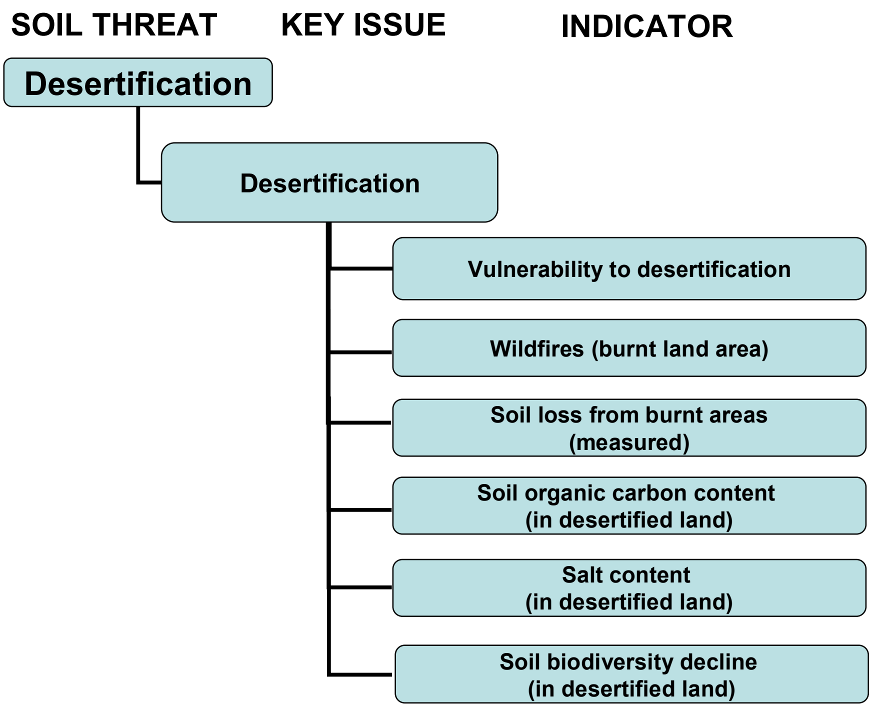

Figure 11.1 Key issue and indicator selection for Desertification

11.2.1.1 Desertification

11.2.1.1.1 DE01 Vulnerability to desertification

The vulnerability of land to desertification can be defined by climatic criteria (e.g. the ratio of average annual precipitation to evapotranspiration or average annual temperature), and soil conditions and vegetation cover in relation to topography (e.g. slope gradient and aspect). At the likely scale of application in a European Soil Framework Directive, it will be impossible to identify specific fields or communes where the risk of desertification is highest, but it will be possible to identify regions where more detailed work should be directed. Therefore, at the European scale, it is only practicable to express the impact of socio-economic drivers through patterns of land use (Kirkby and Kosmas (1999). The MEDALUS (Kosmas *et al.,* 1999a) system is a suitable approach.

Advantages:

i) Methodologies such as MEDALUS are available, tried and tested.
ii) Subsequently redefinition is possible using the same criteria (in case of significant climate change).

Disadvantages:

i) Definitions of arid and semi-arid conditions are to some extent open to interpretation.
ii) In areas at risk of desertification, there is often a dearth of soil and climatic data at the desired resolution. For example, the density of rainfall recording stations is insufficient in relation to the periodicity of precipitation.

Conclusion

This indicator is the most applicable option in Europe at the present time because it is based on existing concepts and available data.

11.2.1.1.2 DE02 Wild fires (burnt land area)

Advantages:

i) The area where vegetation has been destroyed by wild forest and scrub fires, mainly in southern Europe, can be measured (and subsequently monitored) by remote sensing (Natural Hazards Unit, JRC, Ispra; Eva and Lambin, 2000; Fox *et al.,* 2006;).

Disadvantages:

i) There are errors in detecting precisely the degree of destruction of forest and scrubland which is important because the severity and duration of any fire affects the amount of subsequent soil erosion (De Luis *et al.,* 2003).
ii) The effort and costs involved in collecting and processing the data are significant.

Conclusion:

This indicator equates with OM06 ‘Wild fires’ for the threat to soil of ‘Decline In Soil Organic Matter’ (Page 41), which is kept as a candidate indicator for this threat because of differing data requirements. Wild fires are an increasing threat to the environment because as global warming increases, aridity intensifies (Westerling *et al.,* 2006).

11.2.1.1.3 DE03 Soil loss (measured) from burnt areas

Advantages:

i) Methods of measuring soil losses exist (Soto and Dias-Fierros, 1998; De Luis *et al.,* 2003).
ii) Areas affected are clearly visible from the air and/or from remotely sensed images.

Disadvantages:

i) The uncertainty attached to measured losses can be relatively substantial.
ii) Experimentation is difficult and time consuming.

Conclusion:

The primary indicator of soil loss as a result of wild fires is the burnt area DE02, combined with the normal models used for water and wind erosion for estimating soil loss. This indicator (DE03) can provide measured soil losses from burnt areas for validation. Losses are mostly by water erosion following heavy (sometimes torrential) rainfall (Fox *et al.,* 2006), although soil loss can also occur as a result of wind erosion. Runoff is more likely to create gullies than in arid areas than in the humid zone of Europe, but measuring soil loss by gully erosion is difficult because of its episodic nature. The methodology proposed for indicator ER01 rill, inter-rill and sheet erosion (see Section 3.2.1.1.1), is not suitable for gully erosion.

11.2.1.1.4 DE04 Soil organic carbon content in desertified land

Advantages:

i) Methods of measuring soil organic carbon (SOC) content in desertified areas are the same as those used elsewhere (see Chapter 4).
ii) Measurement is standardised and relatively straightforward.

Disadvantages:

i) Collecting and analysing sufficient samples to monitor change is relatively expensive and time-consuming.

Conclusions:

When climatic conditions become more arid, the vegetation cover is diminished resulting in less organic matter being added to the soil (Kirkby *et al.,* 1996). In addition, if increased aridity is accompanied by a rise in average annual temperature, SOM decomposition rates will increase, further decreasing organic matter contents.

11.2.1.1.5 DE05 Salt content in desertified land

Advantages:

i) Standard methods of measuring salt contents exist (see Chapter 9)
ii) The results are directly comparable with areas that are not desertified but that are suffering from salinisation.

Disadvantages:

i) Soil salinisation is not relevant in all areas of desertified land.

Conclusion:

This indicator equates with SL01 ‘Salt profile’ described in the chapter on Soil Salinisation (see page 144), where the methodology described can be applied without further modification.

11.2.1.1.6 DE06 Soil Biodiversity decline in desertified land

Advantages:

i) Changes in biodiversity result from the temperature and moisture changes that accompany the process of desertification.

Disadvantages:

i) Identification of typical species and the derivation of thresholds can be difficult and measurements require significant resources.

Conclusion:

This indicator can be viewed as a combination of BI01-BI03 but it requires more study before implementation. The decline in biodiversity in desertified land is a ‘conventional wisdom’ but has received scant resources and more research is needed. The emergence of this indicator in the policy arena should help address this deficiency.

Table 11.1 Overview of proposed indicators for Desertification

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency (years)	Spatial resolution
DE01	**Desertification**	**What is the extent of desertification in Europe?**	**Vulnerability to desertification**	**km^2**	**S**	**S**	**R**	**1**	**1 km x 1 km aggregated data, pending WP2 results**
DE02	**Desertification**	**What is the current status of soil loss as a result of wild fires in Europe?**	**Wild fires (burnt land area)**	**$km^2\ yr^{-1}$**	**S**	**S**	**R**	**1**	**1 km x 1 km aggregated data, pending WP2 results**
DE03	Desertification	What is the current status of soil loss as a result of wild fires in Europe?	Soil loss (measured) from burnt areas	$t\ ha^{-1}\ yr^{-1}$	S	M	R	1	Point data, few m^2 (5-100) to field-sized units, pending WP2 & WP5 results
DE04	**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**	**%, $g\ kg^{-1}$**	**S**	**S**	**R**	**10-15**	**16x16 km for forests, to be discussed for other land uses after WP2 results**
DE05	Desertification	What is the current status of soil salinisation as a result of desertification in Europe?	Salt content in desertified land	$dS\ m^{-1}$	S	S	R	10-15	national, 1:25,000, in salt- affected areas
DE06	Desertification	What is the current status of decline in biodiversity caused by desertification in Europe?	Soil biodiversity decline in desertified land	number (of species)	S	M	R	10-15	EU or National

DE = Desertification, DPSIR: D = Driver, P = Pressure, S = State, I = Impact, R = Response / Applicability: S = short-term, M = medium-term / Monitoring: G = generally, R = in risk areas only TOP3 indicators in bold letter

11.2.2 Baseline and threshold values

There are a number of approaches to assessing whether an area is desertified or not. 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, but some clarification is given in the paragraphs below.

Defining areas vulnerable to desertification essentially relies on average climatic data providing the index of aridity. Thus, a baseline could be an average amount of annual precipitation in relation to average annual evapotranspiration or mean annual temperature.

Table 11.2 Baselines and thresholds for Desertification

Key issue	Key question	Candidate Indicator	Units	Baseline	Threshold
Desertifi-cation	What is the extent of desertification in Europe?	DE01: Vulnerability to desertification	km^2	Desertified area (km^2 or %) Aridity index = 0.75	Desertified area as a proportion of the potential (km^2 or %) Aridity index <= 0.5
	What is the current status of soil loss as a result of wild fires in Europe?	DE02: Wild fires (burnt land area)	km^2 yr^{-1}	Average of 5 years out of the last 20 with the smallest area burnt annually (km^2)	> 30% increase above the baseline
	What is the current status of soil loss as a result of wild fires in Europe?	DE03: Soil loss (measured) from burnt areas	t ha^{-1} in 1st year after fire	1.5 – 13 t ha^{-1} in 1st year after fire	13 t ha^{-1} yr^{-1}
	What is the current status of soil organic carbon decline as a result of desertification in Europe?	DE04: Soil organic carbon content in desertified land	%, g kg^{-1}	NA	% change in last 15 or 20 years
	What is the current status of soil salinisation as a result of desertification in Europe?	DE05: Salt content in desertified land	mg l^{-1}	NA	% change in last 15 or 20 years
	What is the current status of decline in biodiversity caused by desertification in Europe?	DE06: Soil biodiversity decline in desertified land	number of species	NA	NA

(NA = not available)

The area of land burnt varies from year to year but Baeza *et al.* (2002) reported that in the Valencia region wild land fires have increased over the last 20 years and affected 680,000 ha out of a total of 1,200,000 ha covered by shrubs and forest. We propose a baseline as the area in the 5 years out of the last 20 with the lowest area burnt annually (km^2), although the ecological basis for this is not clear.

Wild fires destroy the vegetative cover, thereby increasing soil erosion by rainsplash and rainwash. De Luis *et al.* (2003) report research on the combined impact of wild fire followed by torrential rainfall in the Mediterranean region. Soil losses were found to be several orders of magnitude higher after fire, but the amount of sediment produced varied greatly and was related to the severity of the fire. A threshold of 13 t ha^{-1} yr^{-1} is proposed as a threshold for soil or sediment loss in the first year from burnt areas though this would be expected to decline sharply as vegetation recovers.

11.2.2.1 DE01: Vulnerability to desertification

For example, land in arid, semi-arid and sub-humid zones with dryness index 0.03-0.65 as defined by the MEDALUS Project (Kosmas *et al.,* 1999b).

Dryness index = (annual precipitation) / (annual potential evapotranspiration).

Baseline	Threshold
0.75	0.5

11.2.2.2 DE02: Wild fires (burnt land area)

Baseline	Threshold
Average of the 5 years out of the last 20 with the lowest area burnt annually (km^2)	Increase of 30% above the baseline

11.2.2.3 DE03: Soil loss from areas burnt by wildfires (measured)

Baseline	Threshold
150-1300 g m^{-2} or 1.5 t ha^{-1} in first year after fire	<1300 g m^{-2} or 13 t ha^{-1} in first year after fire

11.2.3 Data and user requirements

Table 11.3 Summary of data and user requirements for Desertification

Indicator ID	Indicator	Input parameter	Data source	Spatial resolution	Geographical coverage	Frequency	Data quality	Unit	Minimum detectable change
DE01	Vulnerability to Desertification	Average annual precipitation - AAR- (mm/yr); Evapotranspiration (mm/yr); Soil water holding capacity (v/v); landuse; land cover; etc.	Europe: complete coverage with soil data at 1:250,000 scale; detailed soil profile data; full climate data sets at 10km resolution; up-to-date land use	1km x 1km aggregated data	Europe and Mediterranean Basin as a whole	10 years	high	km^2	2000 km^2
DE02	Wildfires (burnt land area)	Area (ha) affected by wild fires	Continuous coverage of Europe by 10m resolution RS data	1km x 1km aggregated data	Europe and Mediterranean Basin as a whole	annual	high	$km^2\ yr^{-1}$	500 km^2
DE03	Soil loss (measured) from burnt areas	soil loss from burnt areas	Continuous coverage of Europe by 10m resolution RS data	1km x 1km	Southern Europe (incl. Mediterranean)	annual	high	$t\ ha^{-1}\ yr^{-1}$	0.5 $t\ ha^{-1}\ yr^{-1}$
DE04	Soil organic carbon content in desertified land	OC content in $g.kg^{-1}$ in 0-10 cm to 0-30 cm layers (depth to be agreed) and/or in A or ploughed layers	harmonised detailed soil sampling programmes at national level inputting data to European database	16x16 km for forests, to be discussed for other land uses after WP2 results	Southern Europe (incl. Mediterranean)	10 years	high	%, $g\ kg^{-1}$	0,20%
DE05	Salt content in desertified land	Total salt content or electrical conductivity (EC) of the saturated soil paste or saturation extract	harmonised detailed soil sampling programmes at national level inputting data to European database	national, 1:25,000, in salt- affected areas	Southern Europe (incl. Mediterranean)	10 years	high	$mg\ L^{-1}$	total salt content: 0.1%; EC: 4 mmhos cm^{-1}; Rate of change in salt content (mmhos $cm^{-1}\ yr^{-1}$): none to slight: < 2; moderate: 2-3; high 3-5; very high: > 5
DE06	Soil biodiversity in desertified land	Number and biomass of species	harmonised detailed soil sampling programmes at national level inputting data to European database	EU or National	Southern Europe (incl. Mediterranean)	10 years	high	No. of species	???

11.2.4 TOP3 Indicators

Table 11.4 TOP3 indicators for Desertification

Key issue	Key question	Candidate indicator	Unit	ID
Desertification	What is the extent of Desertification in Europe?	Vulnerability to desertification	km^2	DE01
Desertification	What is the current status of soil loss as a result of wild fires in Europe?	Wild fires (burnt land area)	$km^2\ yr^{-1}$	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 – is the most important indicator from the policy point of view. The land area vulnerable to or at risk of desertification is the headline indicator because the desertified area in Europe.

DE02 – is selected as a TOP3 indicator because of the destructive capacity of wild fires, and the significant increase in their occurrence in recent years, which may be caused by climate change.

DE04 – is selected as a TOP3 indicator because soil organic matter (SOM) is important to maintaining soil functions.

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12 CROSS-CUTTING ISSUES

During the selection process, a number of indicators were proposed that are common to more than one threat to soil, for example land use change and climate change. Although these indicators are considered to be 'cross-cutting', they are described in the sections where they have been selected as candidate indicators. Topsoil organic carbon content (OM01) is an indicator for decline in soil organic matter, but it is also an indicator (DE04) for desertification. Similarly the burnt area by wild fires (OM06) is also an indicator (DE02) for desertification. These indicators proposed for two different threats, have the same indicator name in each case, but are given different identification codes and have different data requirements.

The following sections describe the all-embracing issues of climate change, land use change and brownfield development in more detail than elsewhere in this report because, even as cross-cutting issues, they encapsulate a number of key processes.

12.1 Climate Change

Climate has a fundamental influence on all environmental factors and processes. The sub-sections which follow comment on the likely influence climate change will have on the main threats to soil.

12.1.1 Soil Erosion

Climate change is likely to affect the distribution and intensity of soil erosion. Where precipitation decreases and temperature increases, rill and inter-rill erosion by overland flow is likely to decrease, but increasing aridity, diminishing vegetation cover, will increase the risk of wind erosion and sediment loss by gully erosion, which although episodic, can remove huge quantities of surface soil during storm events. Where precipitation increases rill and inter-rill erosion is likely to increase because of greater runoff. Most climate change scenarios for Europe predict more extreme events such as heavy rainstorms exacerbated by periods of very high temperatures creating instability in the atmosphere.

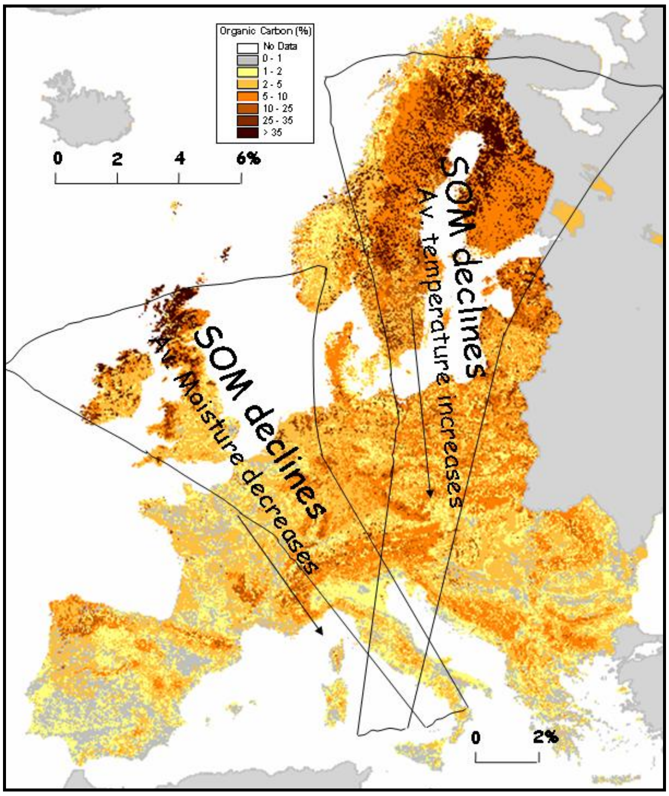
Thus climate change will initiate soil erosion where it did not occur before, or intensify soil erosion where it was established already. Erosion initiated or intensified by climate change may be accelerated by unsuitable land management practices. However, two major components in future erosion studies, a) fluctuating climate patterns and b) changes in land use systems, are explicitly considered in the PESERA model (Kirkby *et al*., 2004). These components do not operate in an isolated manner but interact with each other; both can have important impacts on the occurrence and severity of erosion.

The PESERA Grid Model was run on climatic scenarios for the period 2071-2080 and a land use scenario, which were compared with model runs on base-line conditions. The climatic scenarios were applied to selected 'window areas': southern Spain and Portugal and for an area covering Belgium and northern France (Mantel *et al.,* 2003).

Applying the HADRM3 climate-change scenario (SRES-A2b), developed by the Hadley Centre for Climate Prediction, assuming a complete coverage with maize, shows a significant increase in the area of the Iberian peninsula subjected regularly to rill, inter-rill and sheet erosion (Kirkby *et al*., 2004, p.14). On a 'business-as-usual' basis, the European Environment Agency expects an increase in erosion of 80% in EU agricultural areas by 2050, especially where erosion is already severe (EEA, 2000). Improvements in Global Climate Models and economic forecasts, offer a potential for scenarios of alternative erosion..

12.1.2 Decline in Soil Organic Matter

Climatic conditions, especially temperature and rainfall, exert a dominant influence on the amount of organic matter (OM) found in soils (Figure 12.1). Although there are many factors acting and interacting, when looking at the European scale, moving from a warmer to a cooler climate, the OM content of comparable soils tends to increase. This is because the decomposition rate of soil organic matter (SOM) is accelerated in warm and dry climates, while a lower rate of decomposition is the case for cool and wet regions. Thus, the implication is that global warming is likely to increase the decomposition rates for SOM, leading to a reduction in SOM contents in affected areas and an increase in gaseous carbon emissions, in all but a few areas where low intensity precipitation may be increased.



(After Jones *et al.*, 2004)

Figure 12.1 Influence of temperature and moisture on soil organic matter, as soil organic carbon, in Europe

12.1.3 Soil Contamination

Diffuse soil contamination occurs over large regions due to inputs by air deposition. In regions with high precipitation, e.g. mountainous areas, and where climate change is likely to increase rainfall, the deposition of contaminants is likely to increase. Additionally, fog is causing a further input of pollutants from air deposition, e.g. in the Northern Alpine fringe.

12.1.4 Soil Sealing

Where climate change brings increased precipitation, an increase in sealed surfaces will prevent water from infiltrating into the soil and, as a consequence, runoff (surface water flow) will be accelerated and cause an increase in erosion and flooding of downslope areas. Another consequence of soil sealing interacting adversely with climate change may be the pressure on water resources. Where a decrease in rainfall coincides with an increase in the sealed area, e.g. along the Mediterranean coastline, the supply of water for both urban communities and agricultural production could be reduced substantially.

12.1.5 Soil Compaction

Climate has a significant influence on the predisposition of soils for compaction, as wet soil has a reduced capacity to bare loads than dry soil and consequently will be subject to compaction and deformation. Climate is one of the indicators for Soil Compaction (CP09) and changes in the amount and timing of precipitation could have a major impact on good agricultural practice as it affects soil tillage and trafficking, especially the use of heavy machinery for agricultural operations.

12.1.6 Decline in Soil Biodiversity

Climate is crucial for soil biodiversity as temperature and humidity in the soil are important factors governing the living conditions of soil organisms. Soil microbial biomass is greater in soils from cooler, wetter regions compared to warmer, drier regions (Van-Camp *et al*., 2004c). Thus changes in climatic factors will alter the abundance as well as the composition of the soil fauna community present at a site.

12.1.7 Soil Salinisation

Salinisation and sodification may have a different genesis in the different countries and according to different climatic conditions (Kertez *et al*., 2000 in Van-Camp *et al*., 2004b, p.248). The main factors associated with salinisation and sodification are rainfall and its chemical composition, potential evapotranspiration, atmospheric humidity, temperature and wind velocity. If southern parts of Europe become warmer and drier, as current climate change scenarios predict, then the areas affected by salinisation and sodification are likely to increase, causing some agricultural areas to be become unproductive. One of the main causes of salinisation is the use of groundwater that has become saline for irrigation, because of over-extraction to satisfy the needs of increasing urban populations (soil sealing).

12.1.8 Landslides

Some factors that trigger or contribute to the occurrence of landslides are climatic, e.g. precipitation – rainfall and snowfall, and changes in temperature causing the expansion and contraction of rock and substrate material and/or the melting of frozen debris. Climatic extremes are likely to increase in Europe and, therefore, the likelihood of landsliding

12.1.9 Desertification

The warmer and drier conditions, predicted in the near future for Europe, will extend the area in the south of the continent that suffers from desertification. Thus, the arid and semi-arid zone in the Iberian peninsula, southern France and Italy, is likely to expand northwards. The semi-arid zone in south eastern Europe is likely to expand eastwards as well as to the north.

12.2 Land use change

Land use is another factor which affects all soil threats and requires frequent updating if its impact is to be taken into account in planning the sustainable use of the land. Remote sensing offers the opportunity to monitor land use change, with an accuracy that is improving progressively.

12.2.1 Soil Erosion

Changes in land use have a major impact on rates of soil erosion. One of the most important factors for soil erosion is vegetation cover. The greater the cover of the soil by vegetation, the less soil is removed by water and wind. In general, soil losses are small in forests, slightly larger under grasslands and largest under annual arable and permanent crops. Land use change may also affect soil erosion indirectly by influencing the soil organic matter content. Declining soil organic matter content decreases aggregate stability, thus degrading soil structure, and reduces infiltration capacity, thereby increasing the vulnerability of soil to erode (Van Camp *et al*., 2004b)

12.2.2 Decline in Soil Organic Matter

Land use is an important factor controlling soil organic matter (SOM) contents. Under similar climatic conditions, the organic matter content in the topsoil is lowest in arable land, increases under grassland and forest, and is largest in wetlands.

Agricultural land use practices have a profound impact on the evolution of soil organic matter. Practices that disrupt the soil structure increase decomposition rates of particularly the more labile, or active, fractions of SOM. The residual, or passive, fraction of SOM, is less effective at stabilising soil structure.

Deforestation, the conversion of forest to arable land and the ploughing of permanent pasture for arable cultivation, represent the most drastic impacts, causing significant losses of SOM of up to 20-50 %. These losses are much faster than the accumulation of SOM following afforestation . As a result of these strong relationships, the indicators OM05 (Changes in land cover) and OM09 (Area under organic farming) are candidate indicators for Decline in Soil Organic Matter.

12.2.3 Soil Contamination

Land use also has an effect on soil contamination, e.g. forests filter many more pollutants from the atmosphere than grassland or arable land, thereby increasing contaminant concentrations in soil. Specific land management practices can cause soil contamination such as application of exogenous organic materials or pesticides on agricultural land (Van Camp *et al*., 2004c). The potential inputs of pollutants depend on the agricultural production system, e.g. in organic farming the application of sewage sludge and pesticides are not allowed. Therefore, the indicator CO03 (Area under organic farming) is a candidate indicator for Soil Contamination and is also of relevance for the threats Soil Erosion, Decline in Soil Organic Matter (indicator OM09), Soil Compaction and Decline in Soil Biodiversity.

12.2.4 Soil Sealing

The change of land use is one key issue of the threat Soil Sealing in terms of land consumption (indicator SE03). The actual land use can be seen as a risk factor for Soil Sealing because arable land is more likely to be used for settlement and infrastructure purposes than grassland or forests.

12.2.5 Soil Compaction

Land use and soil management may contribute to soil compaction, especially in arable land, but also in forests. Heavy machinery used for management is causing topsoil compaction and, depending on its weight, also subsoil compaction. Land use also influences soil compaction indirectly by affecting the SOM content, which relates positively to soil structure. Soil with a good structure is less vulnerable to compaction.

12.2.6 Decline in Soil Biodiversity

Soil biodiversity is affected by land use and its change. A land use change may result in a change of occurrence and abundance of soil organisms, often in a very short time. The increasing intensity of agricultural management practises has destroyed habitats, and thus has substantially decreased soil biodiversity (Van Camp *et al*., 2004). Furthermore, land use affects biodiversity indirectly by the effects on SOM quantity and quality, which form the food source for many species.

12.2.7 Soil Salinisation

Land use affects soil salinisation by irrigation and agricultural management. Crop selection and rotation are also important factors, because choosing some crops with high water demands increases the likelihood of salinisation through irrigating with poor quality water.

12.2.8 Landslides

Finally, land use and management practices influence landsliding by affecting the hydrological conditions of the soil. Generally, forest soils can store much more water than arable soils. If drainage is insufficient, prolonged soil water-saturation may increase the likelihood of landsliding.

12.2.9 Desertification

Deforestation and intensive (over) grazing of natural vegetation in the arid and semi-arid zone will exacerbate desertification. Increased urbanisation is also contributing to the desertification process by marginalising the urban fringe.

12.3 Brownfields

This issue is of specific relevance to the threats Soil Contamination and Soil Sealing. 'Brownfields' are developed land with the potential for further development. They are not necessarily contaminated, but many brownfield sites have previously been used for commercial or industrial purposes where contamination has been inevitable from the industrial processes adopted. The re-use of such land automatically involves risk assessment for contamination and in some cases intrusive site investigations, followed by risk management which may require remedial measures to remove or contain('clean-up') the contamination. The benefits, as well as the challenges for the remediation of local soil contamination, go far beyond a prevention of risks to human health and the environment.

As stated in the Community Strategic Guidelines 2007-2013, "the redevelopment of brownfields and rehabilitation of the physical environment are important measures to improve competitiveness of European urban areas. The regeneration of public spaces and industrial sites can play an important role in helping to create the infrastructures necessary for sustainable economic development. Thus the remediation of contaminated sites has supported the aims of proposed reform of cohesion policy." Above all, redevelopment of brownfields supports the reduction in the consumption of greenfield land and contributes to shaping the urban landscape.

Apart from causing soil loss, land consumption causes many consequential pressures on soil ecosystems, including changed relief features, compaction and contamination of soil. It affects above-ground biodiversity because it causes loss, deterioration and fragmentation of habitats.

For both soil threats the indicator 'New settlement area established on previously developed land' is proposed as a candidate indicator for Soil Sealing (SE05) and Soil Contamination (CO09). The same name is used for both threats, but the requirements concerning application and at which spatial resolution, are completely different and thus the separate codes are retained.

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13 OVERVIEW OF ALL PROPOSED INDICATORS

Abbreviations: Indicator ID: ER = Soil eErosion, OM = Decline in Soil Organic Matter, CO = Soil Contamination, SE = Soil Sealing, CP = Soil Compaction, BI = Decline in Soil Biodiversity, SL = Soil Salinisation, LS = Landslides DPSIR, DE = Desertification; D = Driver, P = Pressure, S = State, I = Impact, R = Response Applicability: S = short-term, M = medium-term Monitoring: G = generally, R = in risk areas only TOP3 indicators in bold letters

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
ER01	**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}**	**S**	**S**	**G**	**5 years**	**1 km x 1 km aggregated data, pending WP2 results**
ER02	Water erosion	What is the current status of water erosion in Europe?	Measured soil loss by rill, inter-rill and sheet erosion	t ha^{-1} yr^{-1}	S	S	R	Annual	Point data from field plots
ER03	Water erosion	What is the current status of water erosion in Europe?	Measured soil loss by suspended sediment load in rivers and streams	t yr^{-1}	S	M	R	Annual	Point data, from 5-100 m^2 to river course length or lake-sized units, pending WP2 & WP5 results
ER04	Water erosion	What is the current status of water erosion in Europe?	Observed erosion features (rills and gullies)	m^3 ha^{-1} yr^{-1}	S	M	R	Annual	5 m x 5 m (remote sensed images), pending WP2&5 results
ER05	**Wind erosion**	**What is the current status of wind erosion in Europe?**	**Estimated soil loss by wind erosion**	**t ha^{-1} yr^{-1}**	**S**	**S**	**G**	**5 years**	**1 km x 1 km aggregated data, pending WP2 results**
ER06	Wind erosion	What is the current status of wind erosion in Europe?	Measured soil loss by wind erosion	t ha^{-1} yr^{-1}	S	S	R	Annual	Point data from field plots
ER07	**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}**	**S**	**S**	**G**	**5 years**	**1 km x 1 km aggregated data, pending WP2 results**

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
ER08	Tillage erosion	What is the current loss of soil by tillage practices, land levelling and crop harvest (root crops)?	Measured soil loss by tillage erosion	$t\ ha^{-1}\ yr^{-1}$	S	S	R	Annual	Point data from field plots
OM01	**SOM Status**	**What are the present organic matter contents in topsoils of Europe?**	**Topsoil organic carbon content (measured)**	**%**	**S**	**S**	**G**	**10 years**	**16 km x 16 km for forests, to be discussed for other land uses after WP2 results**
OM02	**SOM Status**	**What are the present C stocks in soils of Europe?**	**Soil organic carbon stocks (measured)**	**$t\ ha^{-1}$**	**S**	**S**	**G**	**10 years**	**16 km x 16 km for forests, to be discussed for other land uses after WP2 results**
OM03	**SOM Status**	**What are the peat stocks in Europe?**	**Peat stocks (calculated or modelled)**	**M t**	**S/I**	**S**	**R**	**10 years**	**National inventories; European soil and organic carbon topsoil databases**
OM04	SOM Quality	What is the present organic matter quality in topsoil in Europe?	C:N ratio of topsoil (measured)	Number	S	S	G	10 years	16 km x 16 km for forests, to be discussed for other land uses after WP2 results
OM05	SOM Changes – human-induced causes	Are there changes in Land Cover that might affect SOM dynamics? Where?	Land Cover Change (estimated by remote sensing, Corine land cover, or statistics)	km^2	P/R	S	G	5 -10 years	25 ha
OM06 Same as (DE02)	SOM Changes – human-induced causes	Where and to what extent are the areas affected by wild fires?	Wild fires (estimated by remote sensing or statistics)	km^2	P	S	R	Annual	50 ha

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
OM07	SOM Changes – human-induced causes	What (and where) are the areas affected by straw burning?	Crop residue burning (estimated by statistics)	km^2	P	S	G (except for forests, deserts)	Annual	NUTS 3
OM08	SOM Changes – human-induced causes	What (and where) are the inputs of exogenous organic matter to soils in Europe, as farmyard manures & slurries?	Exogenous organic matter additions – farmyard manure and other biowaste (proxy indicator, estimated from statistics on livestock and population)	$t\ ha^{-1}$	P/I	S	G (except for forests, deserts)	Annual	NUTS 3
OM09 same as (CO03)	SOM Changes – human-induced causes	What (and where) are the areas under organic farming in Europe?	Organic farming (proxy indicator, area estimated from statistics)	%	R	S	G (except for forests, deserts)	Annual	NUTS 3
OM10	SOM Changes – human-induced causes	Where are the areas in which cultivation (incl. conservation) practices might induce significant changes in soil organic matter?	Cultivation practice (proxy indicator, estimated by statistics, need to define a tillage classification)	%	P/R	M	G	Annual	National statistics; NUTS 1 to 3
CO01	**Diffuse contamination by inorganic contaminants**	**Which areas show critical heavy metal contents in excess of national thresholds?**	**Heavy metal contents in soils**	**%**	**S**	**S**	**R**	**20 years**	**Point data; National**
CO02	Diffuse contamination by inorganic contaminants	Are we protecting the environment effectively against heavy metal contamination?	Critical load exceedance by heavy metals	%	P	M	R	5 years	EMEP-Grid (50 km x 50km)
CO03	Diffuse contamination by nutrients and biocides	What are the environ-mentally relevant key trends in agricultural production systems?	Area under organic farming	%	R	S	G	Annual	National

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
CO04	Diffuse contamination by nutrients and biocides	Is the environmental impact of agriculture developing?	Gross nutrient balance	kg ha^{-1} yr^{-1}	S	S	G	Annual	National
CO05	Diffuse contamination by persistent organic pollutants	Which areas show critical concentration of organic pollutants?	Concentration of persistent organic pollutants	%	S	M	R	5 years	Regional, National
CO06	Diffuse contamination by soil acidifying substances	How is the environmental impact of soil acidification developing?	Topsoil pH	-	S	S	G	10 years	Regional, National
CO07	**Diffuse contamination by soil acidifying substances**	**Are we protecting the environment effectively against acidification and eutrophication?**	**Critical load exceedance by sulphur and nitrogen**	**%**	**P**	**S**	**R**	**2** years	**National; EMEP-Grid (50 km x50 km)**
CO08	**Local soil contamination by point sources**	**How is the management of contaminated sites progressing?**	**Progress in management of contaminated sites**	**% of all sites**	**R**	**S**	**G**	**2** years	**National or defined regions**
CO09	Local soil contamination by point sources	Is developed land efficiently used?	New settlement area established on previously developed land	% of new sites	R	S	G	2 years	National or defined regions
CO10	Local soil contamination by point sources	How many sites exist which might be contaminated?	Status of site identification	Number of sites	S	S	G	2 years	National or defined regions
SE01	**Soil sealing**	**What is the share of actually sealed area in the total land consumed by settlements and transport infrastructure?**	**Sealed area**	**ha; % of consumed land or ha y^{-1}; ha d^{-1}**	**P**	**S/M**	**G**	**3 years**	**data gathering: parcels assessment unit: municipalities (NUTS 5)**

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
SE02	Soil sealing	How much sealed soil is regained or restored by completely or partly removing artificial soil covers?	De-sealing	m^2; % of sealed area or $m^2\,y^{-1}$; $m^2\,d^{-1}$	R	M	R (urban areas)	3 years	data gathering: parcels assessment unit: municipalities (NUTS 5)
SE03	Land consumption	How much land is occupied at what growth rate for building and infrastructure purposes?	Land consumed by settlements and transport infrastructure (built-up land)	ha; % of territory or ha y^{-1}; ha d^{-1} add. units: % of potential permanent settlement area; m^2 capita^{-1}	P	S	G	3 years	data gathering: parcels assessment unit: municipalities (NUTS 5)
SE04	**Land consumption**	**How much bio-productive, semi-natural, or natural land has been converted to urban and other artificial land covers?**	**Land take (Corine Land Cover - CLC)**	**% or ha**	**P**	**S (current res.); M (future res.)**	**G**	**5-6 years**	**current MMU: 25 ha; future MMU: 1 ha**
SE05 also see (CO09)	**Brownfield re-development**	**How much previously developed unused land is currently re-used for settlement to reduce new land consumption on greenfield sites?**	**New settlement area established on previously developed land**	**%**	**R**	**M**	**R (brownfield 'hot spots')**	**Annual**	**data gathering: parcels assessment unit: municipalities (NUTS 5)**
SE06	Fragmentation	What are the impacts of soil sealing (mainly by transport infrastructure corridors) on aboveground biodiversity?	Effective mesh size	km² (index value)	I	S	G	3-5 years	reference area (Fg) = regional level

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
CP01	**Compaction and structural degradation**	**Where and to what extent are soil functions impaired by compaction**	**Density (bulk density, packing density, total porosity)**	**$g\ cm^{-3}$ or $t\ m^{-3}$ % ($v\ v^{-1}$)**	**S**	**S**	**G**	**5 years**	**National and European scale**
CP02	**Compaction and structural degradation**	**Where and to what extent are soil functions impaired by compaction**	**Air capacity (volume of air-filled pores, e.g. at 3, 5 or 6 kPa)**	**% ($v\ v^{-1}$)**	**S**	**S**	**G**	**5 years**	**National and European scale**
CP03	Compaction and structural degradation	Where and to what extent are soil functions impaired by compaction	Permeability (saturated hydraulic conductivity)	$M\ d^{-1}$	S	S	G	5 years	Local and regional scale
CP04	Compaction and structural degradation	Where and to what extent are soil functions impaired by compaction	Mechanical resistance (penetrometer resistance)	MPa	S	S	G	5 years	Local and regional scale
CP05	Compaction and structural degradation	Where and to what extent are soil functions impaired by compaction	Visual assessment (of structure and rooting)	classes	S	S	G	5 years	Local and regional scale
CP06	**Vulnerability to compaction**	**What are the causes and circumstances that result in persistent compaction?**	**Vulnerability to compaction (estimated)**	**class**	**S**	**S**	**G**	**5 years**	**National and European scale**
CP07	Vulnerability to compaction	What are the causes and circumstances that result in persistent compaction?	Drainage condition; (wetness condition, groundwater levels)	class ($d\ yr^{-1}$)	S	S	G	5 years	National and European scale
CP08	Vulnerability to compaction	What are the causes and circumstances that result in persistent compaction?	Soil strength (precompression strength e.g. determined with uni-axial test)	MPa	S	S	G	5 years	local scale

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
CP09	Causes of compaction	What are the causes and circumstances that result in persistent compaction?	Ground pressure - weight of machinery and tyre/track equipment or density and type of stock	Mg, kN, cm, kPa	P	S	G	5 – 10 years	Local and regional scale
CP10	Causes of compaction	What are the causes and circumstances that result in persistent compaction?	Soil management and tillage practice	class code	P/S	S	G	5 – 10 years	Local and regional scale
BI00	Species diversity	Are there changes in the diversity of soil micro organisms?	Microbial and fungal diversity	Number of genotypes k g^{-1} soil (DM)	Impact	M	G or R	3 to 5 years	EU or National based on a grid or a stratified system Point data
BI01	Species diversity	**Are there changes in the diversity of soil macrofauna?**	**Earthworms diversity and fresh biomass**	**Number m^{-2}, g fresh weight m^{-2}**	**Impact**	**M**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI01-1	Species diversity	Are there changes in the diversity of soil macrofauna?	Macrofauna diversity at family and/or specie levels	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI02	**Species diversity**	**Are there changes in the diversity of soil mesofauna?**	**Collembola diversity (Enchytraeids diversity if no earthworms)**	**Number m^{-2}**	**Impact**	**M**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**
BI02-1	Species diversity	Are there changes in the diversity of soil mesofauna?	Acari diversity	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI02-2	Species diversity	Are there changes in the diversity of soil mesofauna?	Nematode diversity	Number m^{-2}	Impact	M	G or R	3 to 5 years	As above or point data
BI03	**Biological functions**	**Are there changes in soil functioning?**	**Microbial respiration**	**g CO_2 kg^{-1} soil (DM)**	**Impact**	**S**	**G**	**3 to 5 years**	**EU or National based on a grid or a stratified system**

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
BI03-1	Biological functions	Are there changes in soil functioning?	Microbial activity based on enzymatic reactions	G substrate metabolized kg^{-1} soil (DM)	Impact	M	G or R	3 to 5 years	As above or point data
SL01	**Soil Salinisation**	**What is the vertical distribution of water soluble salts in the profiles of European salt-affected soils?**	**Salt profile**	**Total salt content: %; electrical conductivity: dS m^{-1}**	**S**	**S**	**G**	**1 - 3 years**	**national, 1:25,000, in salt-affected areas**
SL02	**Sodification**	**What is the chemical reaction and exchangeable sodium percentage (ESP) in the soil profile: the depth of the sodium accumulation horizon?**	**Exchangeable sodium percentage (ESP)**	**ESP: %**	**S I**	**S**	**G**	**1 - 3 years**	**national, 1:25,000, in salt-affected areas**
SL03	**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**	**P**	**S**	**R**	**Annual**	**national, 1:100,000**
LS01	**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)**	**S**	**S**	**G**	**Annual**	**1 km × 1 km**
LS02	**Landslide activity**	**What is the status of displaced material by landslide activity?**	**Volume or mass of displaced material (estimated)**	**m^3 (or km^3) (or tonnes) of displaced material**	**S**	**S**	**G**	**Annual**	**1 km × 1 km**
LS03	**Vulnerability to landsliding**	**What is the susceptibility of slope materials to landslide processes?**	**Landslide hazard assessment**	**Variable**	**S**	**M**	**R**	**5 years**	**1 km × 1 km**

ID	Key issue	Key question	Candidate Indicator	Unit	DPSIR	Applicability	Monitoring type	Frequency	Spatial resolution
LS04	Landslide control	What is the susceptibility of slope materials to landslide processes?	Landslide control measures	ha affected per km^2	S	S	G	Annual	1 km × 1 km
DE01	**Desertification**	**What is the extent of desertification in Europe?**	**Vulnerability to desertification**	**km^2**	**S**	**S**	**R**	**Annual**	**1 km x 1 km aggregated data, pending WP2 results**
DE02	**Desertification**	**What is the current status of soil loss as a result of wild fires in Europe?**	**Wild fires (burnt land area)**	**km^2 yr^{-1}**	**S**	**S**	**R**	**Annual**	**1 km x 1 km aggregated data, pending WP2 results**
DE03	Desertification	What is the current status of soil loss as a result of wild fires in Europe?	Soil loss (measured) from burnt areas	t ha^{-1} yr^{-1}	S	M	R	Annual	Point data, few m^2 (5-100) to field-sized units, pending WP2 & WP5 results
DE04	**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}**	**S**	**S**	**R**	**10-15 years**	**16x16 km for forests, to be discussed for other land uses after WP2 results**
DE05	Desertification	What is the current status of soil salinisation as a result of desertification in Europe?	Salt content in desertified land	dS m^{-1}	S	S	R	10-15 years	national, 1:25,000, in salt-affected areas
DE06	Desertification	What is the current status of decline in biodiversity caused by desertification in Europe?	Soil biodiversity decline in desertified land	number (of species)	S	M	R	10-15 years	EU or National

Environmental Assessment of Soil for Monitoring Volume I: Indicators & Criteria

Annex I: Indicator Fact Sheets

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1.1 ER01 Estimated soil loss by rill, inter-rill and sheet erosion

Key issue Water erosion
DPSIR classification: State

Main information: Water erosion is the wearing away of the land surface by rainfall, irrigation water, or snowmelt, that abrades, detaches and removes geologic parent material or soil from one point on the Earth's surface to be deposited elsewhere; soil or rock material is detached and moved by water, under the influence of gravity. In the case of this indicator, material is removed by surface runoff in rills, inter-rills and sheet wash. Water erosion, caused by surface runoff through rills, inter-rills, and sheet wash, is the most widespread form of soil erosion in Europe.

1.1.1 Example

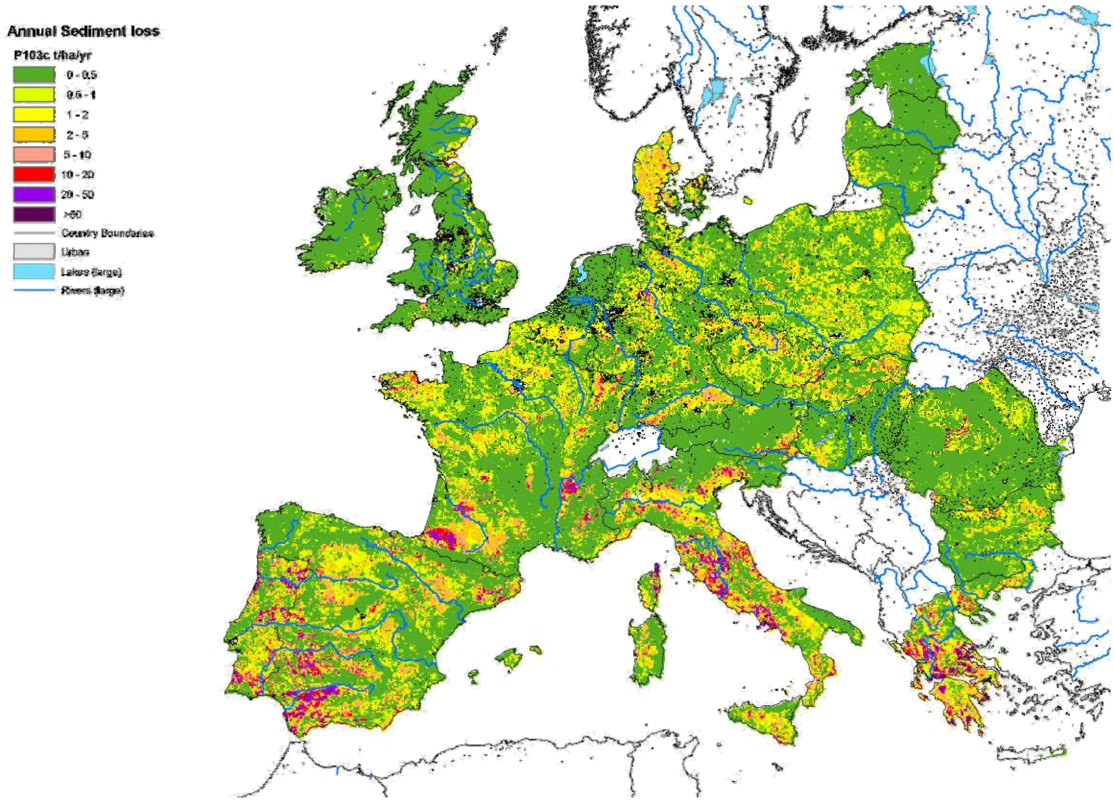

Figure 1.1.1 Pan European Soil Erosion Risk Assessment – PESERA.
[These data have been prepared by the PESERA Project, European Commission FP5 research project - contract no. QLK5-CT- 1999-01323 (Kirkby *et al*., 2004)]

There have been many recently implemented soil erosion risk assessment programmes/projects to assess water erosion at European and national scales (Jones *et al*, 2004a). Many of these are based on erosion models such as USLE (Wischmeier & Smith, 1978), RUSLE (Renard *et al*., 1991, 1997), WEPP (Nearing *et al*., 1989), Morgan-Morgan-Finney (Morgan *et al*., 1984), EUROSEM (Morgan *et al*., 1994), and PESERA (Kirkby *et al*., 2004). Most of these models use numerical data on the factors that cause erosion – soil (texture, surface condition), climate (rainfall), topography (slope) and land use/land cover (vegetation type and cover). The USLE and RUSLE are known to overestimate regional erosion (Boix-Fayos *et al*., 2005), whereas EUROSEM and WEPP are physical models that require large quantities of input data. The model chosen for use at the European scale should be able to simulate scenarios of soil erosion under changing climatic conditions and, most importantly, under different land uses and land management practices leading to changes in vegetation cover specific to Europe. The PESERA model (Kirkby *et al*., 2004), which has been partially tested and validated (Van Rompaey *et al*., 2003), may be the most appropriate for European conditions, because it is a physically-based model that computes runoff, data demands are not excessive and it is possible to conduct scenario analyses.

1.1.1.1 Significance

Data on the loss of soil by water erosion is of fundamental importance because it is the most widespread form of erosion in Europe and has substantial *off-site* as well as *on-site* effects.

1.1.1.2 Policy context

The official 'Communication on a Thematic Strategy for Soil Protection in Europe' (European Commission, 2002) identified eight threats to soil of which erosion is one of three threats identified for priority action, the other two being 'decline of soil organic matter' and 'soil contamination'. The indicator ER01 is relevant for the forthcoming Soil Framework Directive (European Commission, 2006a,b), which will implement tougher action to mitigate soil erosion, and other associated threats to soil. This objective will be achieved by harmonized criteria to establish the status and extent of soil erosion in Europe, and scientifically robust indicators such as ER01 upon which to base monitoring systems.

1.1.1.3 Scientific background

The factors affecting the loss of soil by water erosion are four-fold: soil type – texture, structure (and bulk density; link to soil organic carbon), depth, crustability; land cover – the type of crop/vegetation and its phenology; climate – rainfall amount and intensity; topography – gradient, form and size of slopes. A resolution of 1 km x 1 km is probably appropriate to run an erosion model that can produce meaningful estimates of soil loss at the European scale,. The data sets required are as follows:

Soil: European Soil Database at 1:1,000,000 scale (250,000 scale would be preferable when available) resolved to 1 km, to provide spatial data on soil type, surface texture, depth and crustability (Le Bissonnais *et al*., 2005); soil organic carbon (SOC) at 1 km resolution (Jones *et al*., 2004b,c, 2005) from which the reserve of SOC in the top 20cm; can be calculated; soil texture class and the ratio subsoil/topsoil texture is available from the European soil database; physical structure and bulk density can be derived using pedo-transfer rules (PTR; Van Ranst *et al*. (1995).

Climatic/Meteorological data: Ideally, climatic data are needed at the same resolution as other model input factors, and thus to match the soil data, i.e. 1 km resolution. For Europe, climatic data are not available, nor may exist, at such detailed scale. However, it is possible to interpolate climatic data at various resolutions using geostatistics (e.g. Ragg *et al*., 1988). Average climatic data are needed, preferably for recent international standard periods of 30 years, for example 1961-90, 1971-2000.

Agroclimatic data – rainfall, temperature, evapotranspiration are available from a number of sources. The MARS Project – Monitoring Agriculture with Remote Sensing – has generated agroclimatic data for 50 km x 50 km grid squares across Europe (Vossen and Meyer-roux, 1995) – using an inverse spline function for rainfall and an average adiabatic lapse rate (decline of 6°C per 1000m rise in altitude), the MARS data were interpolated onto a 1 km x 1 km raster for the PESERA Project (Gobin *et al*., 2003; Kirkby *et al*., 2004); other climatic data, at 0.5° or 10' intervals, are available from the Global Historical Climatology Network – GHCN (Easterling *et al*., 1996) and The Tyndall Centre for Climate Change Research (Mitchell *et al*., 2003; New *et al*., 2002).

Topographic data: The Shuttle Radar Topography Mission (SRTM) data sets provide a DEM for Europe at 90 m resolution that is suitable for modelling erosion. Aggregation to 250 m resolution is probably sufficient to run a model at 1 km resolution for Europe, although for regional application 90 m resolution would be more appropriate.

Land use/Land cover data: CORINE Land Cover (CLC) at 250 m resolution provides a historic data set on land use. For erosion modelling it is sufficient to use a relatively small number of land classes.

1.1.1.4 Assessment of results

Example (see Kirkby *et al*., 2004, p.15-16)
The current version of the PESERA grid model may overestimate erosion in valleys and basins where the land is arable but relatively flat, for example the Pontine swamps (I), the Po valley (I), the area east of Bayonne (F) and the dominant part of Denmark.

Many hilly to mountainous areas, such as the Apennines and the Pyrenees, are shown with very low or no erosion. It can be argued that the situation there is stable because of the forest cover, except for landslides which are not catered for by PESERA. In this respect, land use may have too dominant an influence in the model, but opinions on this differ.

Conversely, many areas on the map show erosion rates coinciding with observation and measurement, for example parts of the Guadalquivir and Ebro valleys; around Toulouse in south-west France; the loess belt in Belgium; the Siret catchment in north-eastern Romania; Alto-Adige in Italy; agricultural areas in Czech Republic; many parts of Slovakia; and other areas.

No erosion map at a European scale can be based on detailed knowledge at every point on the continent – an impossible task in practice. Furthermore, it would be impossible to include every factor of local importance in a comprehensive model, and there will always be some anomalies and limitations inherent in the data. However, by applying a common methodology throughout Europe, based on physical understanding, the PESERA Map (S.P.I.04.73) is able to highlight major differences between regions and to highlight areas particularly at risk. It also provides a uniform basis for comparison of erosion estimates across national boundaries and climatic zones.

It should be emphasised that the PESERA model does not have the same accuracy for all conditions in Europe, ranging from level to steeply sloping land; cold to hot and wet to dry conditions; intensive to extensive land management; and bare soil to completely vegetated areas.

To date, PESERA provides the only Europe-wide estimates of soil erosion by water that are based on a harmonised approach and standard data sets. The next step will be to compare the PESERA estimates with national measurements and risk assessments. This will be done systematically using GIS. Combining the results of such comparisons with improved data on climate, soil, land use/cover and topography (e.g. Digital Elevation Model) will lead to improved estimation of soil erosion by water for input to an overall soil protection strategy.

1.1.2 Meta data

1.1.2.1 Technical information

i) **Data sources:** There are several sources that provide relevant data Europe-wide (see above)

ii) **Data description:** see above (scientific background)

iii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring States in the Mediterranean Basin and the former Soviet Union

iv) **Spatial resolution:** 1 km x 1 km to 50 km x 50 km (see above)

v) **Temporal coverage:** Soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; Climatic data are available for international standard periods, for example 1961-90, 1971-2000; topographic data from SRTM are recent and should remain stable; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by the JRC (Ispra)

vi) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at 5 year intervals using updated climatic and land cover data

vii) **Methodology of indicator calculation:** Calculation of the estimated loss of soil (sediment): Agricultural area, forested area and natural areas are all subjected to erosion. For most countries, the estimates of erosion can only be validated against very few experimental sites.

viii) **Availability of baselines and thresholds:** A general baseline exists and thresholds are proposed (see Baselines and Thresholds Section in Indicator Selection Report).

1.1.2.2 Quality information

i) *Strength and weakness*: Detailed information is available for some countries, although spatial and temporal ranges differ. The data are mainly reliable but better resolution (e.g. for climate) and more recent data (for soil) are needed.

ii) *Data comparability:*
Comparability over time: current data sets originate from different periods.
Comparability over space: spatial coverages are the same but resolutions of the different data sets differ, e.g. SRTM at 90 m compared with climatic data at 50 km or 0.5° intervals

1.1.3 Further work required

In order to improve the accuracy and uncertainty it is necessary to gather many more data on the actual loss of soil from water erosion for validation of model estimates. Soil data are needed at 250,000 scale and some parameters such as soil organic carbon require updating. Climatic data are needed at resolutions much finer than 50 km or 0.5°. Land cover data will eventually be needed at five-yearly intervals to estimate the effects of land use change. The geographical coverage for all these data must be Europe-wide in order to support a workable SFD.

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1.2 ER05 Estimated soil loss by wind erosion

Key issue: Wind erosion
DPSIR classification: State

Main information: Wind erosion results mainly from the velocity of moving air. A wind speed of 30-40 km h^{-1} is sufficient to dislodge particles from the soil and transport them either by saltation, deflation or surface creep. Dry winds are more erosive than cold, humid winds. Wind erosion is not as widespread as water erosion in Europe, but it is a serious problem in certain regions – e.g. the glacial outwash areas of northern Germany, the eastern Netherlands, eastern England, parts of Eastern Europe as well as the Iberian peninsula.

1.2.1 Example

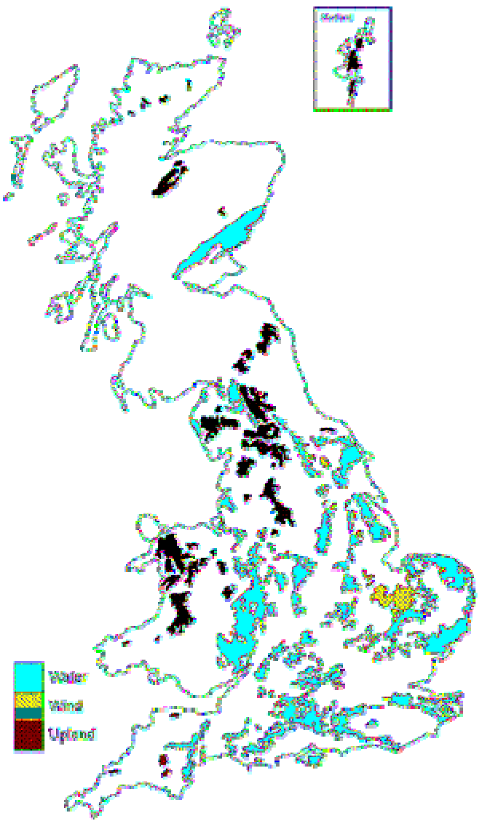


Figure 1.2.1 Soil erosion in Britain, Occurrence (by observation) of wind erosion
[after Boardman and Evans, 2006]

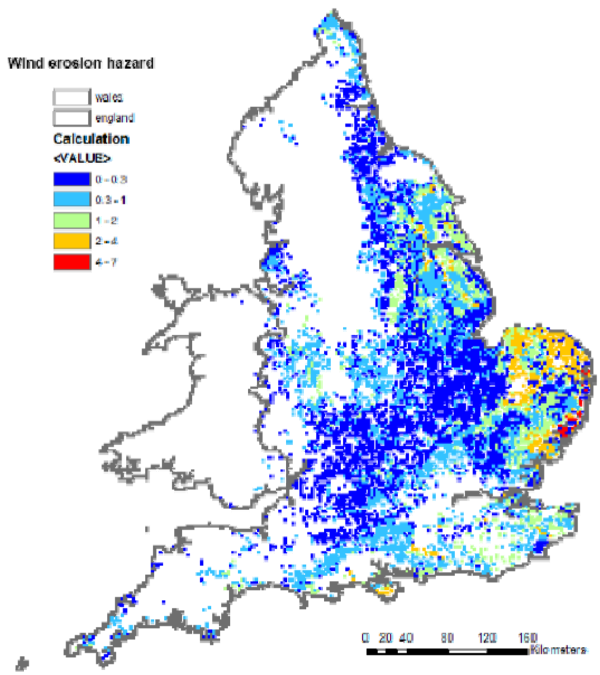


Figure 1.2.2 Annual wind erosion hazard for mineral soils (SOM<5%)
Derived by summation of monthly wind erosion potential, scaled to a range from 0 to 7, based on the RWEQ Qmax parameter. The scale is a quantitative relative scale. Source data: UKCIP 1961-1990 scenario (simulated by HadRM3 with SRES A2 Medium -High emissions scenario); MetOffice 5 km gridded data; and Digital Soils Information from NSRI: NATMAP, SOILSERIES and HORIZON © Cranfield University (NSRI) 2006.

Field and experimental investigations into wind erosion have been conducted in the USA since the 1930s, with the first wind erosion model – Universal Wind Erosion Equation (WEQ) – being developed in the 1960s. The revised WEQ – RWEQ (Fryear *et al*., 1998) – is an improved basis for wind erosion modelling, requiring particle size (sand, silt, clay), soil organic matter contents, and calcium carbonate contents. Soil wetness, liability to form a crust, soil roughness, and climatic data such as wind speed, rainfall and potential evapotranspiration, are also needed as input. Quine *et al*. (2006) describes the modelling in more detail concluding that, although there is a severe lack of high resolution meteorological data, RWEQ provides a logical framework for national scale assessment of wind erosion.

However, Chappell and Thomas (2002) suggested that off-site costs are probably many times those of the on-site costs, based on experience in the USA (Piper, 1989). Pimental *et al*. (1995) estimated that the off-site damage from wind erosion in the USA is of the order of 10 billion US\$ yr^{-1}.

1.2.1.1 Significance

Data on the loss of soil by wind erosion is of fundamental importance because it is a serious problem in certain parts of Europe, and has substantial off-site as well as on-site effects. The on-site and off-site effects of soil loss by wind are discussed by Funk & Reuter (2006) and wind erosion is likely to increase where climate change exacerbates the forces of desertification.

1.2.1.2 Policy context

The official 'Communication on a Thematic Strategy for Soil Protection in Europe' (European Commission, 2002) identified eight threats to soil of which erosion is one of three threats requiring priority action (the other two being 'decline of soil organic matter' and 'soil contamination'). The indicator is relevant for the forthcoming Soil Framework Directive (European Commission, 2006a,b), which will implement tougher action to mitigate soil erosion and other associated threats to soil. This will be achieved by harmonized criteria to establish wind erosion status and a scientifically robust indicator such as ER05, upon which to base monitoring systems that will address tillage erosion.

1.2.1.3 Scientific background

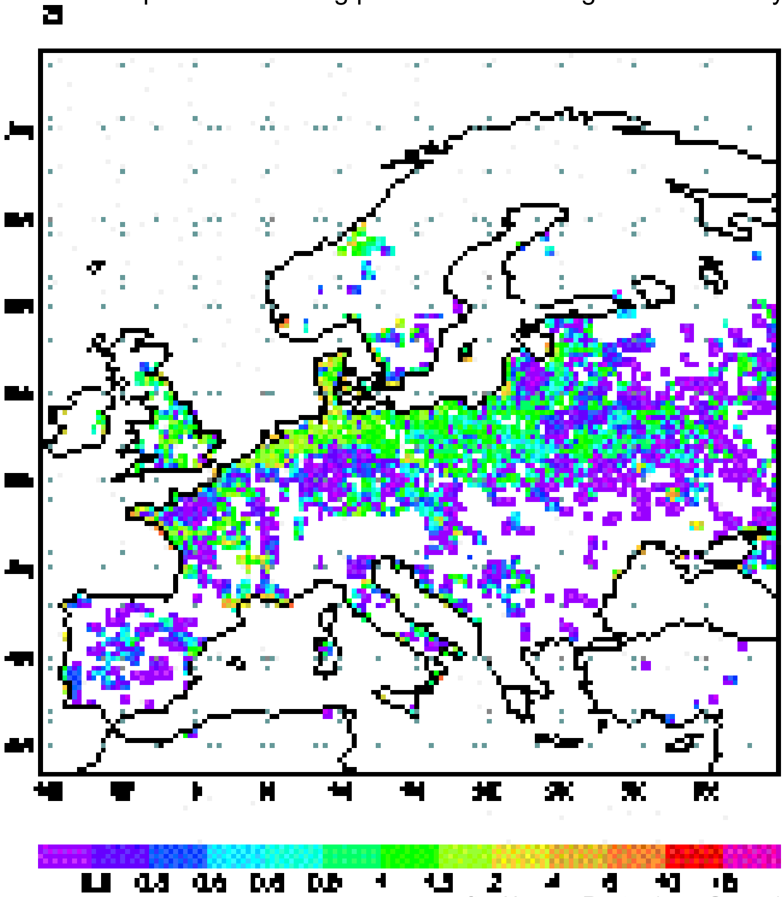
The factors affecting the loss of soil by wind erosion are four-fold: *soil type* – soil texture, structure (& bulk density), soil depth, soil organic carbon content, liability to form a crust, soil surface moistuure; *land cover* – the type of crop/vegetation and its phenology, plant density (e.g. row distance), field size and field alignment; *climate* – wind velocity and duration, evapotranspiration, rainfall, snow depth; *topography* – gradient, form (surface roughness) and curvature of slopes. To run an erosion model estimating soil loss in Europe, a resolution of 1 km x 1 km is probably appropriate but it is unlikely that climate data on a daily basis will be available at this resolution. The data sets required are as follows:

Soil: European Soil Database at 1:1,000,000 scale (250,000 scale would be preferable when available), to provide spatial data on soil type, surface texture, depth, crustability (Le Bissonnais *et al*., 2005); soil organic carbon (SOC) content is available at 1 km resolution (Jones *et al*., 2004b,c, 2005); physical structure and bulk density can be derived using pedotransfer rules(PTRs; Van Ranst *et al*. 1995).

Climatic/Meteorological data: Ideally, climatic data are needed at the same resolution as other model input factors. Therefore, to match the soil data, this would be at a 1 km resolution. Climatic data are not generally available, nor may they exist, at such a detailed scale for Europe. However, it is possible to interpolate climatic data at various resolutions using geostatistics (Ragg *et al*., 1988). The PRUDENCE project provides daily meteorological data on a 12km resolution for the whole of Europe for a 30 year long baseline for free. Data provided by that project have preference over any simple interpolated dataset, because a complete meteorological model has been applied, which harmonises meteorological conditions across all parameters.

Agroclimatic data – precipitation, temperature, evapotranspiration are available from a number of sources: . The MARS – Monitoring Agriculture with remote Sensing – project has compiled agroclimatic data for 50 km x 50 km grid squares across Europe (Vossen and Meyer-roux, 1995) – using an inverse spline function for rainfall and an average adiabatic lapse rate (decline of 6°C per 1000 m rise in altitude) for temperature, the MARS data were interpolated onto a 1 km x 1 km raster for the PESERA Project (Gobin *et al*., 2003; Kirkby *et al*., 2004); other data exist at 0.5° or 10' intervals from the Global Historical Climatology Network – GHCN (Easterling *et al*., 1996) and the Tyndall Centre for Climate Change Research (Mitchell *et al*., 2003; New *et al*., 2002). For assessing wind erosion, data on wind speed (velocity), direction and duration are key additional parameters needed, preferably for a recent international standard period of 30 years, for example

1961-90, 1971-2000. Rainfall and evapotranspiration data are also needed to estimate soil moisture conditions in susceptible soils during periods when strong winds are likely to blow.



after Hannes Reuter (pers Comm.)

Figure 2.3, : Log of number of erosive days on agricultural land
(based on ESDBv2.0, Corine, 30 years daily DMI data)

Topographic data: The Shuttle Radar Topography Mission (SRTM) data sets comprise 90 m DEM data for Europe which are suitable for modelling erosion. Aggregation to 250 m resolution would normally be sufficient to run a model at 1 km resolution for Europe, although, the effect of slope curvature on tillage erosion would make 90 m resolution more appropriate for regional application.

Land use/Land cover data: CORINE Land Cover (CLC) at 100 m resolution provides a historic data set on land use. For modelling wind erosion at European scale, it is sufficient to use a relatively small number of land classes.

1.2.1.4 Assessment of results

Example:
The wind erosion hazard map of England and Wales can be compared with published maps that purport to show areas at risk of wind erosion, for example Boardman and Evans (2006) and Morgan (1985). Morgan's distribution of soils at risk of wind erosion corresponds closely with this wind erosion hazard map with three exceptions: two of these areas, near Ormskirk on the west coast and south of the Wash near the east coast, do not show elevated levels of risk on the hazard map because organic soils dominate and the RWEQ model is only applicable to mineral soils (SOM<5%). The map of Boardman and Evans (2006) portrays soils at risk of water, wind and upland erosion but very little of the arable area of the UK is shown at risk of wind erosion. Given the agreement between the hazard map of England and Wales and the qualitative analysis of Morgan (1985), it is likely that Boardman and Evans (2006) may have underestimated the spatial extent of wind erosion in UK.

1.2.2 Meta data

1.2.2.1 Technical information

i) **Data sources:** there are several sources that provide relevant data Europe-wide (see above).

ii) **Data description:** see above (scientific background)

iii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring states in the Mediterranean Basin and the Former Soviet Union;

iv) **Spatial resolution:** 1 km x 1 km to 50 km x 50 km for various data sets (see above)

v) **Temporal coverage:** soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; (Sub)Daily Climatic data are available for international standard periods, for example 1961-1990, 1971-2000; topographic data from SRTM are recent and should remain stable; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).

vi) **Methodology and frequency of data collection:** modelling, repeated at five year intervals using updated climatic and land cover data.

vii) **Methodology of indicator calculation:** calculation of the estimated loss of soil (sediment): agricultural area, forested area and natural areas are all subjected to erosion. Wind erosion occurs mostly in agricultural areas, and in some natural areas with incomplete ground cover. For most countries, the estimates of erosion can only be validated against very few experimental sites.

viii) **Availability of baselines and thresholds:** the baseline in areas unaffected by wind erosion is zero; in areas that suffer wind erosion, average values are reported in the literature and thresholds are proposed (see D2-Section 3.2.2)..

1.2.2.2 Quality information

i) **Strength and weakness:** detailed information is available for some countries though spatial and temporal coverages differ. The data are mainly reliable but better resolution (e.g. for climatic data) and more up-to-date data (for soil) are needed; there is a dearth of data on wind speed, direction and duration in Europe yet these data are of crucial importance .

ii) **Data comparability** :
Comparability over time: current data sets come from different periods. *Comparability over space:* spatial coverage is the same but resolutions of the different data sets differ, e.g. SRTM at 90 m compared with climatic data at 50 km or 0.5° intervals.

1.2.3 Further work required

Soil data are needed at a 1:250,000 scale and some parameters, such as soil organic carbon content, should be updated. Land cover and land management data will eventually be needed at five-yearly intervals to estimate the effects of land use change.

Modelling wind erosion in future should incorporate the following elements: a crop growth model, local topographic controls, field dimensions, field boundary characteristics and calibration to allow derivation of quantitative rates. Detailed field measurements will be needed to achieve this.

There is also a clear need to develop a systematic predictive model of wind erosion of organic soils as these are not accommodated in existing models and field data suggest that these are soils that are amongst the most sensitive to wind erosion in the UK (see Quine *et al*., 2006).The geographical coverage for all these data must be the whole of Europe in order to support a workable SFD.

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1.3 ER07 Estimated soil loss by tillage erosion

Key issue: Tillage erosion
DPSIR classification: State

Main information: Tillage erosion has been the subject of a number of studies in the past decade (see Quine *et al*., 2006). In this project, tillage erosion includes soil removed by crop harvesting and land-levelling, a process most common in the Mediterranean region. Modelling of tillage erosion, proposed by Govers *et al*. (1996), has evolved to the stage exhibited by WATEM (Van Oost *et al*., 2000). Though spatially variable, tillage erosion is regarded as highly predictable on the basis of current processes and estimated rates are considered to be a robust assessment of the magnitude of tillage erosion (Quine *et al*., 2006).

1.3.1 Example

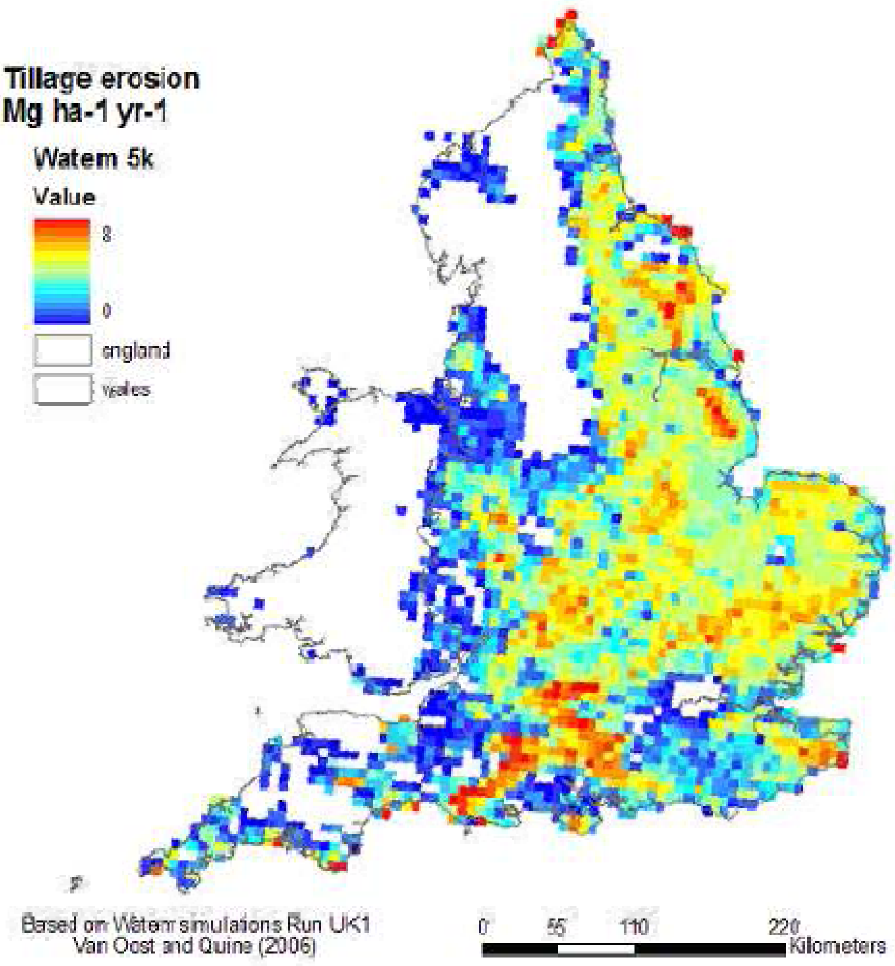

Figure 1.3.1 Modelling of Tillage Erosion in Britain

Simulated tillage erosion rates aggregated at a 5 km grid, derived using the WATEM model assuming a tillage transport coefficient of 600 kg m^{-1} yr^{-1}. Curvature is derived from SRTM 90 m topography and is corrected for underestimation based on comparison with high resolution data for three test sites in the UK. RMSE of map is ca. 22% (see Quine *et al*., 2006).

The WATEM model has been applied in England and Wales and it could be applied to Europe (Van Oost and Quine, in prep), using similar data sets to those described for ER01. Modelling tillage erosion requires curvature data for slopes which are derived from a Digital Elevation Map (DEM) of higher resolution than 1 km or even 250 m. A SRTM sourced DEM at 90 m resolution was used for England and Wales. The main constraint to modelling tillage erosion is the lack of spatial data on tillage implements used and details of cultivation practices such as directionality and speed, at both national and European scale.

1.3.1.1 Significance

Tillage erosion has been identified as an increasing problem in agricultural areas in recent years, although it is less widespread than water erosion. The off-site effects are considered to be more serious than those on-site.

1.3.1.2 Policy context

The official Communication on a Thematic Strategy for Soil Protection in Europe (European Commission, 2002) identified eight threats to soil of which erosion is one of three threats requiring priority action, the other two being 'decline of soil organic matter' and 'soil contamination'. Jones *et al*. (2004a) identify tillage erosion alongside water and wind erosion as an integral part of land degradation in Europe by erosion. The indicator (ER07) is relevant for the forthcoming Soil Framework Directive (European Commission, 2006a, 2006b) that will implement tougher action to mitigate all aspects of soil erosion, and other associated threats to soil. This will be achieved by harmonized criteria that establish tillage erosion status and scientifically robust indicators, such as ER01, ER05 and ER07, upon which to base monitoring systems.

1.3.1.3 Scientific background

The intensity of tillage erosion depends on a number of factors(Van Oost and Govers, 2006):

1. Slope variation or curvature: tillage erosion is most severe in areas of rolling topography;
2. Management parameters: tillage depth, tillage speed, plough direction and tillage implement type.

To run an erosion model to estimate soil loss by tillage erosion at European scale, a resolution of 1 km x 1 km is probably appropriate. The data sets required are as follows:

Soil: European Soil Database at 1:1,000,000 scale (250,000 scale would be preferable when available), to provide spatial data on soil type, surface texture, depth and crustability (Le Bissonnais *et al*., 2005); estimated soil organic carbon (SOC) content is available at 1 km resolution (Jones *et al*., 2004b,c, 2005); soil texture class and the ratio subsoil/topsoil texture is available from the European Soil Database; physical structure and bulk density can be derived using pedotransfer rules (PTRs; Van Ranst *et al*., 1995).

Climatic/Meteorological data: Ideally, climatic data are needed at the same resolution as other model input factors. To match the soil data, this would be at 1 km resolution. At the European scale, climatic data are not available, nor may they exist, at such a detailed scale. However, it is possible to interpolate climatic data at various resolutions using geostatistics (Ragg *et al*., 1988). In the case of soil loss by crop harvesting (SLCH), moisture content of the soil is critical and the rainfall during the period September to December is an important parameter in northern Europe. Average climatic data are needed, preferably for recent international standard periods of 30 years, for example 1961-90, 1971-2000.
Agroclimatic data – rainfall, temperature, evapotranspiration - are available from a number of sources: The MARS – Monitoring Agriculture with remote Sensing – has compiled an agroclimatic database for 50 km x 50 km grid squares across Europe (Vossen and Meyer-roux, 1995) – using an inverse spline function for rainfall and an average adiabatic lapse rate (decline of 6°C per 1000 m rise in altitude), the MARS data were interpolated onto a 1 km by 1 km raster for the PESERA Project (Gobin *et al*., 2003; Kirkby *et al*., 2004); other data exist at 0.5° or 10' intervals from the Global Historical Climatology Network – GHCN (Easterling *et al*., 1996) and the Tyndall Centre for Climate Change Research (Mitchell *et al*., 2003; New *et al*., 2002).
Topographic data: The Shuttle Radar Topography Mission (SRTM) data sets comprise 90 m DEM data for Europe, which are suitable for modelling erosion. Aggregation to 250 m resolution is

probably sufficient to run a model at 1 km resolution for Europe, although for regional application 90 m resolution is more appropriate.
Land use/Land cover data: CORINE Land Cover (CLC) at 250 m resolution provides an historic data set on land use. For erosion modelling it is sufficient to use a relatively small number of land classes.
Management parameters: Reliable information on directionality (e.g. relative proportion of different types of implement, tillage direction, turning circle, etc.) is not available for large areas (national or continental).

1.3.1.4 Assessment of results

A number of tillage models have been developed during the last decade and all modelling applications to date have addressed large spatial scales: points, fields, small catchments (Quine *et al*., 2006). In this national study, that points the way forward for a similar European study (Van Oost, pers comm.), a model of reduced complexity is preferred because detailed models make demands on the quality and quantity of topographic and management data that cannot be met by current national or European scale data sets. The simple diffusion-type model is regarded as robust, reliable and accurate because of its successful application by a number of researchers (Quine *et al*., 2006).

1.3.2 Meta data

1.3.2.1 Technical information

i) **Data sources:** There are several sources that provide relevant data Europe-wide (see above).
ii) **Data description:** see above (scientific background)
iii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring States in the Mediterranean Basin and the Former Soviet Union;
iv) **Spatial resolution:** 1 km x 1 km to 50 km x 50 km (see above)
v) **Temporal coverage:** Soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; Climatic data should ideally be available for international standard periods, for example 1961-90, 1971-2000; topographic data from SRTM are recent and should remain stable; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).
vi) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at 5 year intervals using updated climatic and land cover data.
vii) **Methodology of indicator calculation:** calculation of the estimated loss of soil (sediment): in agricultural areas. For most countries, the estimates of erosion can only be validated against very few experimental sites.
viii) **Availability of baselines and thresholds:** A general baseline exists and thresholds are proposed.

1.3.2.2 Quality information

i) **Strength and weakness:** detailed information is available for some countries though spatial and temporal coverage differ. The data are mainly reliable but better resolution (e.g. for climate) and more recent data (for soil) are needed.
ii) **Data comparability:**
Comparability over time: current data sets come from different periods.
Comparability over space: spatial coverages are the same but resolutions of the different data sets differ, e.g. SRTM at 90 m compared with climatic data at 50 km or 0.5° intervals

1.3.3 Further work required

In order to improve the accuracy and to reduce the uncertainty, it is necessary to gather many more data on the actual loss of soil from tillage erosion for validation of model estimates. Soil data are needed at a scale of 1:250,000 and some parameters, such as soil organic carbon, should be updated. Climatic data are needed at resolutions much finer than 50 km or 0.5°. Land cover data will eventually be needed at 5 yearly intervals to estimate the effects of land use change.

More detailed information on regional patterns of cultivation sequences and equipment, and improved topographic data, with detailed information concerning field dimensions, boundaries and the spatial organisation of fields (Van Oost *et al*., 2000) are needed. The use of such data within the modelling framework will require additional experimentation. All these data must cover the whole of Europe in order to support a workable SFD.

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1.4 OM01 Topsoil organic carbon content

Key issue: Soil organic matter status
DPSIR classification: Status

Main information: Organic carbon is the primary constituent of soil organic matter and affects, directly and indirectly, many components of agro-ecosystems and their environmental functions. Changes in soil organic carbon content are expected to be faster in topsoil than in deeper horizons. Topsoil organic carbon content is the simplest indicator that can be measured, and provides an indication of the evolution in organic matter. Numerous data are already available on topsoil organic carbon content in Europe. Topsoil organic carbon content is also relevant to soil erosion and decline in soil biodiversity.

1.4.1 Example

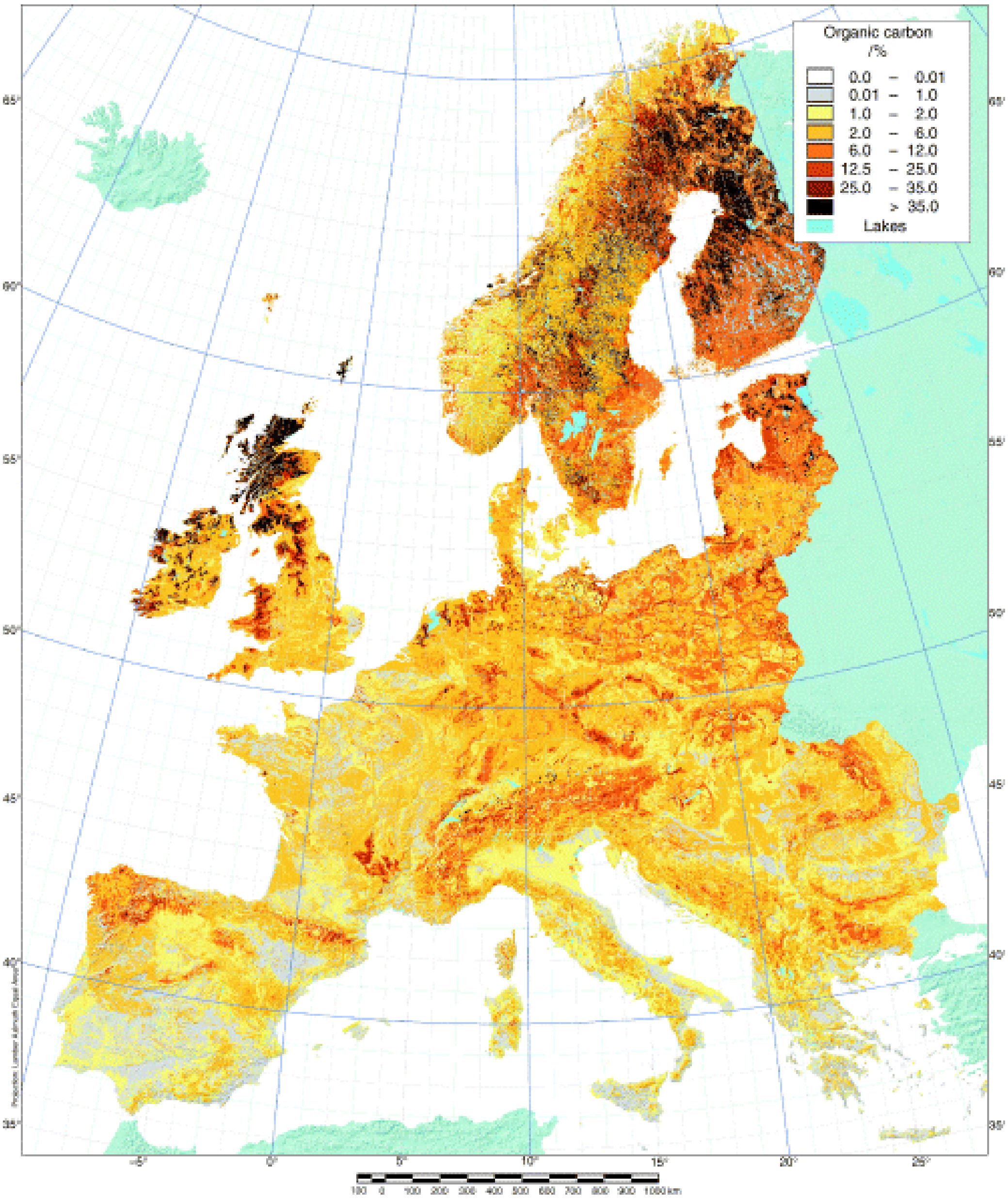

Figure 1.4.1 Organic carbon content in topsoil of Europe (after Jones *et al*., 2005)

1.4.1.1 Significance

Data on topsoil organic carbon content at several dates can provide an indication of the trends in soil organic matter (increase, decline, stable) and rate of change over time. However, this detection of change requires a large number of samples.

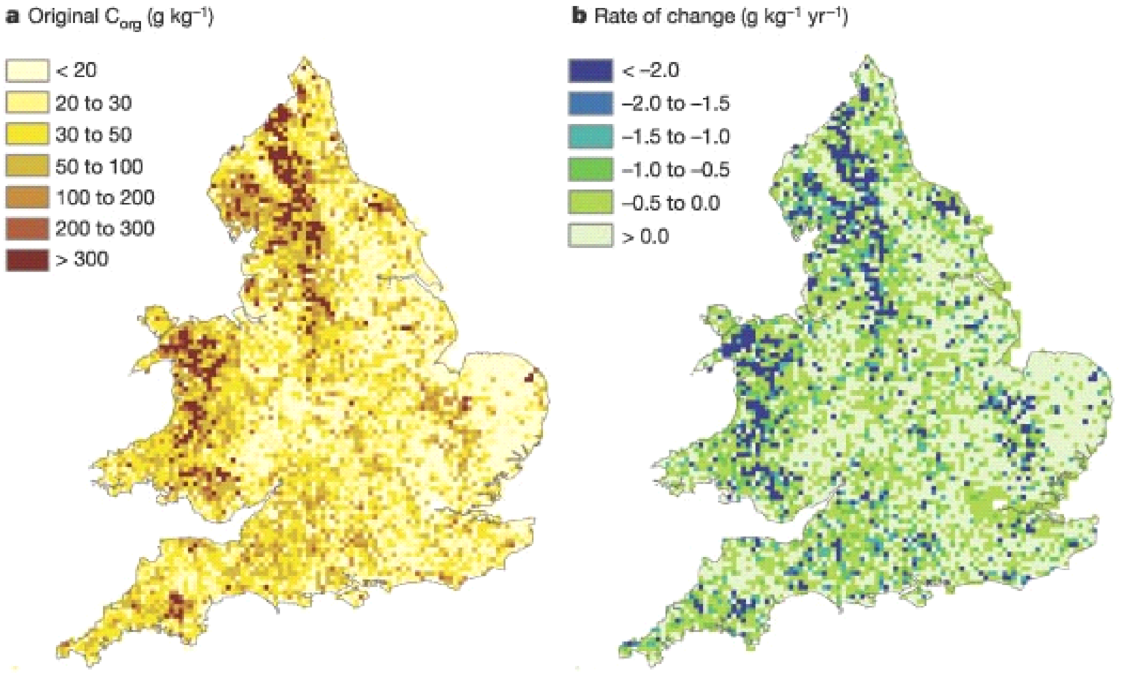

Figure 1.4.2 Changes in topsoil organic carbon content in England and Wales from 1978-2003 (Bellamy *et al*., 2005)

1.4.1.2 Policy context

The Communication on Soil Protection (European Commission, 2002) addressed the issue of ‘decline in soil organic matter’ and the need for data and indicators at the European scale. The indicator is relevant for the Strategy for Soil Protection (European Commission, 2006a,b). The Common Agricultural Policy already provides opportunities for the build-up of soil organic matter. Agri-environmental measures include support to organic farming, conservation tillage, integrated crop management, management of low intensity pasture systems, and the use of certified compost.

1.4.1.3 Scientific background

Topsoil organic carbon content is strongly dependent on geo-climatic factors (Jones *et al*., 2005), on land cover and land use changes (McGrath and Loveland, 1992; Arrouays and Pelissier, 1994) on soil type and clay content (Arrouays *et al*., 2001, 2006), on combinations of clay contents and precipitation (Verheijen *et al*., 2005), and on and management practices (Carter 1992; Soussana *et al*., 2004). Therefore, baselines values should be site-specific (i.e. the value measured at a site on a given date). However, ranges of reference values specified for different land uses, clay content, and climate can be derived from soil data referring to an initial inventory (Verheijen *et al*. 2005; Arrouays *et al*., 2001, 2006).

1.4.1.4 Assessment of results

Bellamy *et al*. (2005) used data from the National Soil Inventory of England and Wales obtained between 1978 and 2003 to show that organic carbon was lost from soils across England and Wales over the survey period at a relative mean rate of 0.6% yr^{-1}. The rate of change was proportional to initial soil organic carbon contents. It is likely that under current monitoring systems in most other countries, it would not be possible to identify trends over time because of lack of sufficient data.

1.4.2 Meta data

1.4.2.1 Technical information

i) **Data sources**: national soil inventories and soil monitoring data.

ii) **Description of data:** point data, gravimetric organic carbon content of topsoil (g kg^{-1}).

iii) **Geographical coverage:** Topsoil organic carbon is one of the most widely available indicators in Europe. The median density of sites for the 'topsoil organic carbon content' indicator is 1 site per 306 km².

iv) **Spatial resolution:** 7 km x 7 km to 30km x 30 km

v) **Temporal coverage:** 1975-2007 (depending on countries)

vi) **Methodology and frequency of data collection**: sampling of soil in the field and analytical determination in the laboratory, repeated at least every ten years.

vii) **Methodology of indicator calculation:** calculation of the statistical distribution of soil organic carbon content for combinations of land use and soil type. Calculation of the mean rates of change.

viii) **Availability of baselines and thresholds:** Universal baselines or thresholds are not available for the whole of Europe. Baseline values could be calculated using SOC-clay relationships for combinations of land use, climate and soil type.

1.4.2.2 Quality information

i) **Strength and weakness:** For most countries detailed information is available, different spatial and temporal coverage occur. The data are reliable.

ii) **Data comparability:**
Comparability over time: Time steps are highly variable amongst countries.
Comparability over space: Sampling depths range from 0-15 cm to 0-30 cm; analytical methods vary amongst countries but are roughly comparable.

1.4.3 Further work required

In order to improve the accuracy and uncertainty it is necessary to establish relationships between the results obtained using various analytical methods. The geographical coverage should be improved to get a more European picture. One of the main difficulties remaining is the hamonisation of sampling depths.

1.4.4 References

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1.5 OM02 Soil organic carbon stock

Key issue: Soil organic matter status
DPSIR classification: Status

Main information: The organic matter contained in the Earth's soils is a large reservoir of carbon, containing about 1500 Pg C (Post et al. 1982; Eswaran et al. 1993; Batjes 1996), that can act as a sink or source of atmospheric CO2. About half of this carbon stock is contained in topsoil. Moreover, changes in organic carbon stocks have been shown to be faster in topsoil than in deeper horizons (Arrouays and Pelissier, 1994). Topsoil organic carbon stock determination requires measurements of organic carbon content in fine earth (particles <2mm), of coarse elements, and of soil bulk density. Numerous data are available on topsoil organic carbon content in Europe. However, soil bulk density data are often lacking.

1.5.1 Example

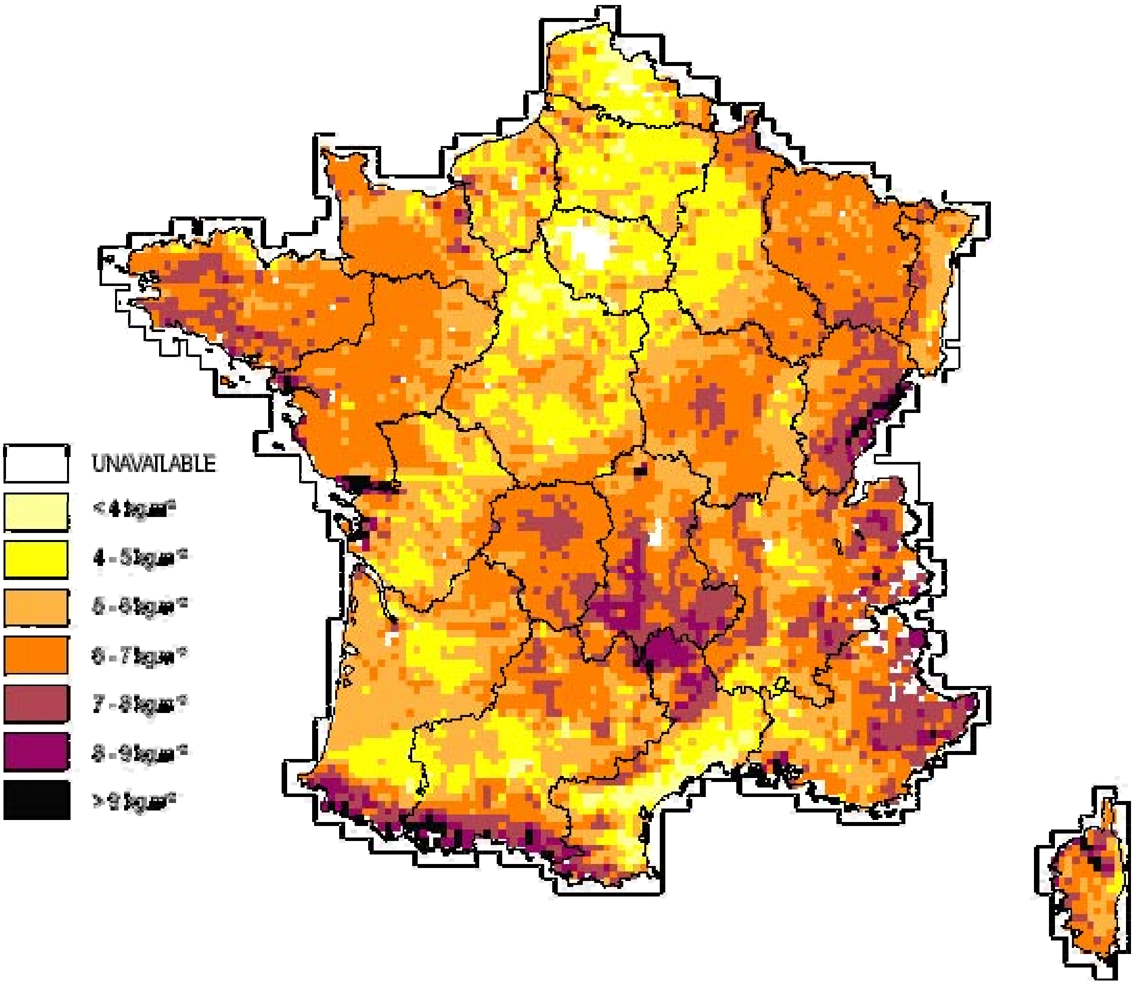

Figure 1.5.1 Organic carbon stocks in topsoil of France (after Arrouays *et al.*, 2001)

1.5.1.1 Significance

Data on topsoil organic carbon stocks at several dates can provide an indication of the trends in soil organic stocks (increase, decline, stable) and of the fluxes between soils and atmosphere. However, this detection of changes requires a large number of samples.

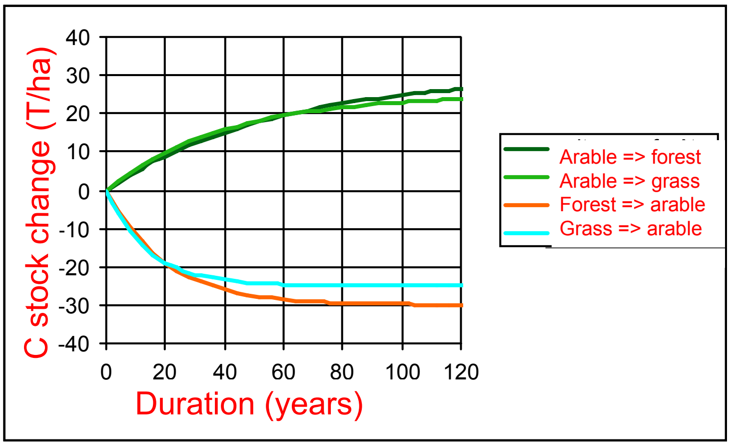

Figure 1.5.2 Relative changes in topsoil carbon stocks following some land use changes (Arrouays *et al*., 2002)

1.5.1.2 Policy context

The Kyoto Protocol (United Nations Framework Convention on Climate Change) allows signatory countries from Annex I to subtract from their national greenhouse gas emissions any sequestration of greenhouse gases induced by 'additional human activities'. These activities may include the storage of carbon in the soil. Such storage could be a result of afforestation and re-forestation (Article 3.3. of the Kyoto Protocol), and agriculture and forestry management (Article 3.4.). The amounts deductible under the terms of the 'agriculture' section of Article 3.4 are not, in principle, limited; each country fixes the levels it undertakes to ensure, but their accounting is conditioned by the requirement for verification of claimed sequestration by an independent method. The Common Agricultural Policy already provides opportunities for increasing soil organic carbon stocks through support to organic farming, conservation tillage, integrated crop management, management of low intensity pasture systems, use of certified compost and others.

1.5.1.3 Scientific background

Topsoil organic carbon stock is strongly dependent on geo-climatic factors (Jones *et al*., 2005), on land cover and land use changes (McGrath and Loveland, 1992; Arrouays and Pelissier 1994) on soil type and clay content (Arrouays *et al*., 2001, 2006), on combinations of clay contents and precipitation (Verheijen *et al*., 2005), and on management practices (Carter 1992; Soussana *et al*., 2004). Therefore, the baselines values should be site-specific (i.e. the value measured at a site on a given date).

1.5.1.4 Assessment of results

In the example shown for France (Arrouays *et al*. 2001), carbon stocks in French soils were estimated to be about 3.1 Pg. The main controlling factors of the soil carbon stocks distribution were identified as follows: land use, soil type, contrasting climatic conditions (elevation), and clay content.

Regarding changes of organic carbon stocks, Sleutel *et al*. (2003) used a large data set on Flemmish cropland soils from measurements made during the period 1989-2000, showing that in the entire study area, soil organic carbon stocks had either decreased, or at best had remained stable.

1.5.2 Meta data

1.5.2.1 Technical information

i) **Data sources:** national soil inventories and soil monitoring data.

ii) **Description of data:** point data, organic carbon content of soil (g kg-1), soil bulk density (g cm-3).

iii) **Geographical coverage**: Measurements of soil organic carbon content are available in all countries; however, a noticeable number of countries do not determine soil bulk density

iv) **Spatial resolution:** point data

v) **Temporal coverage:** 1975 to 2007 (depending on countries)

vi) **Methodology and frequency of data collection:** frequency once from some countries, yearly to ten years for others (depending on the country).

vii) **Methodology of indicator calculation:** Calculation of the statistical distribution of soil organic carbon stocks for combinations of land use and soil type, and/or for a given area. Calculation of net changes.

viii) **Availability of baselines and thresholds:** No universal baselines and thresholds are available for the whole of Europe. Baseline values could be estimated by carbon stocks at a given date. One approach would be to set thresholds so that total carbon stocks over a given area should not decrease.

1.5.2.2 Quality information

i) **Strength and weakness**: For most countries detailed real information is not available, as bulk density measurements are often missing. Different spatial and temporal coverage occurs. Bulk densities are often estimated using average values or statistical relationships with other available parameters.

ii) **Data comparability**:
Comparability over time: Time steps are highly variable amongst countries.
Comparability in space: Sampling depths range from 0-15 cm to 0-30 cm. Analytical methods vary between countries but remain approximately comparable. Bulk densities are estimated using methods that differ between countries.

1.5.3 Further work required

In order to improve the accuracy and uncertainty, it would be necessary to establish relationships between the results obtained using various analytical methods. The geographical coverage should be improved to provide a more comprehensive European picture. One of the main difficulties remains the harmonisation of sampling depths. Bulk density measurements should be undertaken systematically.

1.5.4 References

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1.6 OM03 Peat stock

Key issue: Soil organic matter status
DPSIR classification: Status

Main information: Peat is soil that is characterised by sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material. The rate of peat accumulation depends upon water regime and temperature. Estimates of the mass of carbon stored globally in peatlands of the world range from 120 to 400 Pg (Franzén, 2006). Therefore, peat soils are crucially important as a potential sink or source for atmospheric carbon dioxyde. Peat is currently under various threats: unsustainable drainage and land clearing activities for agricultural or development purposes, peat fires, global warming and its impacts, over-exploitation of resources and others. In Europe, peat is mainly located in the northern latitudes, one third being found in Finland, and more than a quarter in Sweden (Montanarella et al., 2006). There is no harmonised exhaustive inventory of peat stocks in Europe. A first attempt to map peat areas has been made by Montanarella et al. (2006). However, this estimate is still approximate, and lacks information on peat depth. Bulk density of peat is required to convert organic matter contents of peatlands into regional stocks.

1.6.1 Example

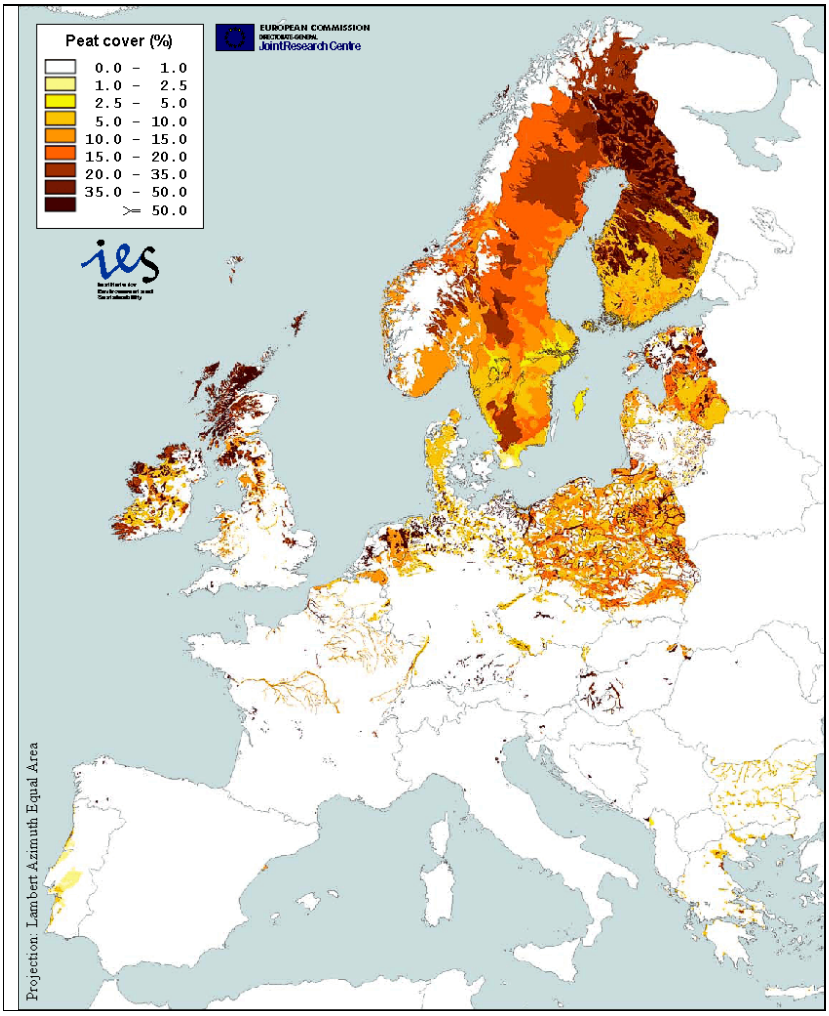

Figure 1.6.1 Relative cover (%) of peat and peat-topped soils in the soil mapping units of the European Soil Database (after Montanarella *et al*., 2006)

1.6.1.1 Significance

Peat cultivation and extraction has caused a significant decline in the extent of peatlands and peat stocks (Hutchinson, 1980). Peat soils form habitats to some rare plant and animal species. The objective of the indicator is to provide information on decline or increase in peat stock.

1.6.1.2 Policy context

The need for peatland protection is recognised in the communication on soil strategy from the European Commission (European Commission, 2002). Peat soils are natural resources which require a sustainable use as recommended by the 'Thematic Strategy on the Sustainable Use of Natural Resources' (European Commission, 2005).

1.6.1.3 Scientific background:

The area of peatland in Europe was estimated by Montanarella *et al*. (2006). For some countries, more accurate estimates have been produced (Burton, 1996; Shier, 1996). There is a concern that many high-latitude peat soils may have switched from being net sinks, to net sources, of atmospheric carbon, due to climate change and atmospheric deposition of nutrients (N, P, K). The baseline value could be the present observed peat stock. A threshold or target value could be that no more decline in peat stock is observed. However, this target might be difficult to reach in the context of global warming.

1.6.1.4 Assessment of result example

The first attempt to estimate the area of peatlands in Europe (Montanarella *et al*. 2006) showed that more than half of the total area of peatlands is located in two countries: Finland and Sweden. The remainder is in Poland, the UK, Norway, Germany, Ireland, Estonia, Latvia, The Netherlands and France. Small areas of peatland also occur in Lithuania, Hungary, Denmark, and the Czech Republic. Peat soils are mostly absent in southern parts of Europe.

Regarding decline of peat Franzén (2006) investigated 14 peat sites in Sweden between 1997 and 2005. He found that in some sites peat soils had subsided at a rate which was approximately four times the average rate of formation of circumboreal peats.

1.6.2 Meta data

1.6.2.1 Technical information

i) **Data sources:** national soil inventories and soil monitoring data; national peat Inventories.
ii) **Description of data:** point data, maps, estimates of peat stocks.
iii) **Geographical coverage:** National inventories of peat stocks have been realized in some countries. Measured bulk density data is often missing.
iv) **Spatial resolution:** point and aggregated data
v) **Temporal coverage**: unknown
vi) **Methodology and frequency of data collection**: once from some countries.
vii) **Methodology of indicator calculation**: mapping of peatland area and depth, sampling for data on peat bulk density, followed by calculation of peat stocks.
viii) **Availability of baselines and thresholds**: No baselines and thresholds available for the whole Europe. Baselines could be estimated by an inventory at a given date. One approach could be to set thresholds so that peat stocks over a given area should not decrease.

1.6.2.2 Quality information

i) **Strength and weakness**: For most countries detailed information is not available, as peat depth and bulk density measurements are often missing.
ii) **Data comparability:**
Comparability over time: Most countries do not have time series on peat stocks. *Comparability in space:* National inventories of peat stocks have been realized using different

techniques and scale of soil survey, using different criteria to classify soils and to sample them. Therefore, the data are too disparate to be integrated at a European scale.

1.6.3 Further work required

An exhaustive harmonised inventory of peat soils in Europe, including the delineation of peatland areas, and the measurements of peat depth and bulk density should be the priority to get an unbiased baseline value.

1.6.4 References

Burton, R.G.O. (1996). The peat resources of Great Britain. In: Lappalainen, E. (ed.) Global Peat Resources. International Peat Society, Jyskä, Finland, pp. 79-86.

European Commission (2002). Communication of 16 April 2002 from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions: Towards a Thematic Strategy for Soil Protection [COM (2002) 179 final]. (At: http://europa.eu.int/scadplus/printversion/en//lvb/l28122.htm; last accessed: 25.10.2005).

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1.7 CO01 Heavy metal contents in soils

Key issue: Diffuse contamination by inorganic contaminants
DPSIR classification: State

Main information: This indicator identifies where contents of heavy metals exceed national thresholds in Europe. The reasons for heavy metal contamination in upper soil horizons can be, e.g., anthropogenic influence due to industry, traffic, use of fertilizers and sewage sludge or natural pedo-geochemical enrichment due to weathering processes, so that the origin of the contamination cannot be derived directly from this indicator.

1.7.1 Example

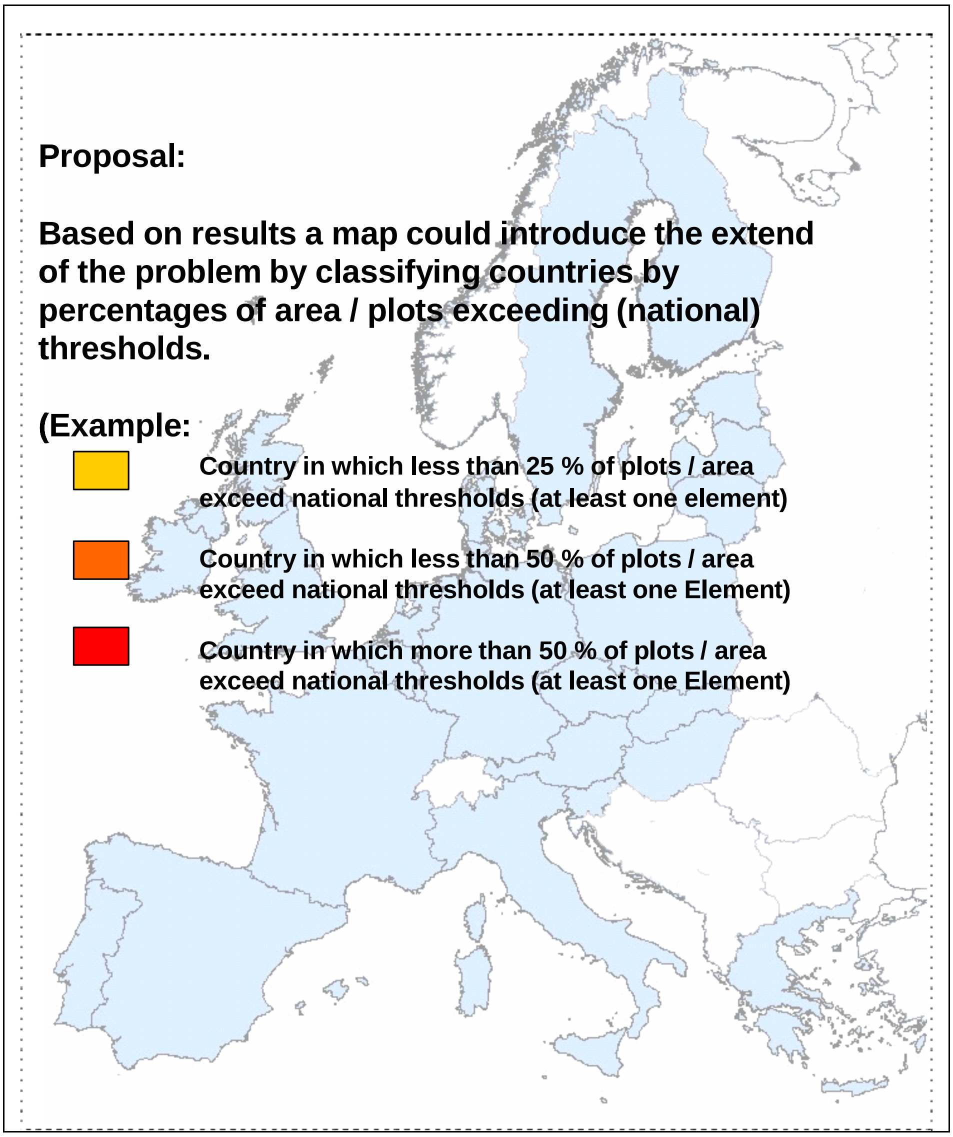

Figure 1.7.1 Example for data presentation. Extent of heavy metal critical load exceedance per country, using defined categories

The example histogram in Figure 1.7.2 showing Zn contents for soils of different texture in several EU Member States is taken from a preliminary investigation of heavy metal contents and organic carbon in European soils conducted by the Geosciences and Natural Resources (BGR), Hannover (Utermann, *et al.* 2003), under contract to the European Commission, Joint Research Centre, Ispra (I).

1.7.1.1 Significance

Chemical impacts related to human activities can be detected in soils all over the world even in regions with sparse human populations that are distant from sources of contamination emanating from densely populated areas (ISO/DIS 19258). Choosing thresholds for the various contaminating substances should focus clearly on the potentially adverse impacts on the environment or human health (EEA, 2005). The exceedance of thresholds for heavy metal contents gives a first impression of the extent of the problem. In the long term, the target should be 0% exceedance of national thresholds.

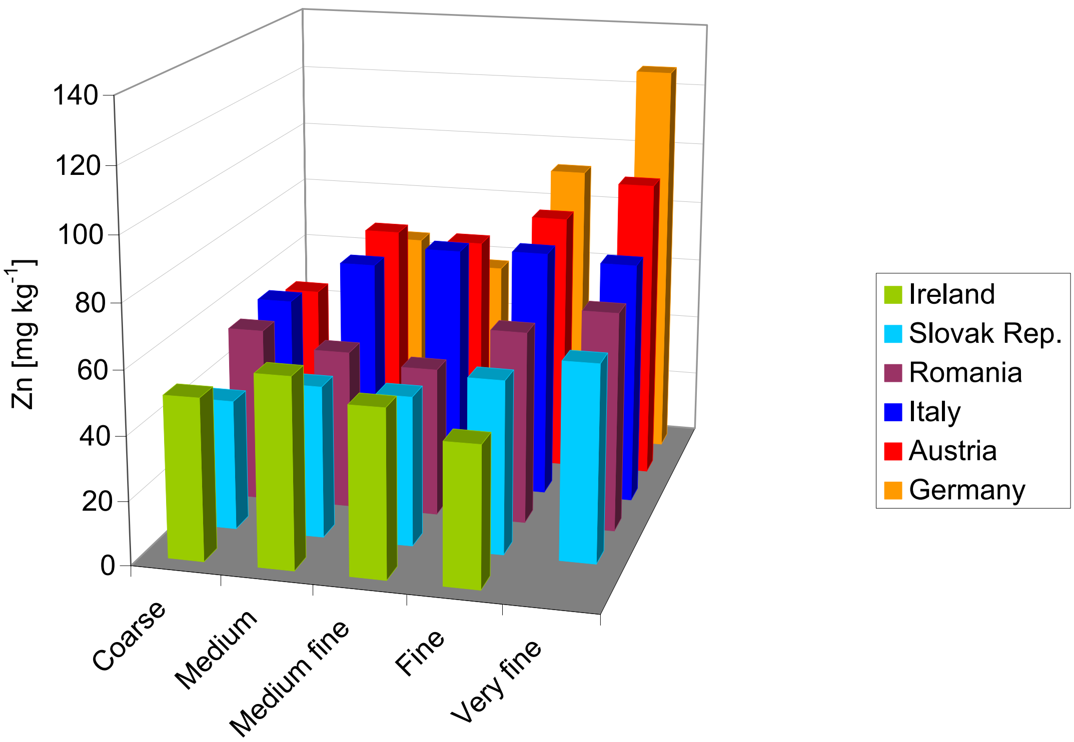

Figure 1.7.2 Example of data presentation: Zn content for comparison with the threshold values (source Utermann *et al*., 2003)

1.7.1.2 Policy context

Contamination is one of the main threats to soil identified in the EU soil communication (European Commission (2002); prevention of soil contamination has strong links with policies on chemical substances and with environmental protection policies for water and air. It has also strong links with policies concerning certain land uses for instance agriculture (see the Report of the Technical Working Groups – Contamination and Land Management - introduction notes (Vegter *et al.,* 2004).

1.7.1.3 Scientific background

The contents of heavy metals in soils may originate from natural pedo-geochemical properties, anthropogenic sources or a mixture of these two fractions. Ratios of these fractions vary widely depending on the type of substances, the type of soil and land use and the nature and extent of external impacts (ISO/DIS 19258). Because of their toxicological effects, heavy metals may seriously affect the health of human beings and other animals. The extent of toxicological effects on humans, as well as on the environment (e.g. water, air), depends on the solubility and mobility of the specific elements and the interactions between them.

1.7.1.4 Assessment of results

The example from the short term study conducted by Utermann *et al.* (2003) revealed a lack of harmonisation between the current national databases of heavy metal contents in the soils of Europe. This is particularly true with respect to spatial representativity, some countries having adopted much denser sampling programmes than others. Furthermore, there is a lack of standardisation in the methods of analysis used.

1.7.1.5 Sub-indicators

The Cd, Cu, Hg and Pb contents should be measured on monitoring samples. It is recommended that, because of their anthropogenic importance, the results for Cd, Cu and Pb should be reported.

1.7.2 Meta data

1.7.2.1 Technical information

i) **Data sources:** national soil databases; national background and threshold values;

ii) **Description of data:** Site description (coordinates, land use, parent material), profile descriptions (soil type, horizons, horizon depth, sampling depth, fine earth, texture), chemical analyses (content of heavy metals, method of analyses, detection limits)

iii) **Geographical coverage**: EU 27 (recommended)

iv) **Spatial resolution:** depending on existing monitoring programmes and size of the country

v) **Temporal coverage:** approx. 20 – 25 years (recommended for comparability)

vi) **Methodology and frequency of data collection:** depending on existing monitoring programmes

vii) **Methodology of indicator calculation**: No calculation needed (except reference to different soil depths and analytical methods is given)

viii) **Availability of baselines and thresholds:** depending on existing monitoring programmes and national thresholds

1.7.2.2 Quality information

i) **Strength and weakness:** depending on existing monitoring programmes

ii) **Data comparability:**
Comparability over time: depending on existing monitoring programmes
Comparability over space: depending on existing monitoring programmes

1.7.3 Further work required

- Review of national background values,
- Compilation, selection and documentation of (national) thresholds,
- Harmonization of analytical methods

1.7.4 References

AG Bodenindikatoren (2007). Konzept für ein nationales Set von Bodenindikatoren. Heft 75. Wien (in preparation).

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Utermann, J., Düwel, O. and Nagel, I. (2003). Trace Element and Organic Matter Contents of European Soils: Final Report - Results of the ‘Short Term Action. Unpublished Report by Federal Institute for Geosciences and Natural Resources (BGR), Hannover to the European Commission, Joint Research Centre, Ispra, 40pp.

Vegter , J., Huber, S. and Gentile, A.R. (2004). Strategic overview and status of contamination. In: Van-Camp. L., Bujarrabal, B., Gentile, A.-R., Jones, R. J. A., Montanarella, L., Olazabal, C. and Selvaradjou, S.-K. (Editors). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. EUR 21319 EN/4. Office for Official Publications of the European Communities, Luxembourg.

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1.8 CO07 Critical load exceedance by sulphur and nitrogen

Key issue: Diffuse contamination by nutrients and biocides
DPSIR classification: Pressure

Main information: The indicator targets the question whether we are protecting the environment effectively against acidification and what progress is being made towards the targets for reducing the exposure of soils to acidification. There have been clear reductions in acidification of Europe's environment since 1980, but with some tailing off in that improvement after 2000.

1.8.1 Example

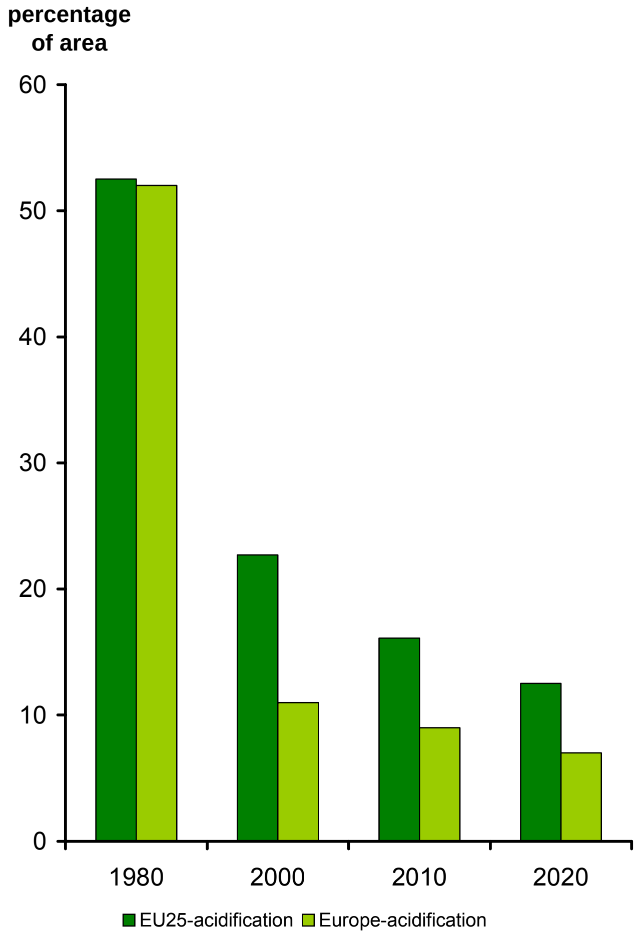

Figure 1.8.1 EU-25 and European-wide ecosystem damage area (average accumulated exceedance of critical loads), 1980-2020

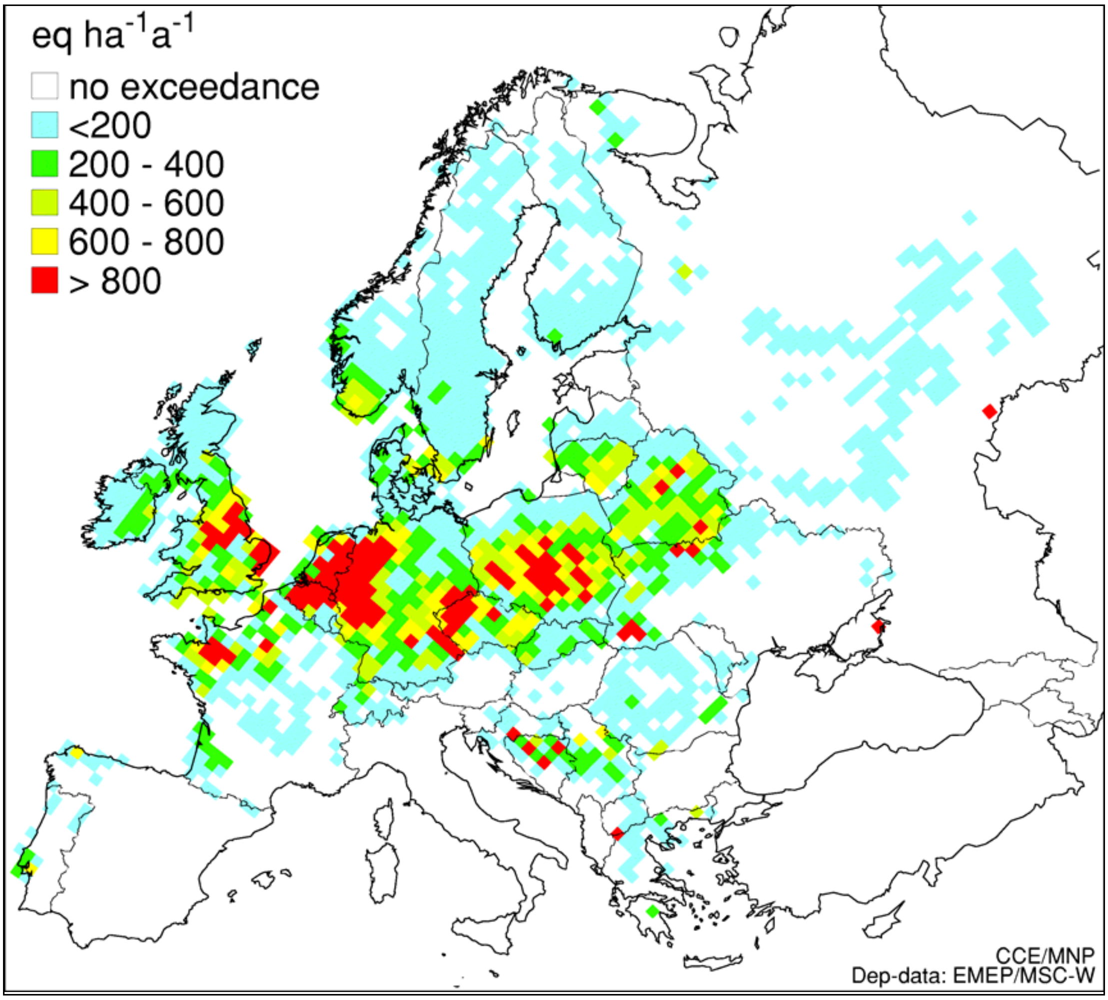

Figure 1.8.2 Exceedance of the critical loads for acidity in Europe (as average accumulated exceedances, 2000, Ver.1.00)

Source:http://themes.eea.europa.eu/IMS/IMS/ISpecs/ISpecification20041007131526/IAssessment1116513959574/view_content

1.8.1.1 Significance

There have been substantial reductions in areas subjected to deposition of excess acidity since 1980 (Figure 1.8.1). The map (Figure 1.8.2) shows the spatial distribution over Europe of acidification.

1.8.1.2 Policy context

The indicator is part of the EEA CSI Indicator 'Exposure of ecosystems to acidification, eutrophication and ozone', which itself is seen as relevant information for the Clean Air for Europe (CAFE) programme. Especially in the context of soil deterioration due to acidifying substances it provides relevant information in the field of diffuse contamination. Targets are set in the National Emission Ceiling Directive (2001/81/EC), e.g. for acidification: reduction in areas exceeding critical loads for acidification by 50% (in each 150 km resolution grid square) between 1990 and 2010.

1.8.1.3 Scientific background

Critical loads for acidification should be calculated according to the Mapping Manual of the UNECE-ICP Modelling and Mapping. The exceedance is the difference between the critical loads and the actual loads of acid depositions (SOx, NOx, NHx).

1.8.1.4 Assessment of result example

There have been substantial reductions in areas subjected to deposition of excess acidity since 1980 (Figure 1.8.1). However, current data makes it difficult to assess the quantitative improvements since 1990 (these being the standards established in the National Emissions Ceilings Directive, NECD, 2001/81/EC) as acidification status in this base year (1990) remains to be estimated using the latest critical loads and deposition calculation.

By 2000, all Member States, except for six, had less than 50% of their ecosystem areas in exceedance of acidity critical loads. Further substantial progress is anticipated for virtually all countries in the period 2000-2010. The current status in the countries of the EU-27 remains poorer than across the broader European continent.

Evaluation of the progress in achieving the NECD 50% reduction in acidification target is hampered by the changes in critical load assessments completed by countries themselves since the Directive was negotiated. Difficulties in managing 'double counting' (areas containing critical loads for more than one ecosystem type) exist for some countries.

1.8.2 Meta data

1.8.2.1 Technical information

Since the indicator is part of the Core Set of Indicators by the EEA, see: http://themes.eea.europa.eu/IMS/CSI for details.

i) **Data sources:** National authorities

ii) **Description of data:** Biomass uptake by plants, parent material, critical leaching, actual deposition of nitrogen, sulphur and base cations emission data (sulphur and nitrogen), meteorological data

iii) **Geographical coverage:** EU 27

iv) **Spatial resolution:** 50 km x 50 km EMEP grid

v) **Temporal coverage:** 1991 up to 2005 (every 2 years)

vi) **Methodology and frequency of data collection:** Critical load data is reported biannually by national authorities to UNECE/EMEP and to EU.

vii) **Methodology of indicator calculation:** Reported data includes both newest estimates (two years in arrears) and updates of emissions from previous years. Emission data are stored and verified at EMEP/MSC-W. Using these emissions, EMEP/MSC-W calculates atmospheric transport of sulphur and nitrogen pollutants using the EMEP Unified Model at a spatial resolution of 50 km and according to modelled meteorological conditions adjusted towards observations. The Co-ordination Centre for Effects uses the resulting deposition estimates to calculate exceedances over reported critical loads for acidity and nutrient nitrogen. In 2004, the CCE updated this database with national updates of critical loads. These updated estimates have been used for the calculations for 1980, 2000, 2010, and 2020. Nitrogen and sulphur deposition in each model grid-cell are used for calculation of the average accumulated exceedances of the critical loads that is the area-weighted average of exceedances accumulated over all ecosystem points in an EMEP grid cell. The total area of ecosystems exposed to exceedances in a country is expressed as a percentage of the total country area. These areas are summed to provide two estimates, one for the EU 27, and for one for a larger region comprising most countries party to the Convention on Long-range Transboundary Air Pollution.
(Source: http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007131526/guide_summary_plus_public)

viii) **Availability of baselines and thresholds**: Baseline to be defined (e.g. the first available maps of critical loads exceedances), the threshold is the critical load itself.

1.8.2.2 Quality information

i) **Strength and weakness:**
The indicator is one of 37 already existing indicators reported regularly by the EEA in the frame of the CSI.

ii) **Data comparability:**
Comparability over time: good (depending on existence of methodological changes) *Comparability over space:* medium (different application approaches of the mapping manual by national authorities)

1.8.3 Further work required

More accurate data would improve the results, and better adjustment of data and methodologies are needed.

1.8.4 References

A detailed list of references is given by EEA:
http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007131526/guide_summary_plus_public

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1.9 CO08 Progress in the management of contaminated sites

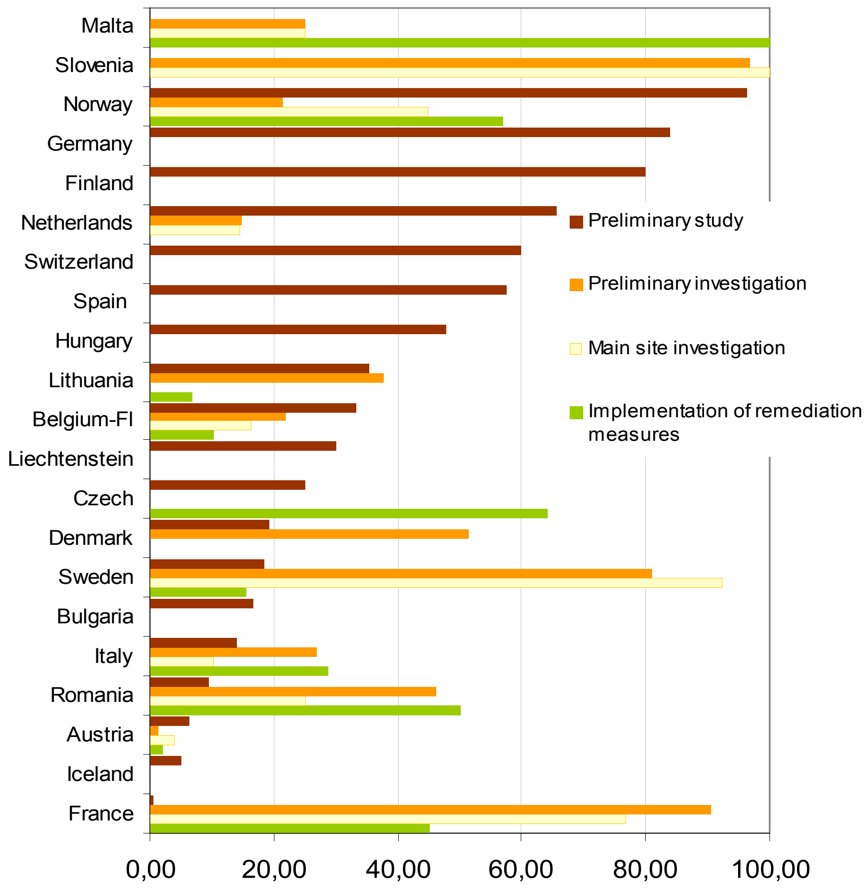
Key issue: Local soil contamination by point sources
DPSIR classification: Pressure

Main information: Local soil contamination is a characteristic of regions where intensive industrial activities, inadequate waste disposal, mining, military activities or accidents pose a threat to soil. 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 water pollution, direct contact by humans with polluted soil, uptake of contaminants by plants and explosion of landfill gasses EEA (1999).

Management of contaminated sites is a tiered process starting with a preliminary survey (searching for sites that are likely to be contaminated), followed by performing site investigations where the actual extent of contamination and its environmental impacts are defined, and finally implementing remedial and after care measures.

The indicator shows the progress within defined management steps in the EU Member States. The indicator is also a defined EEA core set indicator.

1.9.1 Example



Unit: Percentage of the estimated total number of sites per management step

Figure 1.9.1 Progress in the management of contaminated sites for selected European countries: Degree of completeness of management steps compared to estimated number of sites to be processed at each management step.

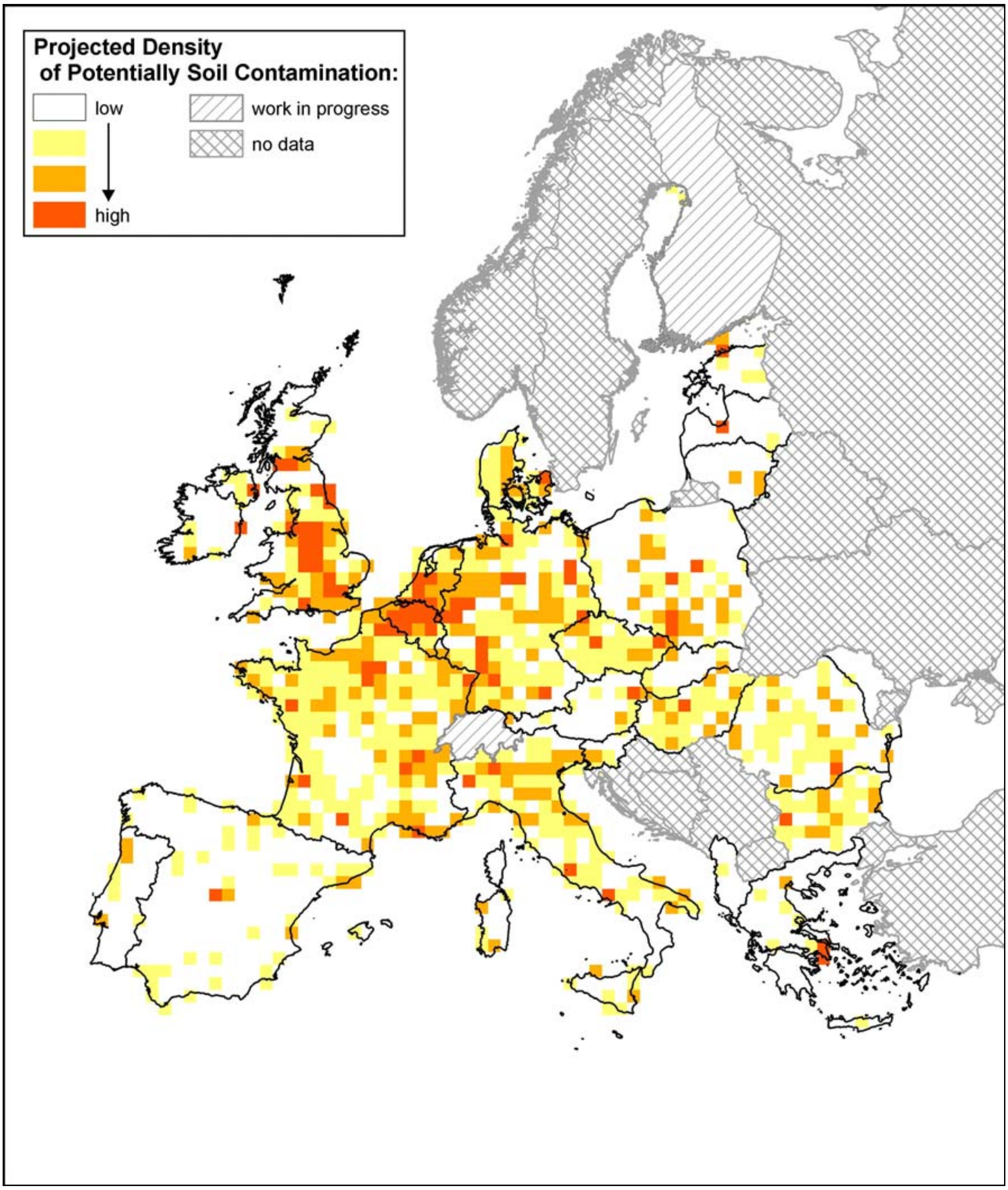
Table 1.9.1 Available data related to Figure 1.9.1

Abbreviations: pr.inv. = preliminary investigation; m.s.i. = main site investigation; r.a. = remediation measures

Processing step 2002	Preliminary study			Preliminary investigation			Main site investigation			Implementation of remediation measures			Measures completed
Country	***estimated total number***	***identified***	*% identified*	***estimated total number***	***completed***	*% identified pr. Inv.*	***estimated total number***	***completed***	*% identified m.s.i.*	***estimated total number***	***under progress***	*% identified r.a.*	
France	900.000	3.619	0,40	3.619	3.276	90,52	1.482	1.139	76,86	3.276	1.482	45,24	1.794
Iceland	100	5	5,00		3			3		3		-	3
Austria	30.000	1.870	6,23	20.000	255	1,28	2.500	98	3,92	2.500	56	2,24	70
Romania	40.000	3.833	9,58	1.855	855	46,09	200	50	25,00	100	50	50,00	50
Italy	100.000	14.017	14,02	9.812	2.643	26,94	5.888	609	10,34	2.944	847	28,77	1.214
Bulgaria	6.812	1.138	16,71	58	n.a.	-	n.a.	n.a.	-	n.a.	n.a.	-	n.a.
Sweden	38.000	7.000	18,42	2.100	1.700	80,95	1.300	1.200	92,31	900	140	15,56	500
Denmark	30.000	5.810	19,37	14.000	7.213	51,52							6.794
Czech	4.978	1.253	25,17		159			13		500	321	64,20	87
Liechtenstein	*100*	*30*	30,00										
Belgium-Fl	76.200	25.344	33,26	76.200	16.688	21,90	23.000	3.752	16,31	10.750	1.109	10,32	135
Lithuania	15.000	5.319	35,46	1.646	619	37,61	n.a.	73	-	73	5	6,85	62
Hungary	30.000	14.334	47,78					230			112		
Spain	26.440	15.228	57,59	2.111		-		103			9		212
Switzerland	50.000	30.000	60,00	12.500			3.000			3.000			100
Netherlands	350.000	240.000	68,57	186.000	27.400	14,73	82.000	11.900	14,51	70.000	n.a.		9.300
Finland	25.000	20.000	80,00								400-500		2.000
Germany	362.000	304.091	84,00	n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.
Norway	4.000	3.848	96,20	559	120	21,47	568	255	44,89	268	153	57,09	504
Slovenia	2.692			262	254	96,95	119	119	100,00				
Malta	300			4	1	25,00	4	1	25,00	1	1	100,00	
Estonia	n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.
Greece	n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.
Ireland													
Latvia		255											
Luxembourg													
Poland													
UK	n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.

1.9.1.1 Significance

Emissions from local sources have impacts on the quality of soil and water, particularly groundwater. Management of contaminated sites aims at assessing adverse effects caused by localised sources, and at taking measures in fulfilling/re-establishing environmental standards according to the existing legal requirements.



source: EEA Corine Landcover (industrially used land) and ESRI data (urbanised areas). Source: Schamann *et al*. (2003)

Figure 1.9.2 Areas with high expectation for local contamination; unit: area of urban and industrial areas per pixel ($m^2\ km^{-2}$); pixel size: 50 km x 50 km

1.9.1.2 Policy context

At the European scale, remediation and prevention of soil contamination will be addressed by the forthcoming Soil Thematic Strategy (European Commission, 2006a,b). Existing EU legislation addresses the protection of water and sets standards for water quality, whereas no legal standards for soil quality exist. Nevertheless, specific standards for soil quality and policy targets have been put in place in several EEA member countries. In general legislation aims at preventing new contamination and sets targets for the remediation of sites where environmental standards have already been exceeded.

1.9.1.3 Scientific background

The proposed indicator is the result of 10 years of research and expert consultation carried out by the European Environment Agency. The work started with a general survey on the state of contaminated sites management in the EU and EFTA countries (Prokop *et al.,* 2000), and continued with several pilot studies and workshops with EEA Member State representatives, where a common agreement on an achievable procedure was developed (Prokop, 2002). One of several outputs was the production of a map showing European regions with a high potential for local soil contamination based on a model (see Figure 1.9.2).

One of the key conclusions of this process was the agreement that harmonisation of existing national registers on contaminated sites could not be achieved in the short-term. As a result, a common agreement was adopted to describe individual management steps and to measure the progress of these management steps against national targets.

1.9.1.4 Assessment of results

Management of contaminated sites is a tiered process. An improved description of the main steps of contaminated sites management is provided in Table 1.9.3. Remediation (final step) involves much greater financial and time resources than site investigations (first step). Detailed information on site identification is available, whereas only scarce data are available concerning further steps of the management process such as remediation measures. Although there are few data available on remediation, it can be assumed that to date the main progress is still made with the preliminary management steps focusing on site investigations. Progress in management of contaminated sites varies considerably from country to country.

A high proportion of remediated sites in the new EEA member countries, compared to estimated remediation needs, could imply a far advanced management process. However, in these countries surveys are also incomplete, which may lead to an underestimation of the problem. The numbers of sites treated at each management step in each country cannot be compared directly, because of different legal requirements, different degrees of industrialisation and different hydro-geological conditions and approaches,.

After comparison between the data requests of 2002 and 2000, a better definition of the processing steps was introduced. As a consequence of the comprehensible and clearer classification system, some countries have revised their initially estimated numbers, resulting in more comparable data. However, several countries have adjusted their estimated numbers per processing step according to the new definition and for example reduced the numbers. Consequently, the reported years cannot be compared with each other in those countries. There is a trend in increasing the number of expected sites for all management steps compared to earlier estimations. Two countries (Netherlands and Belgium/Flanders) expect a considerably smaller percentage of sites to be remediated compared to the total number of potentially contaminated sites identified.

1.9.2 Meta data

1.9.2.1 Technical information

i) **Data sources:**
The main source is the EIONET data flow. The following surveys were performed in recent years:
EEA/EIONET 2005/2006 for information of 2004.
EEA/EIONET September 2003 for information of 2002.
Data from 2000 refer to the Pilot EIONET data flow, updated January 2002.
Data of new EEA member countries from 2000 was obtained from EEA-ETC/TE Data request February 2002. Regional data was obtained from a pilot regional data collection (Autumn 1999).
Data of 2000 has been used for the preparation of the EEA UNEP report 'Down to earth: soil degradation and sustainable development in Europe'. EEA and UNEP (2000).
Regional data was published in the Second Workshop on contaminated sites (Prokop, 2002).

ii) **Description of data:** Data refer to completion of defined management steps at contaminated or potentially contaminated sites. The definitions in Table 1.9 have to be considered.

iii) **Geographical coverage:** EU 27; data currently not available from all Member States

iv) **Spatial resolution:** Currently aggregated national data; aggregation to regions or provinces is preferable.

v) **Temporal coverage:** This indicator was first monitored in 1998 in selected European regions. Regular data updates are carried out on an annual basis. EEA performed data updates in 2000, 2002, 2003, and 2005.

vi) **Methodology and frequency of data collection:** The methodology is based on measuring the progress of defined management steps. Annual data updates are recommended

vii) **Methodology of indicator calculation:** For the calculation of the indicator the following input data are necessary:
Number of sites with management step X completed (in a defined region)
Estimated total number of sites in need of management step X

viii) **Availability of baselines and thresholds:**
For this indicator a threshold can only be defined in the sense of a political agreement. At a European level no targets have been established yet. National targets exist in most EEA countries (see Table 1.9).

Table 1.9.2 CO08 Definitions

Term	Definition
Contaminated site	A well-delimited area where the presence of soil contamination has been confirmed and the severity of possible impacts to ecosystems and human health are such that remediation is needed, specifically in relation to the current or planned use of the site. The remediation or clean-up of contaminated sites can result in a full elimination or in a reduction of these impacts
Potentially contaminated site	Includes any site where soil contamination is suspected but not verified and investigations need to be carried out to verify whether relevant impacts exist.

Table 1.9.3 Definition of managements steps for the management of contaminated sites

Tier no./title	Description
Tier 1: Site identification/ Preliminary Study	Investigation carried out by reference to historical records and other sources which provide information on the past and present usage of the site. It also includes available information about local soil properties and hydrology and may include a site reconnaissance. From this investigation the possibility of contamination can be deduced, and hypotheses can be formulated on the nature, location, and distribution of the contamination. The preliminary study may provide sufficient information for an assessment of the site to be made, to determine whether there is a need for further action. It is likely that it will be necessary to carry out at least a limited investigation of the site (preliminary site investigation) to test the validity of the hypotheses formulated in the preliminary study. On the basis of available information the preliminary survey has the goal of assessing whether potentially polluting activities have taken place and whether contamination can be suspected. The aim is to determine the type and location of polluting substances and consists of the following steps: examine the relevant history and information, formulate hypothesis on spatial distribution, possible extent and type of contamination, - conclusions with regard to further investigation
Tier 2: Preliminary investigation	Preliminary investigations are carried out to confirm the existence of contamination. In most cases the results of the preliminary investigation form the basis to definitely classify sites as contaminated. The preliminary site investigation follows on from the preliminary study and is carried out principally to verify the presence of contaminated soil, including the identification of polluting substances, their distribution, their concentration levels and the location of such substances in the environmental media (soil, water, air). This involves on-site investigation which includes collecting samples of ground, surface water, groundwater, and soil gas, where appropriate, which are then analysed. The data and information produced are then assessed to determine if the hypotheses from the preliminary study are correct. It may become apparent as a result of the preliminary site investigation, for example, that the contamination pattern is more complex or concentrations of contamination are greater than anticipated. In this situation the information achieved may be inadequate to make decisions with a satisfactory degree of confidence, and it will be necessary to carry out a main site investigation to produce sufficient information. The preliminary site investigation will incorporate the following main stages: Design an investigation strategy to test the hypotheses formulated in the preliminary study, and which takes into account the findings of that study (for example hazards to investigators and the environment); Carry out the site investigation and associated analysis of samples; Determine the validity of the hypotheses; Determine the requirements for further investigation.
Tier 3: Main site investigation	The main site investigation is carried out provided that the contamination has been confirmed. According to the national guidelines for site identification and investigation the goal of the main investigation is to determine the need for remediation or other measures to eliminate or reduce the exposure to the contamination. Major goals are - to define the extent of the contaminated area and the degree of contamination – to assess the risks of the involved hazards. This will involve the collection and analysis of soil, surface water, groundwater, and soil gas samples in order to obtain all the information necessary for the assessment of human and environmental risks. The detail required will depend upon the objectives of the investigation. The requirement for further information and data is to enable a full assessment of the risks presented by the contamination and also to enable any containment or remediation actions to be properly designed with more accurate quantification of the costs.

	This will require a more detailed investigation which should be carefully designed, taking into account the information developed in the earlier stages of investigation, and the objectives. A main site investigation should never be carried out as the first investigation, since knowledge of the site is required in order to design the investigation to achieve the maximum benefit and maximum information. The main site investigation should be preceded by a preliminary study and a preliminary site investigation. As a result there should be a considerable amount of information available when the main site investigation is designed: a good indication of the contaminants present; an indication of the extent of the contaminated area(s) (in three dimensions); an indication of the distribution of the contamination (homogeneous or heterogeneous); a knowledge of the soil composition and geology of the site; a knowledge of the hydrology and hydrogeology (local or at least regional).
Tier 4: Implementation of remediation measures	Risk reduction measures as elaborated in course of the main site investigation step are under progress (remediation including safety measures, restrictions, etc.; not included: monitoring, monitored natural attenuation).
Tier 5: Measures completed	(Land-use) restrictions or remediation and/or safety measures to reach different quality targets are realised. Monitoring of environmental media has proven that agreed remediation-targets have been met.

Table 1.9.4 National target for the management of contaminated sites according to EIONET priority data flow 2003.

Country	Year	Policy target or technical target.
Austria	2030-2040	Essential part of the contaminated sites problem should be managed .
Belgium (Flanders)	2006 2021 2036	Remediation of the most urgent historical contamination. New contamination to be remediated immediately. Remediation of urgent historical contamination. Remediation of other historical contamination causing risk.
Bulgaria	2003-2009	Plan for implementation of Directive 1999/31/EC on Landfill of waste.
Czech Republic	2010	Eliminate the majority of old ecological damage.
France	2005	Establish information system on polluted soil (BASIAS) to provide a complete scope of the sites where soil pollution could be suspected.
Hungary	2050	Handling of all sites. Government Decision No. 2205/1996 (VIII.24.) adopted National Environmental Remediation Programme (OKKP).
Lithuania	2009	Waste disposal to all landfills not fulfilling special requirements should be stopped. All waste landfills not fulfilling special requirements should be closed according to approved regulations.
Malta	2004	Closure of Maghtab and il-Qortin waste disposal sites.
Netherlands	2030	All historical contaminated sites investigated and under control and remediated when necessary.
Norway	2005	Environmental problems on sites with contaminated soil, where investigation and remediation is needed, shall be solved. On sites where further investigation is needed, the environmental state shall be clarified.
Sweden	2020	Environmental quality objective: a non-toxic environment.
Switzerland	2025	The ‘dirty’ heritage of the past should be dealt with in a sustainable way within one generation.
UK (England and Wales)	2007	The Environment Agency aims to substantially remediate and/or investigate 80 Special Sites identified under Part IIA Regime (Environmental Protection Act 1990).

1.9.2.2 Quality information

i) **Strength and weakness:**
Good availability of data at the national scale where contaminated sites management is centralised. Better definition of indicator and clear definition of management steps were introduced which leads to better comparability. Different and inconsistent definitions exist regarding site management steps in the various countries, as well as different stages of progress and priorities.

ii) **Data comparability:**
The information provided by this indicator has to be interpreted and presented with caution, due to uncertainties in methodology and problems of data comparability. There are no common definitions of a 'contaminated site' across Europe, which creates problems when comparing national data to produce European assessments. For this reason, the indicator focuses on the impacts of the contamination and progress in management, rather than on the extent of the problem (e.g. number of contaminated sites). Comparability of national data is expected to improve in the future, as the EU common definitions are introduced in the context of the STS.

In reporting the progress against a national baseline some countries may change their estimates in successive years. This may depend on the status of completion of national inventories (e.g. at the beginning of registration not all sites are included, but after a more accurate screening the number of sites may increase dramatically; the reverse has also been observed due to changes in national legislation).

Not sufficiently clear methodology and data specifications may have induced countries to interpret data requests in different ways and, therefore, provide information which may not be fully comparable. This is expected to improve in the future, as better specifications and documentation of the methodology is provided.

Most of the data integrate information from the whole country. However, the process differs from country to country depending on the degree of decentralisation. In general, data quality and representativeness increase with the centralisation of the information (national registers).

With regard to monitoring the extent of local soil contamination, EEA performed various exercises in pilot areas. One key approach included the categorisation of contaminated sites according to impact levels (i.e. impact level 1 = minor impacts to environment, 3 = significant impacts to environment). This approach would allow better defining of the status of local soil contamination in Europe. However, a common acceptance of this approach cannot be achieved in the short-term. Impact levels were presented and published by Prokop (2002), Prokop. *et al*. (2000a,b), and Schamann. *et al*. (2003).

1.9.3 Further work required

- Guidance for the definition of national policy targets
- Increase acceptance of terminology
- Introduction of 'impact levels' see above: ii Data comparability.

1.9.4 References

The proposed indicator is part of the EEA core set indicator CSI015, more details can be found at the EEA website, at the following internet address:
http://themes.eea.europa.eu/IMS/IMS/ISpecs/ISpecification20041007131746/IAssessment1116497286336/view_content [last accessed 06/04/2007]

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1.10 SE01 Sealed area

Two different presentation formats:
- Area size of sealed surface area
- Growth rate of sealed surface area

Key issue: Soil sealing
DPSIR classification: Pressure

Main information: Sealed area is the most direct and a largely self-explaining indicator for the process of soil sealing. While the absolute area size of sealed surface area provides information on the state of soil sealing, the growth rate results from time series comparison and indicates the change or trend of sealing. In particular when compared to the extent and growth rate of entire land consumption, the share of sealed area in the land totally consumed provides indications of the intensity of land use and soil consumption in built-up areas. The indicator is highly representative and meaningful to the key issue under consideration and easy to calculate, to interpret, to comprehend and to communicate. As databases based on national cadastral maps (land use registers) can be expected to be existent in most countries, no additional costs for data gathering should arise.

1.10.1 Example

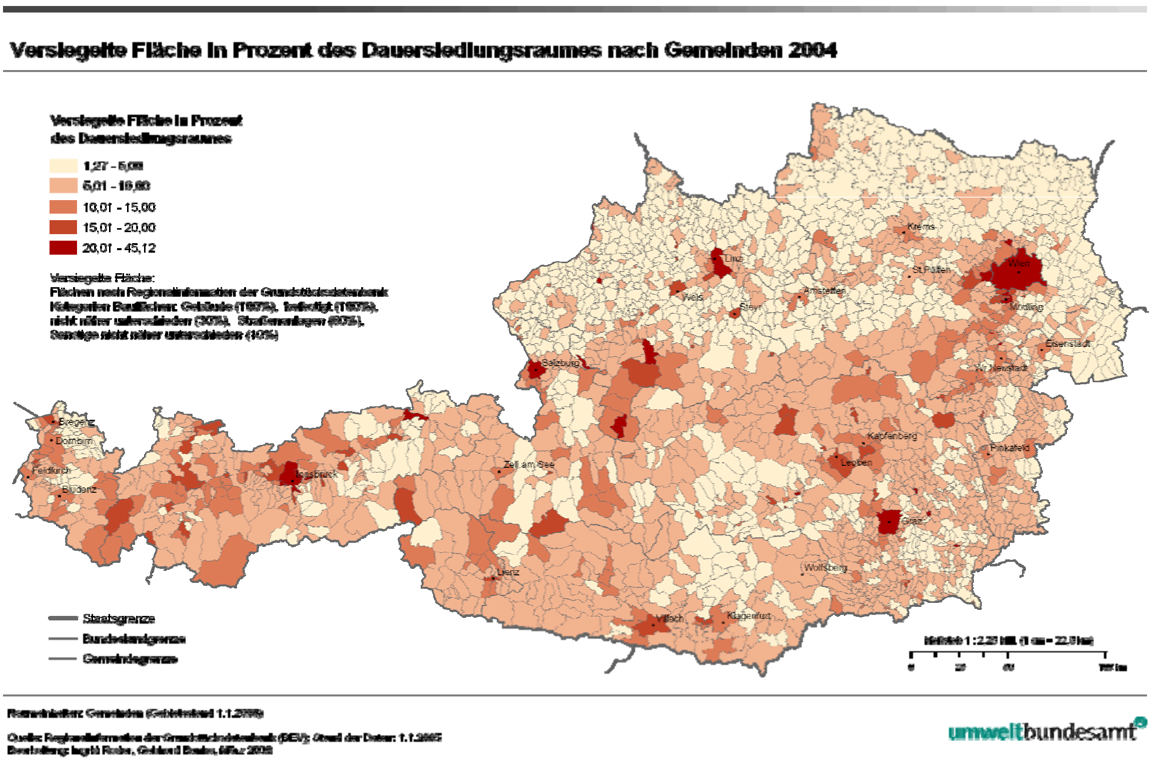

Figure 1.10.1 Sealed area in percent of potentially settleable area in the municipalities of Austria 2004

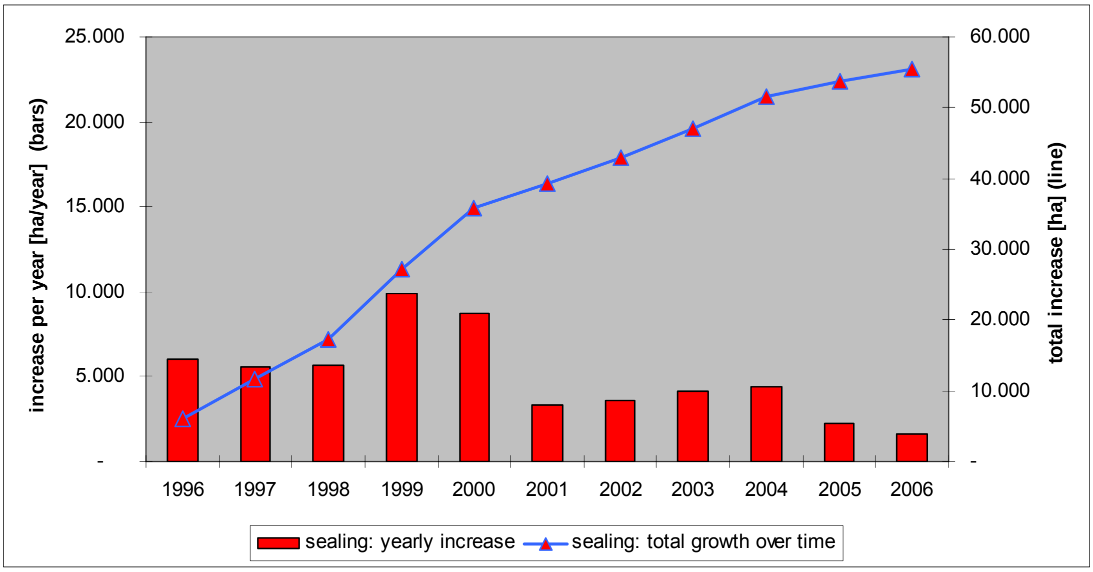

Figure 1.10.2 Growth of sealed areas in Austria from 1996 to 2006 (per year and total)

1.10.1.1 Significance

Sealing is one of the key soil threats mentioned in the upcoming soil thematic strategy, and reduction of newly sealed area is a political target in several national sustainability strategies.

1.10.1.2 Policy context

In some Member States, political target values for reduction of sealing rates either already exist (e. g., Austria) or have been recommended by expert institutions (e. g., Germany). Although direct country-to-country data comparability in terms of absolute area size of sealed area may be limited due to different categories used in national databases, yet comparison of growth rates between Member States is possible and useful and provides good comparative information on trends in different Member States. Efforts to assess soil sealing on a homogenous European level have already been carried out. However, due to inconsistencies of underlying categories in national databases no final conclusions could be drawn, yet. On the other hand, as the indicator relies on national cadastral map-based databases, this makes it appropriate to provide useful, significant and reasonably accurate information on national, regional or even local scales.

1.10.1.3 Scientific background

Soil sealing - defined as the destruction or covering of soil by buildings, constructions and layers or other bodies of completely or partly impermeable artificial material (asphalt, concrete, etc.) (Burghardt et al., 2004) - is the most intense form of land consumption and a main cause of human-induced soil loss. Being a part of the broader process of land consumption, it is the most visual and most direct form of human appropriation of land and constitutes the most extreme form of land use change. Sealing threatens sustainable development because it is to a large extent an irreversible process that causes an increasing shortage of land resources that are available for future generations as well as for purposes other than land development. Within the overarching process of land consumption, sealing is the one sub-process affecting ecological functioning of soils in the strongest and most negative way. By disrupting the contact between the pedosphere and other ecological compartments (biosphere, hydrosphere, atmosphere), sealing of the soil surface causes various impacts on the water budget (such as inhibition of water infiltration and groundwater renewal, increase of surface water runoff, increase of flood risks, reduction of evapo-transpiration), on element cycles and mass- and energy flows, on the micro- and meso-climate, on soil structure (compaction, etc.), and on biodiversity of soils (reduced soil respiration, decline of number, abundance and diversity of biotic communities, etc.). It also causes extremely negative impacts on aboveground ecosystems, e. g. by reducing net primary production to zero. As a subset of the entire land consumed by development of settlements, infrastructure, trade estates and industrial areas, the share of sealed area in the total built-up land indicates the intensity of land consumption. Therefore, sealing is a key threat to soils, and size and growth rate of sealed surface area are highly significant and representative indicators that relate directly to this soil threat.

1.10.1.4 Assessment of results

Linking soil sealing to the available soil resources gives a far more adequate representation of reality than just absolute sealing numbers as such. As urban agglomeration will always show high absolute numbers of soil sealing, the sealed area in relation to the available area (for settlement, agriculture, etc.) also shows that besides the urban agglomeration zones also rural communities are already in a critical status regarding the consumption of soil by sealing. These areas constitute often communities with high touristic impact, due to the large amount of touristic infrastructure needed in mostly quite narrow alpine valleys. Examples therefore are the Salzkammergut region, famous for summer tourism and the alpine valleys of Tyrol- with largely winter tourism.

With regard to the temporal development the data are not quite straight forward to interpret. Due to changes in nomenclature and methodology no consistent trend over time can be drawn. However, what can be seen out from the data above is the fact that soil sealing is still an unsolved problem in Austria, reaching a yearly increase in sealed area of more than 1,500 ha. Although currently this value is one of the lowest measured within the last decade, it is still much too high for a sustainable development.

1.10.2 Meta data

1.10.2.1 Technical information

i) **Data sources**: Currently national cadastral systems (Example: Austrian database from Bundesamt für Eich- und Vermessungswesen); Differentiation of the following land use classes linked to sealing: settlements (building – 100% sealed; sealed surface – 100% sealed), Traffic (roads – 60% sealed)

ii) **Description of data**: For example Austria data origins from aerial photo interpretation combined with field surveys for surveying reasons and land registry. Land use aspects are of secondary priority, while the main focus is still lain on registration of parcel borders. Land use layers are a complementary product of official land registry and are used to identify building borders within a parcel. The parcel based data is aggregated for statistical purposes on community level confirming the regional information (Regionalinformation), which is updated on a yearly basis.

iii) **Geographical coverage**: For example Austria complete country

iv) **Spatial resolution**: Example Austria: sub-parcel level (identification of single buildings within parcels)

v) **Temporal coverage**: For example Austria 5-7 years regularly plus ad-hoc changes on request and based on regular surveying updates

vi) **Methodology and frequency of data collection:** For example Austria see point 2

vii) **Methodology of indicator calculation**: The statistical regional information of the land registry is used for the indicator calculation. The class sealed area is aggregated from the sub-classes mentioned under point 1 (settlements and traffic-subclasses). Using one time periode the presentation form 1 of the indicator “area size of sealed surface area” can be expressed as absolute number or in percentage of reference area (mostly community area or regular square grid e.g. 1*1 km^2). Using two periods in time the second presentation form of the indicator – the “growth rate of sealed surface area” can be calculated as percentage of increase of initial value or again as absolute increase in hectare. However it is recommended to relate the presentation form 1 (“area size of sealed surface area” to the available surface area within the reference area). The available surface area in Austria is often referred to as the potentially permanent living area (calculated as sum of total area minus alpine areas, water surfaces and forest).

viii) Availability of baselines and thresholds:

Table 1.10.1 Examples of baselines for SE01

Country (reference year)	Baseline description
Austria: Baseline (2005):	area size: 181,800 ha or 45% of consumed land growth rate 2001-2005: approx. 9,8 ha/day
Germany (2003)	approx. 50% of settlement area are sealed Expert recommendation for political target value for Germany (UBA Berlin, 2003): in the long term net growth rate (balance of sealing and de-sealing) shall be reduced to zero.
Norway: Baseline (2005):	Area size of consumed agricultural land at national level: 2,000 ha per year. Political target: as only 3% of the national area is agricultural land the consumption of valuable soil qualities should yearly be reduced by 50 % in 2010.

1.10.2.2 Quality information

i) **Strength and weakness**:
Availability: Data for Austria is available for 1,200.- €/year (app. €15 per 1,000 km2). Reliability: medium. Accuracy is medium as the calculation of soil sealing degrees is especially affected by database inconsistencies and assumptions. Uncertainty is regarded as high, because no empirical knowledge is available to which extent the current database reflects the Austrian wide situation. The data represent the complete territory in a relatively large time window. Therefore the uncertainty in smaller regions is often quite high compared to the actual real situation of sealing.

ii) **Data comparability:**
Comparability over time: Temporal changes in land use classes and nomenclature especially during 1990-2000 makes it impossible to expand the time periods beyond 2000. From 2001 on nomenclature has been kept constant. Changes in nomenclature are however expected to occur from 2007 onwards again (reduction of classes, simplification). *Comparability over space:* Data not comparable between different countries based on varying nomenclature and land use/land cover definitions.

1.10.3 Further work required

As soil sealing has received attention also outside the soil community, solutions for an improvement of monitoring data are in sight. Under the joint programme GMES (Global Monitoring for Environment and Security of EC and ESA (European Space Agency) a European wide soil sealing layer with a resolution of 1 ha will be available by early 2008. The current CORINE Land Cover programme is enhanced by this high resolution layer. The sealing product will provide identification of all built-up area larger than 1 ha in Europe and a discrimination of sealing percentages (1-100 percent in 10% steps) within urban areas. The work will be carried out in 2006-2007 under a joint mechanism coordinated by the European Environment Agency.

1.10.4 References

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1.11 SE04 Land take (CLC)

Key issue: Land consumption
DPSIR classification: Pressure

Main information: Land take by the expansion of urban and other artificial land developments is the main cause of the increase of soil loss due to human activities. The indicator quantifies how much, in what proportions and at what growth rate soil is lost by converting agricultural, forest, semi-natural and natural land to urban and other artificial land covers. Cross-country comparison of assessment results shows to what extent individual Member States contribute to land take in Europe. It also provides information on the drivers of land take, because it allows analysis of land cover flows.

1.11.1 Example

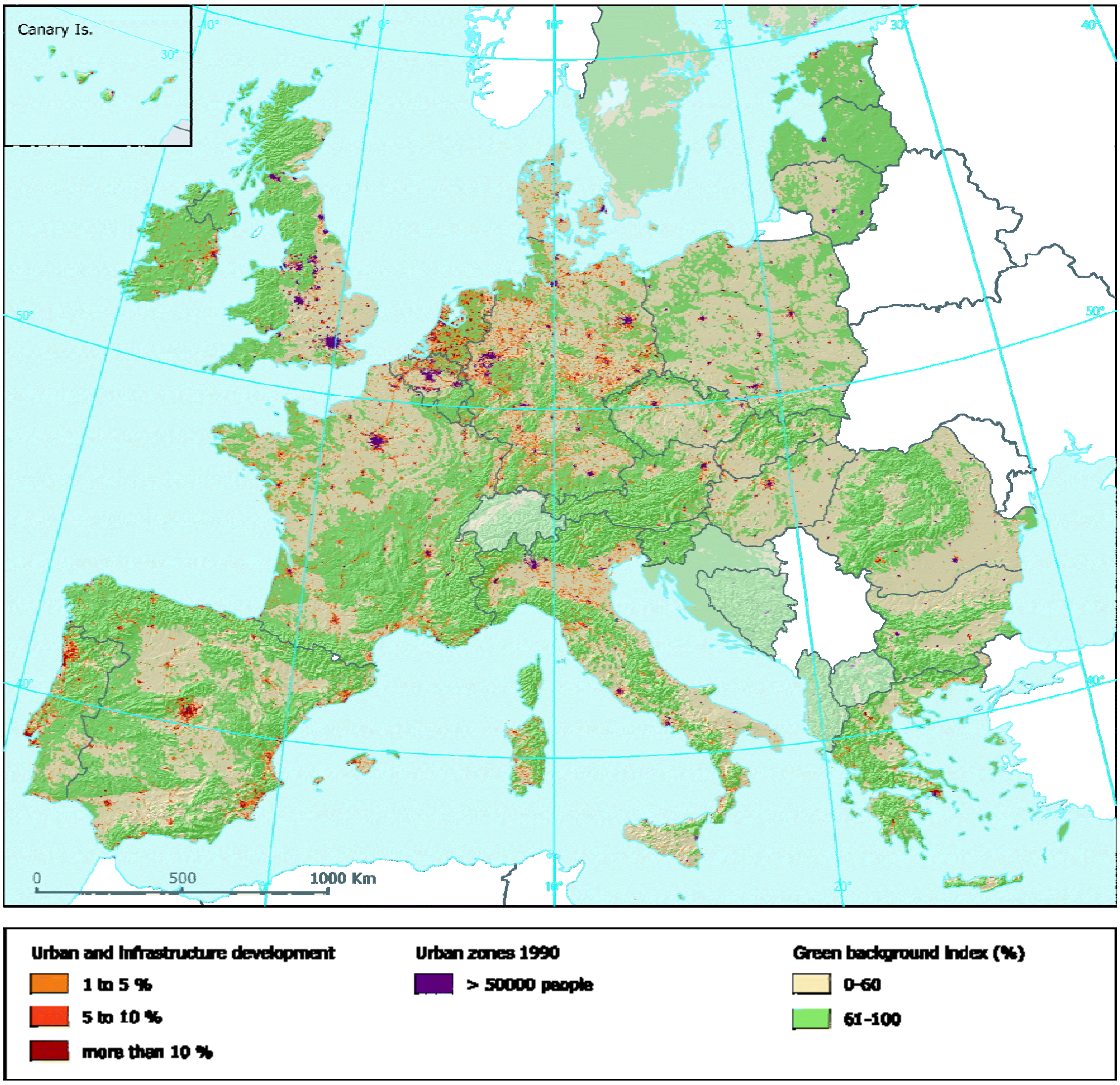

Figure 1.11.1 Sprawl of urban and other artificial land development, 1990-2000 (SE04 a)

Source: EEA, 2005; Corilis, 2005; LEAC, 2005.

Table 1.11-1 Land uptake by human activities and overall land take for EU23 (2005). Values are averaged over a 10 year period.

Land cover flows	Observed change	% of Total artificial land cover uptake	mean annual change	% of country urban land 1990	mean annual change as % of total Europe urban land uptake	Country area hectares	mean annual change as % of country surface	overall land cover change %	overall mean annual land cover change %	mean annual change as % of overall annual change
	(ha)	(%)	(ha)	(%)	(%)	(ha)	(%)	(%)	(%)	(%)
Land take by housing, services and recreation	496,085	52	49,608		100.00		0.015			5.23
Land take by industrial & commercial sites	297,382	31	29,738		100.00		0.009			3.13
Land take by transport networks & infrastructures	30,486	3	3,049		100.00		0.001			0.32
Land take by mines, quarries and waste dumpsites	13,7466	14	13,747		100.00		0.004			1.45
Total artificial land cover take	961,418	100	96,142	6.8	100.00	14,159,133	0.029			10.13
Country surface					439.71	330,720,497		2.87	0.29	

Source (Table 1.11-1 & Table 1.11-2): National statistics from land cover accounts (LEAC/CLC), Hazeu, G., Paramo, F. & Weber, J.-L.; EEA, Copenhagen, 2005.
(http://themes.eea.europa.eu/IMS/IMS/ISpecs/ISpecification20041007131735/IAssessment1116504972257/view_content)

Table 1.11-2 Country Comparison of total artificial land cover uptake (2005)

		Total artificial land cover uptake						
Number of years	Country	Observed change (ha)	mean annual change (ha)	% of country urban land 1990	mean annual change as % of total Europe urban land uptake	Artificial area 1990 (ha)	mean annual change as % of artificial area 1990	mean annual change as % of country overall annual change
15	Austria	11919	795	3.5	1	340528	0.2	31.22
10	Belgium	19961	1996	3.3	2	605517	0.3	33.52
10	Bulgaria	3509	351	0.6	0	541021	0.1	2.89
8	Czech Republic	11324	1416	2.4	1	475426	0.3	2.21
10	Denmark	13485	1348	4.5	1	297631	0.5	23.62
6	Estonia	2432	405	2.8	0	85647	0.5	1.98
10	France	138857	13886	5.4	14	2560094	0.5	12.39
10	Germany	205945	20594	7.6	21	2723207	0.8	23.80
10	Greece	32119	3212	13.5	3	238445	1.3	13.17
8	Hungary	10107	1263	1.9	1	519131	0.2	2.67
10	Ireland	31958	3196	31.2	3	102275	3.1	5.70
10	Italy	83941	8394	6.2	9	1348014	0.6	21.27
5	Latvia	121	24	0.1	0	83747	0.0	0.05
5	Lithuania	716	143	0.3	0	210586	0.1	0.45
11	Luxembourg	1602	146	8.4	0	19124	0.8	39.69
14	the Netherlands	84644	6046	23.0	6	367918	1.6	50.90
8	Poland	19752	2469	1.9	3	1021850	0.2	7.80
14	Portugal	66124	4723	39.1	5	168985	2.8	7.04
8	Romania	8093	1012	0.5	1	1488260	0.1	2.71
8	Slovakia	5331	533	1.9	1	274381	0.2	2.70
5	Slovenia	285	57	0.6	0	49804	0.1	12.97
14	Spain	172718	12337	27.1	13	637542	1.9	7.27
10	United Kingdom	36476	3648	2.0	4	1780684	0.2	10.05
10	Europe23	961418	96142	6.8	100	14159133	0.7	10.13

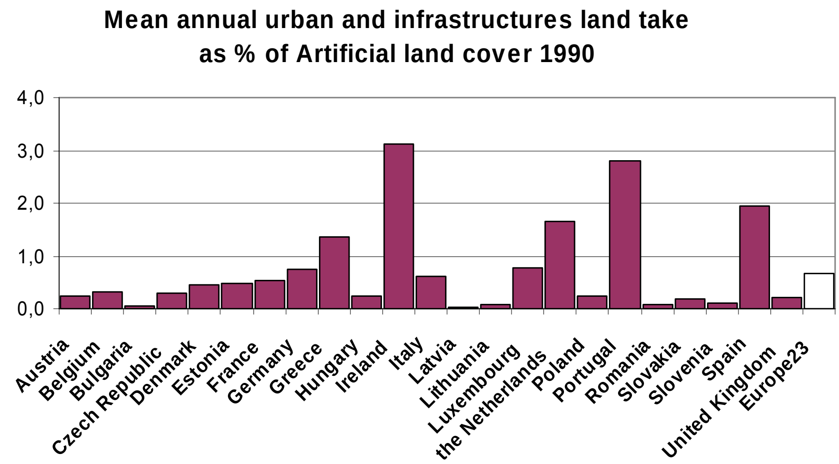

Figure 1.11.2 Example for indicator presentation (SE04 b).

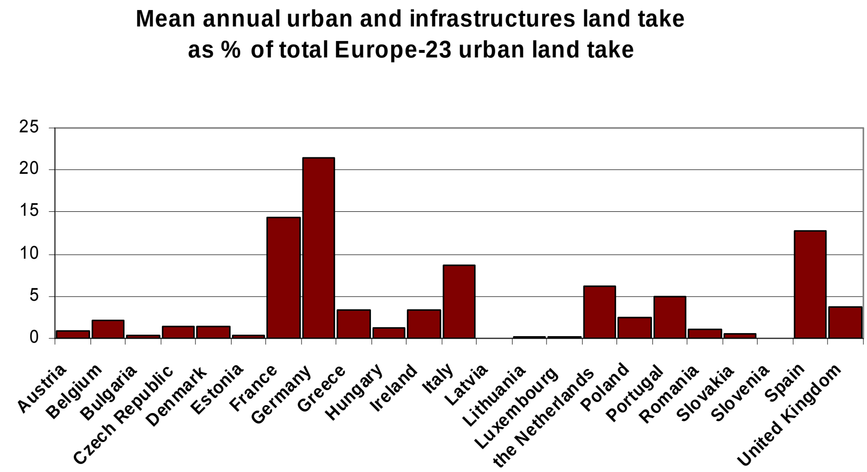

Figure 1.11.3 Example for indicator presentation (SE04 c).

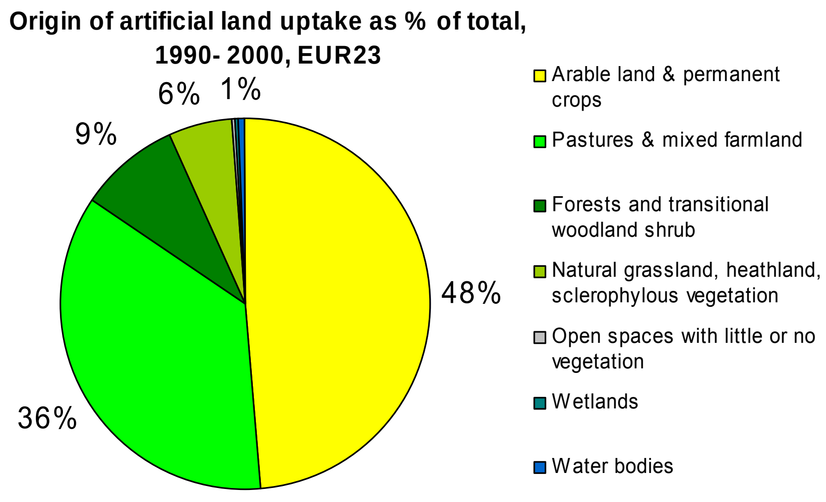

Figure 1.11.4 Example for indicator presentation (SE04 d)

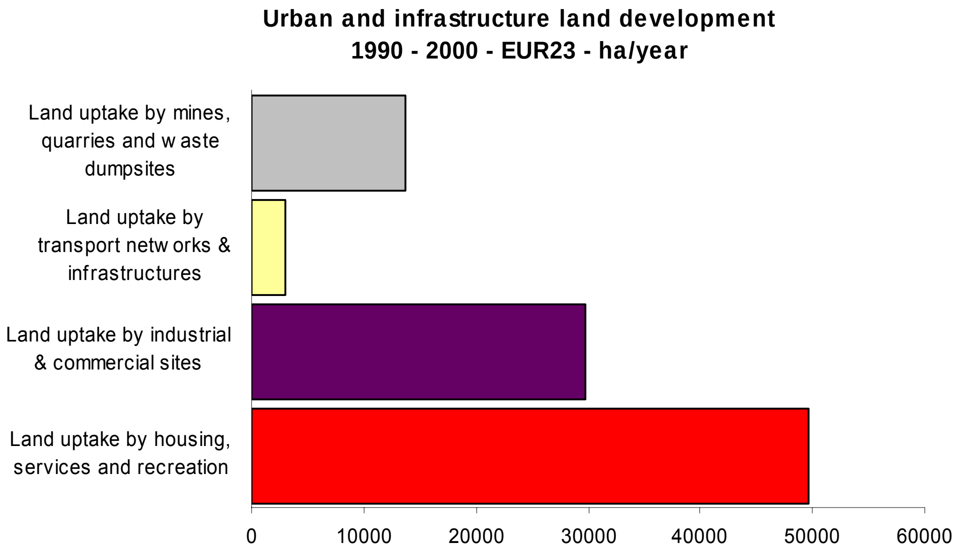

Figure 1.11.5 Example for indicator presentation (SE04).

1.11.1.1 Methodology

This indicator provides an overview of the quantitative state and trend of land consumption in Europe. It quantifies how much, in what proportions and at what growth rate soil is lost by converting agricultural, forest, semi-natural and natural land to urban and other artificial land developments.

Land consumed/taken by artificial land covers is composed of both sealed areas (e.g. buildings, road surface, car parks, etc.) and unsealed areas (e.g. house gardens, unsealed parts of road corridors, etc.). While 'sealing' refers to the direct covering of soil by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.), 'land consumption' is a broader concept that relates to all land development for settlement-related human activities by which previously undeveloped land is turned into built-up areas. Thus, sealed land is a sub-set of the total land consumed, and land take is the overarching concept combining both key issues land consumption and sealing.

1.11.1.2 Significance

Agricultural land, forests, semi-natural and natural areas are disappearing in favour of the development of artificial surfaces. Apart from causing soil loss, this causes many consequential pressures on soil ecosystems, including change of relief features, compaction, contamination, and depletion of soil organic matter, and it affects aboveground biodiversity through habitat loss, deterioration and fragmentation.

This indicator supports qualitative analysis of the processes of land use change. Such information is indispensable for decision making on, and the planning and implementation of, adequate strategies for the reduction of soil loss by land consumption, as well as for monitoring the effectiveness of control measures.

1.11.1.3 Policy context

Soil sealing is recognized as one of the key threats to soils in the Soil Thematic Strategy of the European Commission (2002). There are no specific political targets at the European scale, although different documents reflect the need for better planning to control urban growth. Land consumption and soil sealing have become priority issues on many national sustainable development policy agendas. For example, reduction of new land consumption is a political target under the national sustainability strategies of Austria (BMLFUW, 2002, 2005; Umweltbundesamt, 2004), Germany, the UK and Switzerland, and corresponding indicators are applied in the respective national monitoring systems (e.g. BMLFUW, 2004, 2006; BFS, 2003a, 2003b).

1.11.1.4 Scientific background

Consumption of soils due to sealing and land take are the important processes for the engineering function of soil, but negatively affect the habitat, regulation, and production functions of soil (see the ENVASSO Glossary of Key Terms) by disrupting the contact between soil and other ecological compartments. Sealing in particular creates life-hostile sites and may increase surface water runoff, resulting in a higher risk of catastrophic floods (Burghardt *et al*., 2004). The information function is affected to a lesser extent.

In addition to the direct effects on the surface itself, the indirect impacts of land consumption affect large areas due to habitat fragmentation and disruption of ecological corridors. Also, land development alters the typical visual quality of the landscape, reduces its suitability for recreational uses and thereby negatively affects the quality of human life. Moreover, a variety of environmental and human health agents, such as pollutants and noise, are emitted from built-up land, released into the environment and may cause large-scale detrimental effects on natural and social systems. Thereby, land consumption acts as a source of external effects on environmental and human health (Lexer *et al*., 2005; Banko *et al.*, 2004).

1.11.1.5 Data availability

The indicator is currently calculated from the CORINE Land Cover (CLC) database (CLC1990 – CLC2000) using the land cover accounts (LEAC) methodology. The pan-European dataset is made available via the EEA.

1.11.1.6 Assessment of results

Land uptake by urban and other artificial development in the 23 countries covered by Corine Land Cover 2000 amounted to 917,224 hectares in 10 years. It represents 0.3% of the total territory of these countries. This may seem low, but spatial differences are very important and urban sprawl in many regions is very intense. Considering the contribution of each country to new total urban and infrastructure sprawl in Europe, mean annual values range from 22% (Germany) to 0.02% (Latvia), with intermediate values in France (15%), Spain (13.3%) and Italy (9.1%). Differences between countries are strongly related to their size and population density.

The pace of land take observed by comparing it with the initial extent of urban and other artificial areas in 1990 gives another picture: the average value in the 23 EU countries covered by CLC2000 ranges up to annual increase of 0.7%. Urban development is fastest in Ireland (3.1% increase in urban areas per year), Portugal (2.8%), Spain (1.9%) and the Netherlands (1.6%). However, this comparison reflects different initial conditions, e.g. Ireland had a very small amount of urban area in 1990 and the Netherlands one of the largest in Europe. Urban sprawl in new Member States is generally lower than in the EU15 countries, in absolute and relative terms.

The largest land cover category being taken by urban and other artificial land development (average for 23 countries) is agriculture land. During 1990-2000, 48% of all areas that changed to artificial surfaces were arable land or permanent crops. This process is particularly important in Denmark (80%) and Germany (72%). Pastures and mixed farmland are, on average, the next category being taken, representing 36% of the total. However, in several countries or regions, these landscapes are the major source for land take, for example in Ireland (80%), and the Netherlands (60%). The proportion of forested and natural land taken for artificial development during the period is important in Portugal (35%), Spain (31%) and Greece (23%) (EEA, 2005).

1.11.2 Meta data

1.11.2.1 Technical information

i) **Data sources:** The indicator is currently calculated from the CORINE Land Cover (CLC) change database (CLC1990 – CLC2000) using the land cover accounts (LEAC) methodology. The pan-European dataset is made available via the EEA.

ii) **Description of data:** CLC data are remote sensing data mapped from Landsat satellite images. The units of measurement are hectares. CLC data are aggregated statistical data derived from area changes between defined land cover classes. The indicator builds on a homogenous database that is standardised across all Member States, which is up to now lacking for cadastral map-based data on land consumption and soil loss. Thus, land take allows for good cross-country comparison on a pan-European scale, which makes the indicator very appropriate to provide a general overview on EU level. However, due to the scale of the minimum mapping unit of 25 ha, only processes exceeding this threshold can be analysed.

iii) **Geographical coverage: Assessments** are currently available for 27 European countries.

iv) **Spatial resolution:** The minimal mapping unit (MMU) of the land cover change database is currently set to 5 ha, and the database for the final polygon presentation is 25 ha, i.e. only land cover changes larger than 5 and/or 25 ha are recorded (technical detail: due to inconsistencies between countries the 5 ha MMU is applied different, depending on the so called ‘island-polygon" problem’. Considerable improvements in spatial resolution up to a MMU of 1 ha can be expected in the short–term to medium-term future (GSE Fast Track Service Land), which will imply strong improvements of the indicator performance.

v) **Temporal coverage:** Assessments oat the European scale are available for the period from 1990 to 2000..

vi) **Methodology and frequency of data collection**: Remote sensing data (satellite images). For frequency, cf. temporal coverage. In the future, assessments will possibly be updated every 5 years. Since the given spatial resolution is the limiting factor for sensitivity to changes, shorter frequencies are neither required nor useful

vii) **Methodology of indicator calculation:** Changes from agriculture, forest and semi-natural/natural land (CLC2 to CLC5) to urban land (CLC1) are grouped according to the land cover accounts methodology. Land cover change values are converted to grid cells which are aggregated by countries. Results are presented as average annual change, as percentage of the total area of the country, as percentage of EU27, and as percentage of the various land cover types taken by urban and artificial development. Only polygonal transport areas are recorded in the indicator; land uptake by linear transport infrastructures development will be integrated in a further step on the basis of a high resolution geographical database of transport infrastructures. Land take is an established indicator of the EEA core set. The methodology is tested and acknowledged.

viii) **Availability of baselines and thresholds:** baseline data and assessments for 27 EU Member States are available for the period 1990 – 2000. The recommended approach to the determination of thresholds within the ENVASSO project is to define the threshold as the mean annual urban land take of a defined reference year (or the preceding reporting period, respectively). Numerically speaking, this implies that the threshold is identical to the baseline, or should be lower than the baseline (continuous decrease of land take from reporting period to reporting period). Thus, thresholds are easily available because they are to be directly derived from the baselines.

1.11.2.2 Quality information

i) **Strength and weakness**: Land take is an established indicator of the EEA core set (CSI 014), and the methodology is well-tested and acknowledged. Overall data quality and accuracy is medium due to limited spatial resolution (current MMU: 5 - 25 ha), which in practice restricts sensitivity of the indicator for detecting short-term changes and its usefulness for more detailed assessments at national scales. If more accurate national assessments are desired, calculation of land consumption with the help of cadastral map-based national databases offers a very useful complementary monitoring approach. However, considerable improvements of accuracy are to be expected for the medium-term future (MMU: 1 ha), which implies that the indicator holds very promising potential.

Calculation of the indicator builds on a homogenous data set that is standardised across Europe, which allows for good country-to-country comparability, and general overview at a pan-European scale (as a consequence of the ‘island-polygon’ 5-ha rule, only such countries should be compared directly that apply the same interpretation of that rule to their assessment methodologies). Also, current data quality is sufficient to allow for detection of significant changes in annual land take at national scales and to identify trends.

ii) **Data comparability:**
Comparability over time: Regular updates of the first 1990 – 2000 assessment are scheduled every 5 years. Comparability over time will depend to some extent on continuity and consistency of defined land cover classes and mapping methods. *Comparability over space:* Standardised database on pan-European scale allows very good comparability across countries. Inconsistencies between countries due to mapping changes may cause biased results.

1.11.3 Further work required

The expected improvement of spatial resolution in terms of Minimal Mapping Units (MMU > 1 ha) will increase accuracy considerably (GSE Fast Track Service Land). Continuity of data gathering and assessment methodology over time will be a critical factor for successful monitoring.

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1.12 SE05 New settlement area established on previously developed land

Key issue: Brownfield re-development
DPSIR classification: Response

Main information: This indicator measures the area size and share of new settlement area (housing, commercial and industrial sites, infrastructure, etc.) established on previously developed land ('brownfields') in relation to the total area of newly developed land. The indicator quantifies changes in the rate of brownfield re-development, it informs about how much recycling of brownfields contributed to reducing new consumption of undeveloped 'green land', and it shows whether defined policy targets are met.

1.12.1 Example

The proposed indicator is monitored under the UK sustainable development strategy, with the geographical coverage of England and Wales. Indicator results are published in the internet as in the example given below (DEFRA, 2005).

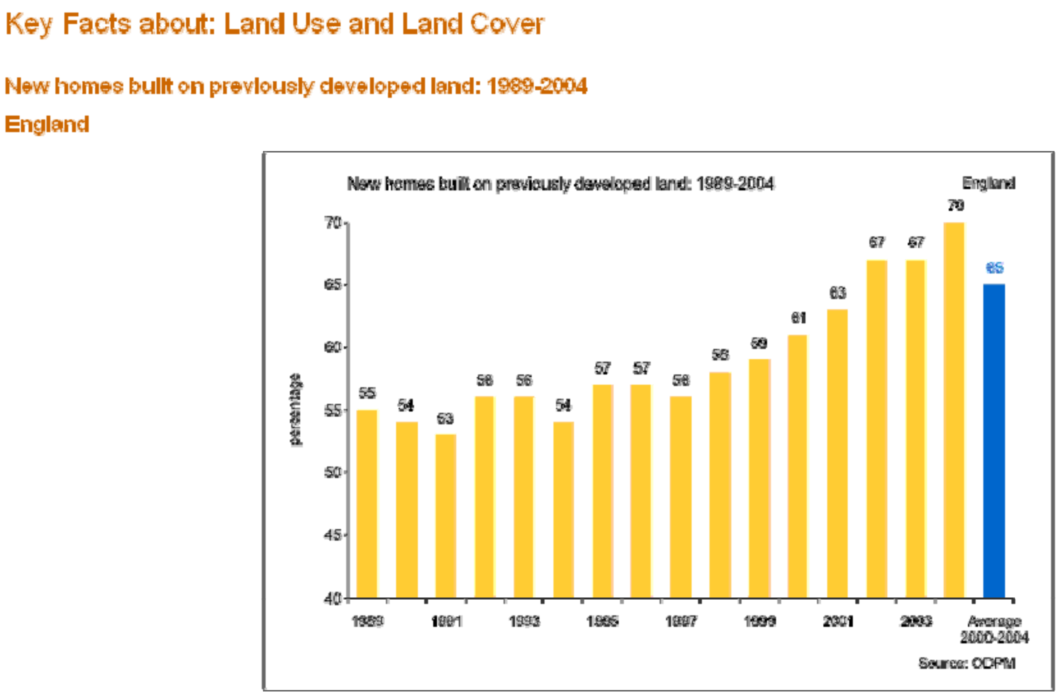

Figure 1.12.1 Evolution of brownfield re-use in the UK between 1989 and 2003.

Source: DEFRA, 2005: e-Digest of Environmental Statistics, Published June 2005
http://www.defra.gov.uk/environment/statistics/land/kf/ldkf07.htm

This is a UK Government sustainable development strategy indicator. In England, provisional figures for 2004 indicate that 70% of new homes (including the conversion of existing buildings, i.e. ca. 3%) were built on previously developed 'brownfield' land. The UK Government has set a target of 60% to be achieved by 2008.

Indicator values are much higher in urban areas and there is also considerable regional variation. Over the period 2000 to 2007, London had the greatest values (>90%, excluding conversions) and the East Midlands and the South West had the smallest values (ca. 50%).

1.12.1.1 Methodology

This indicator measures the size of new settlement areas (housing, commercial and industrial sites, infrastructure, etc.) established on previously developed land ('brownfields') and expresses it as percentage of the total area of newly developed land.

1.12.1.2 Significance

Land consumption is the main cause of the increase of direct soil loss due to human activities. Agricultural land, forests, semi-natural and natural areas are disappearing in favour of the development of artificial surfaces, causing many pressures on soil ecosystems, including change of relief features, compaction, contamination, depletion of soil organic matter, and a reduction biodiversity by habitat fragmentation.

Re-development of previously developed land that is currently not used offers a largely underexploited potential for reducing soil losses. The indicator is highly meaningful to the threat 'soil sealing' and is characterized by good comprehensibility and a clear key message. Moreover, it is highly relevant to the key issue of 'local soil contamination by point sources' because re-development of brownfields is a driving force for the implementation of restoration and clean-up measures.

Monitoring of the indicator is required because it shows to what extent defined respective policy targets are met. As a response indicator brownfield re-development has high policy relevance, by measuring the effectiveness of political decisions and practical actions, it provides information that can be fed back directly into the policy cycle.

1.12.1.3 Policy context

Soil sealing was recognised as one of eight threats in the preparatory work for the EU Soil Thematic Strategy (European Commission, 2002). Similar, the Thematic Strategy on the Urban Environment (European Commission, 2005) refers to the sustainable management of soil resources. A policy framework at the European scale with the objective to support the re-development of brownfield sites is expected to be defined under the Thematic Strategy and its follow-up legislation.

However, land consumption, soil sealing and appropriate response measures have become priority issues on many national sustainable development policy agendas. For example, reduction of new land consumption is a political target under the national sustainability and spatial development strategies of Austria, Germany, the U.K. and Switzerland, and numerical targets have been set in a number of countries (BMLFUW, 2002, 2005; ÖROK, 2002; Umweltbundesamt, 2004a; Deutsche Bundesregierung, 2002, 2004; BFS, BUWAL & ARE, 2003b; Schultz & Dosch, 2005), with corresponding indicators being applied in the respective national monitoring systems (e. g., BMLFUW, 2004, 2006; UBA Berlin, 2005; BFS, BUWAL & ARE, 2003a, 2003b). Also, expert proposals for indicators relating to land consumption and soil sealing have been submitted under the Alpine Convention (Alpine Convention, 1994, 2004).

Brownfield re-development has been recognized as a key implementation strategy in order to accomplish land consumption reduction targets in a number of national strategy documents (BMLFUW, 2002; RNE, 2004) and its application has been recommended by various relevant expert reports (Umweltbundesamt, 2004a, 2004b; UBA Berlin, 2003, 2004a, 2004b; SRU, 2002). The UK has an operational policy targeting brownfield redevelopment. In Germany, a national expert report recommended a phased, tiered approach to target values: new settlements should be developed on previous brownfields in the following percentages: (i) 25% of entire new settlement area from now on; (ii) 50% until 2010; and (iii) 75% until 2020 (UBA Berlin, 2003).

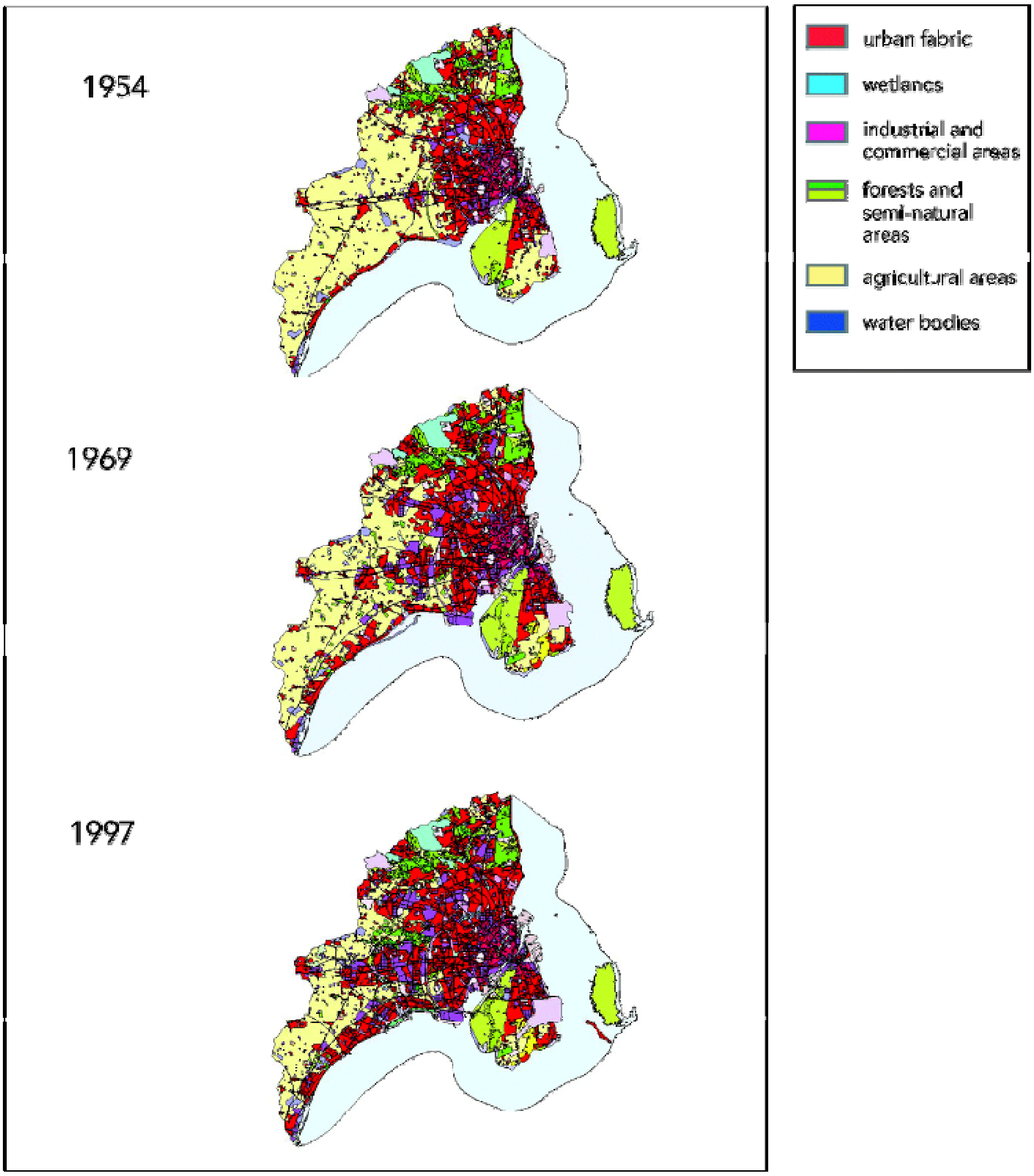

Figure 1.12.2 Example of greenfield consumption in Copenhagen (Denmark) between 1954 and 1997.

Source: EEA, 2002: Towards an urban atlas. Assessment of spatial data of 25 European cities and urban areas (2002). Environmental issue report No 30. Luxembourg: Office for Official Publications of the European Communities, p. 79.

1.12.1.4 Scientific background

Increasing consumption of ‘greenland’ is due to a general increase in the number of households and average residential space per capita since 1980, a trend that has accelerated since 1990 (EEA, 2003). Figure 1.12.2 shows the land take or ‘urban sprawl’ around Copenhagen between 1954 and 1997. The increase in residential space includes an increase of sealed soil which lacks ecological functions, such as water run-off, storage of carbon and lack of habitat.. An increase of flooding incidents in urban areas was observed in recent years (PIK, 2000). Land consumption leads to loss of soil that is largely irreversible and causes an increasing shortage of land resources available to future generations (Lexer *et al*., 2005; Banko *et al*., 2004).

This indicator is particularly useful in connection with target values for brownfield re-development. The setting of any numerical target values is mainly a normative political decision, which should build on a broad political participation and negotiation process involving relevant stakeholders and guided by technical expertise. Regional differentation of target values is highly recommended because of, (i) regional differences in economic history (e.g. intensity of industrialisation), and (ii) an often asymmetric regional distribution of brownfield site availability and economic demands for land development. The larger the stock of brownfields and the economic demand for land development with a region, the higher the target value should be set.

Note: the UK government restricted the monitoring to 'new homes' built on previously developed land. This excludes building activities for industrial and commercial purposes (e.g. business parks, industrial zones) and for public purposes (e.g. services, social infrastructure). A broader interpretation of the term 'new settlements', i.e. including industrial, commercial and public building activities, is recommended.

1.12.1.5 Data availability

Data from local authorities in the Member States are needed. For example, based on extrapolation of brownfield data from representative case study areas, and referring only to previously developed industrial and commercial land, a recent study has revealed that in Austria the stock of such brownfields amounts to 8.000 – 13.000 ha, with a growth rate of 1,100 ha/year or 3 ha/day. Compared to the average growth rate of new land consumption from 2001 to 2005 of 15,8 ha/day, this implies that approximately one fifth of the Austrian demand for newly developed land could be satisfied by re-developing the continuously newly occurring brownfield sites.

In other words, the current stock of brownfield sites is about twice as large as the average annual newly developed land (Umweltbundesamt, 2004b). Moreover, in many cases brownfield sites are characterized by favourable location, good access to the transport network and existing equipment with infrastructure, which implies that often little additional efforts for preparation of sites for building are required. Brownfield sites may be contaminated to differing extents, which would require appropriate clean-up measures, but the predominant portion of brownfield stocks is not contaminated at all, or only to a minor degree (Umweltbundesamt, 2004b).

Similar data are needed for other Member States to implement this indicator.

1.12.1.6 Assessment of results

The assessment example from the UK (see Section 1.1.1) shows that building activities on developed land increased steadily over the years. In England, provisional figures for 2004 indicate that 70% of new homes (including the conversion of existing buildings, i.e. ca. 3%) were built on previously developed 'brownfield' land. The UK Government has set a target of 60% to be achieved by 2008.

Furthermore, between 1996 and 1999, 67% of all new commercial and industrial sites have been established on previously developed land. The site density on converted land is much higher than on newly designated green land, which contributes further to saving soils on undeveloped sites. Increasing exploitation of brownfield sites demonstrates the effectiveness of the strategy and shows that the rate of brownfield re-development is much greater than the growth rate of brownfield stocks (Higgins, 2004; Hoggart, 2004).

1.12.2 Meta data

1.12.2.1 Technical information

i) **Data sources:** The total area of newly developed land (land consumption for settlements and related purposes) is usually recorded by means of land registers (cadastral maps), which are in most countries gathered and computed in national statistical databases.

ii) **Description of data:** This indicator requires two input parameters: (i) the area of re-developed brownfield sites and (ii) the total area of newly developed land (land consumption for settlements and related purposes). In both cases, the initial raw data are parcel-specific and the physical measurement unit are absolute nominal area values (hectares).

iii) **Geographical coverage:** Currently, systematic monitoring on a national scale is done only in the UK. The required geographical coverage would be the EU 27, with particular focus on regions with large stocks of brownfields (e. g. urban agglomerations and sub-urban areas, industrialized regions, regions with a longer history of industrialization) and greater economic demands for land development.

iv) **Spatial resolution:** The required spatial resolution differs for the assessment unit and the observation unit. Monitoring is performed at the local scale and based on parcel-specific data. Since the indicator shall provide regional assessments, the aggregated assessment units should range from NUTS5 to NUTS3.

v) **Temporal coverage**:

vi) **Methodology and frequency of data collection**: Monitoring should be based on continuous data collection; aggregation of data for desired spatial assessment units and indicator assessment should be done annually.

vii) **Methodology of indicator calculation:** The indicator is defined as below:

$$\frac{Area\,of\ new\ settlements\ on\ developed\ land\ (ha)}{Total\ area\ of\ new\,settlements\,(ha)} * 100 = New\,settlements\ on\ developed\ land\ (\%)$$

viii) **Availability of baselines and thresholds:** The baseline is defined as the percentage of re-developed brownfield sites (extent and rate of brownfield re-development) in a given reference year. The threshold is defined as the indicator value of a defined baseline year. Numerically speaking, this implies that the threshold is identical to the baseline (no decrease compared to the baseline) or should be greater than the baseline.

1.12.2.2 Quality information

i) **Strength and weakness**:
Monitoring of the indicator is successfully being practised in the U.K., and the methodology is tested and proven. However, there may currently be a lack of data availability in countries other than the U.K. Since data gathering is done at individual parcel scale, data accuracy and spatial resolution is high. In countries with smaller overall brownfield stocks than the U.K., the ability of the indicator to detect significant trends might be rather limited at national level. Hence, monitoring should focus on regions with higher stocks of brownfields (urban / industrialized regions). For areas with smaller overall brownfield stocks it is better to use the absolute area values (ha) of settlements built on previously developed land instead.

ii) **Data comparability:**
Comparability over time: this indicator is highly appropriate for time-series comparisons. *Comparability over space:* comparability of absolute indicator values is limited.

1.12.3 Further work required

Monitoring requires establishment of a reporting system regarding the area and previous development status of land where building activities occur at national/regional scales. These parameters must be recorded by local/regional authorities and stored in databases. A brownfield cadastre (inventory of available brownfield sites) would be supportive, but is not required for monitoring the indicator.

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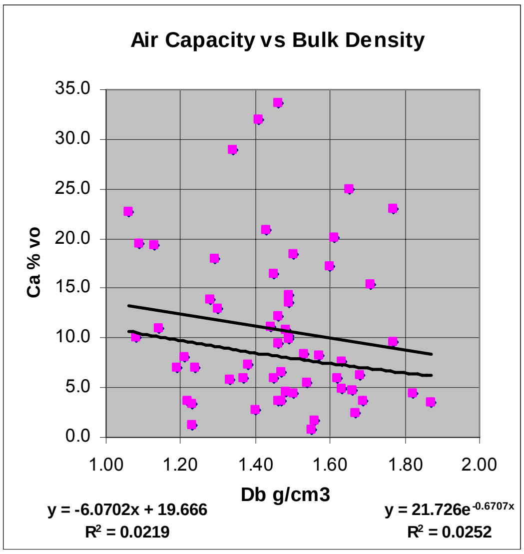
1.13 CP01 Density

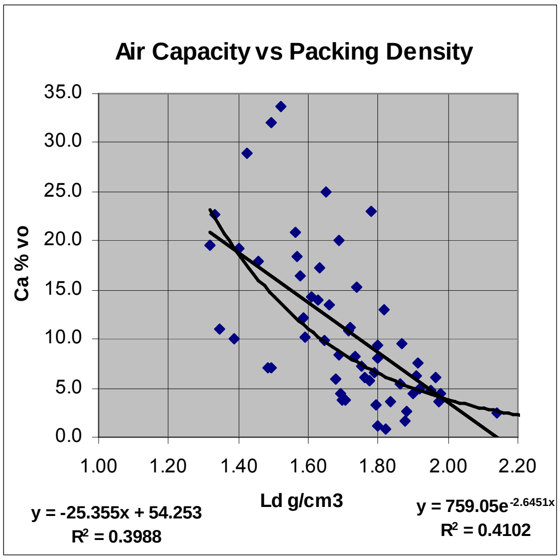
Key issue: Compaction and structural degradation
DPSIR classification: State

Main information: Soil compaction is the 'densification and distortion of soil by which total and air-filled porosity are reduced, causing a deterioration or loss of one or more soil functions' (see glossary). Soil compaction may reduce soil functions by: decreasing soil permeability; increasing soil strength; partly destroying soil structure; altering soil fabric and affecting soil behaviour characteristics. Anthropological soil compaction can be initiated by e.g. wheels, tracks or rollers, the passage of cultivation machinery, and the passage of draft or grazing animals. This indicator is defined by soil density and there is an inverse correlation with air capacity (air-filled porosity - see CP02), i.e. air capacity at low suction (i.e. field capacity) decreases as bulk density increases.

1.13.1 Example



Air capacity (Ca) or porosity = air-filled pores at 5kPa
Bulk density – D_b



Packing density – L_d
$L_d = D_b + 0.009\,C$ where C = clay content (% w w^{-1})

Figure 1.13.1 Bulk density and packing density related to porosity (Ca) for the assessment of compaction in European soils

1.13.1.1 Methodology

Knowledge concerning the vulnerability of soils to compaction in Europe is now an increasingly important requirement within agriculture and for planning environmental protection measures. Subsoil compaction has been the subject of two recent EU-funded Concerted Actions (Van den Akker, 1999; Van den Akker and Canarache, 2001) and during these projects a database of experimental results on subsoil compaction has been compiled (Van den Akker *et al.*, 2003). Ideally, vulnerability to compaction should be assessed by direct measurement of soil strength (bearing capacity), but currently such measurements are extremely scarce. Similarly, knowledge of soil mechanics is not advanced enough to allow extrapolation of likely compaction damage from experimental sites to soils in general.

This indicator, based on a simple measurement or estimate of soil bulk- or packing density, is proposed as a proxy for bearing strength. Soil density is inversely proportional to porosity, thus as density increases porosity decreases. Dense, compact soils restrict rooting and hinder or obstruct the movement of air, water and nutrients in the rooting zone. Bulk density can be measured directly in the field as described by Hodgson (1997, p.112-113) or in the laboratory on undisturbed cores

(Hall *et al.*, 1977; Smith and Thomasson, 1982). Changes in compaction can then be detected by repeated measurements that show bulk density to be increasing or decreasing. Soil compaction can result from natural causes (e.g. compression by glacier ice from the Last Glaciation), as well as from anthropogenic activities, such as the passage of agricultural or forestry machinery, construction traffic and grazing animals).

1.13.1.2 Significance

Soil compaction, particularly in subsoils, is an increasingly serious problem in Europe, affecting areas under agroforestry as well as intensive arable farmland (Van den Akker et ak., 2003). The environmental impacts that can ensue from compaction (Van den Akker, 1999) are now clearly identified, thus measuring or estimating the density changes in soil will be an increasingly important requirement for determining the extent (actual and potential) of areas within Europe experiencing or at risk of compaction (Jones *et al.*, 2003).

1.13.1.3 Policy context

The official 'Communication on a Thematic Strategy for Soil Protection in Europe' (European Commission, 2002) identified eight threats to soil, of which soil compaction is one. The indicator is relevant for the forthcoming Soil Framework Directive (European Commission, 2006a,b), which will implement tougher action to mitigate soil compaction, along with the other threats to soil. This will be achieved by harmonized criteria to establish soil compaction status and the indicator CP01 is one such criterion that could be a fundamental component in future monitoring systems.

1.13.1.4 Scientific background

Porosity is a more important measure of the degree of soil compaction than bulk density, but estimates of the total volume of voids are unreliable. However, field estimates of the volume of pores > 0.06 mm (and a diameter > 0.0002 mm) can be made from particle-size class and an estimate of packing density, which is more easily estimated in the field than bulk density. Packing density or 'Lagerungsdichte' was initially defined by Benecke (1966) and its use developed by Renger (1970, 1971). It has been used as a basis for assessing porosity and as a measure of structural state of soil in the UK since the 1970s (Hodgson, 1976, 1997; Hall *et al.*, 1977; Jones and Thomasson, 1993). The justification for this is clear from

Packing density (Ld) can be calculated from the equation:

$$Ld = D_b + 0.009\ C$$

where C = clay content (% w w^{-1})
D_b = bulk density, t m^{-3} (g cm^{-3})

Thomasson (1982) proposed the use of three classes of packing density to describe the structural state of soil material and categorise its apparent compactness: low Ld < 1.40, medium Ld 1.40 – 1.75 and high Ld > 1.75 t m^{-3} (g cm^{-3}). Hodgson (1976, p.39) describes the field properties of these three classes of packing density, and a more comprehensive scheme, based on size and shape of peds and the degree of ped development, is shown in Figure 2 (see also Hodgson, 1997 p.47-49). The volume of pores greater than 0.06 mm can be regarded as approximately equal to air capacity at 5 kPa. Soils with high packing density (> 1.75 t m^{-3}) are slightly (<10% pores > 0.06 mm) or very slightly porous (<5%). Very slightly porous soils (< 5% pores > 0.06 mm) are very compact and have high packing densities, either as a result of natural or anthropogenic forces.

Jones and Thomasson (1993), emphasising the value of packing density as a threshold parameter of soil structural conditions, concluded that soils with high packing density are fairly easy to identify in the field or from core samples. However, taking undisturbed cores, especially of subsoils, is not an easy task (Hall *et al.* 1977), and consequently Hodgson (1997) provides three 2-way tables (matrices) for estimating packing density from soil texture and structure observed in the field. Figure 1.13.2 illustrates the assessment of structural conditions in fine-textured (clay loam and clayey) subsoil horizons.

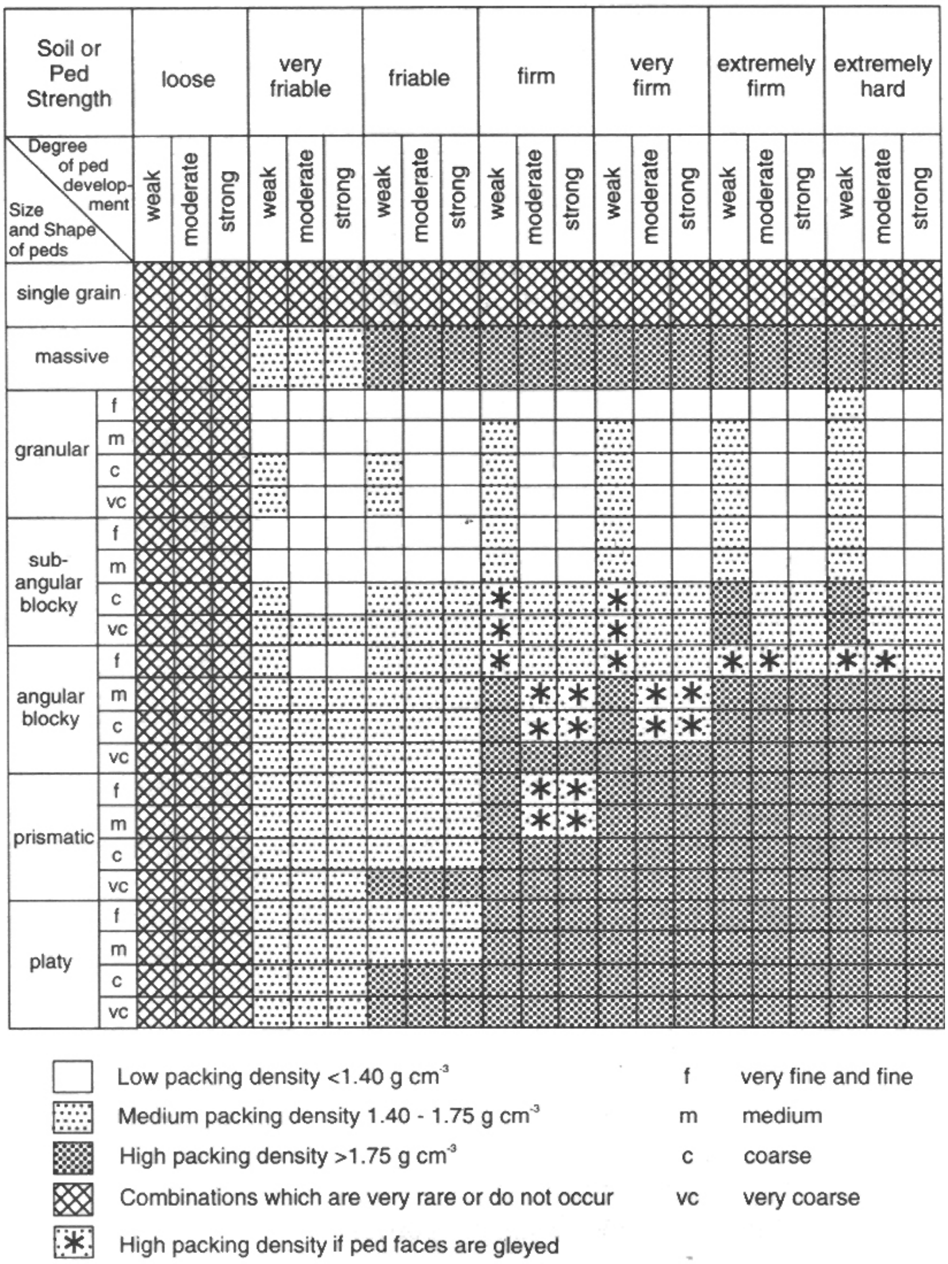


Figure 1.13.2 Assessment of packing density from soil structure and strength of subsoil horizons with sandy clay loam, clay loam, silty clay loam, sandy clay, clay or silty clay loam texture. [After Hodgson, 1997, p.49]

The soil properties that are required for estimating or calculating packing density are:

i) Soil texture, determined from the proportion of sand, silt and clay (% by weight), and expressed as a texture class (see FAO, 2006, p.27; Schoeneberger *et al.*, 1998 {USDA Field Handbook);
ii) Soil structure, the type, size and degree of ped or clod development (Hodgson, 1997, p.37-46; FAO, 2006, p.44-47) strongly influences porosity, permeability and the nature of macro-pores;
iii) Bulk density (t m^{-3}).

The following properties are useful additional aids to estimating soil structural conditions:

i) Soil organic matter content, often expressed as percentage soil organic carbon (w w^{-1});
ix) Soil moisture (water) content (% vol.).
x) Soil moisture potential (kPa).

If soil particle-size grades (sand, silt and clay in %) are not known then it has been shown that experienced operators, with regular calibration against standard samples, can estimate clay and silt contents, providing data sufficiently accurate for estimating packing density (Hodgson *et al.*, 1976) .

1.13.1.5 Data availability

Soil: A European Soil Database at 1:1,000,000 scale (1:250,000 scale would be preferable when available), to provide spatial data on soil type, surface and subsurface texture, depth, physical structure and bulk density (derived using pedotransfer rules – PTRs; Van Ranst *et al.* 1995). Soil organic carbon (SOC) content is available at 1 km resolution (Jones *et al.*, 2005). The European Soil Database also contains a soil profile analytical database (Breuning-Madsen and Jones, 1995; Hiederer *et al.*, 2006) and pedotransfer functions derived from the HYPRES database (Wösten *et al.*, 1998). Other databases containing soil bulk density and water retention data for Europe include the WISE database (Batjes, 1995) and the IGBP Global Soils Data Task database (Scholes *et al.*, 1999).

Land use/land cover data: land use affects the bulk density of soil such that the same soil type under woodland or forest may have lower bulk densities than under arable agriculture (except immediately after cultivation. Thus CORINE Land Cover (CLC) at 250 m resolution provides a historic data set on land use that can be used to help estimate spatial variations in bulk density.

Geographical coverage of data sets: Europe

1.13.1.6 Assessment of results

Measuring soil bulk density is a standard procedure in which the uncertainty attached to measured values is known. Clay content for calculating packing density is determined by standard particle analysis, for which the uncertainty of measurements is also known.

1.13.2 Meta data

1.13.2.1 Technical information

i) **Data sources:** several sources provide relevant Europe-wide data (see above).
ii) **Geographical coverage**: EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring States in the Mediterranean Basin and the Former Soviet Union;
iii) **Spatial resolution:** from field to national scale, though density measurements for European soils are generally scarce.
iv) **Temporal coverage:** soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; Land cover data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).
v) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at five year intervals using updated land cover data.
vi) **Methodology of indicator calculation:** procedures for measuring soil bulk density and clay content are well known and fully documented. Procedures for estimating bulk density and packing density have been developed over the past 30 years and, although the values obtained are less reliable than direct measurements, these procedures enable spatial data on soil density to be generated for areas where no direct measurements have been made and/or where such data are unlikely to be forthcoming in the near future.
vii) **Availability of baselines and thresholds**: a general baseline exists and thresholds are proposed.

1.13.2.2 Quality information

i) **Strength and weakness:** detailed information is available for some countries though spatial and temporal coverages differ. The data are mainly reliable but many more direct measurements of soil density are needed; there is a dearth of data on soil physical properties throughout western Europe yet these data are of crucial importance for assessing soil compaction.

ii) **Data comparability: comparability over time:** current data sets originate from different periods and been determined by different analytical techniques. Comparability over space: spatial coverage is insufficient at the present time.

1.13.3 Further work required

The main tasks for future improvement of the approach described for this indicator (CP01) are:

i) Measure bulk density for many more soil types in Europe than have been examined to date;

ii) The two-way tables for estimating packing density in UK soils need to be extended to encompass the full range of European soils and conditions;

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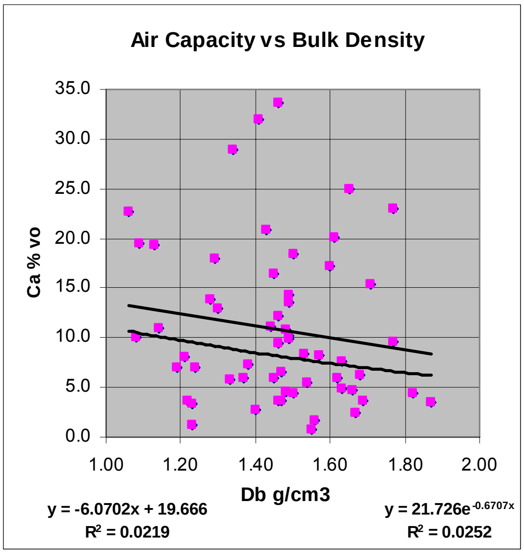
1.14 CP02 Air capacity

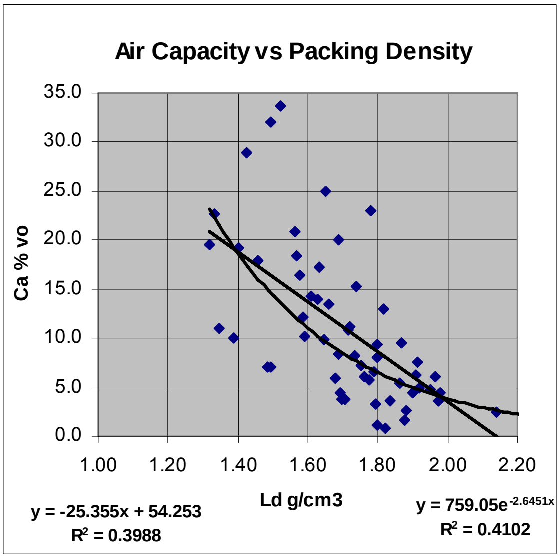
Key issue: Compaction and structural degradation
DPSIR classification: State

Main information: Soil compaction is the densification and distortion of soil by which total and air-filled porosity are reduced, causing a deterioration in, or loss of, one or more soil functions. Soil compaction may reduce soil functions by: decreased soil permeability; increased soil strength; partly destroyed soil structure; altered soil fabric and soil behaviour characteristics. Anthropological soil compaction can be initiated by e.g. wheels, tracks or rollers, the passage of cultivation machinery, and the passage of draft or grazing animals. This indicator is defined by air capacity, the air-filled pore volume at a specified suction, and it has a strong relationship with aeration and functioning of the root zone, which is particularly important for the filtering capacity of soil.

1.14.1 Example



(a) [Jones, unpublished data]



(b) [Jones, unpublished data]

Air capacity (C_a) = air-filled pores at 5kPa (% v/v)
Bulk density – D_b

Packing density – L_d
$L_d = D_b + 0.009\ C$ where C = clay content (% w/w)

Figure 1.14.1 Air capacity (C_a) related to (a) bulk density and (b) packing density for the assessment of compaction in European soils

1.14.1.1 Methodology

Knowledge concerning the vulnerability of subsoils to compaction in Europe is now an increasingly important requirement within agriculture and for planning environmental protection measures. Subsoil compaction has been the subject of two recent EU funded Concerted Actions (Van den Akker, 1999; Van den Akker and Canarache, 2001) and under these projects a database of experimental results on subsoil compaction has been compiled (Van den Akker *et al.,* 2003). Ideally, subsoil vulnerability to compaction should be assessed by direct measurement of soil bearing capacity, but currently no direct practical tests are available. Similarly, knowledge of soil mechanics is not advanced enough to allow extrapolation of likely compaction damage from experimental sites to soils in general.

This indicator, based on a simple measurement or estimate of air capacity (air-filled pore volume) at a specified suction (e.g. 5, 6 or 3 kPa), is proposed as a measure of the degree of densification. Air capacity is the volume of pores > 0.06 mm ESD (equivalent spherical diameter). It is generally inversely proportional to soil bulk density, thus as density increases the volume of air-filled pores decreases. Dense, compact soils restrict rooting and hinder root development and a small proportion of air-filled pores (<10%) obstructs the supply of air and movement of water in the rooting zone. Air capacity can be determined from laboratory measurements on undisturbed soil cores taken in the field as described by Hall *et al.* (1977, p.5-22; Smith and Thomasson, 1982). Compaction can then be detected by repeated measurements that show air capacity to be decreasing. Air capacity should not be confused with total porosity which is the volume of all pores which are not occupied by solid (mineral or organic) material.

1.14.1.2 Significance

Soil compaction, particularly in subsoils, is an increasingly serious problem in Europe (Van den Akker *et al.*, 2003), affecting areas under agroforestry as well as intensive arable farming. The environmental impacts that can ensue from compaction (Van den Akker, 1999) are now clearly identified, thus measuring or estimating the changes in air capacity will be an increasingly important requirement for determining the extent (actual and potential) of areas within Europe where compaction has occurred or is likely in the future (Jones *et al.*, 2003).

1.14.1.3 Policy context

The official 'Communication on a Thematic Strategy for Soil Protection in Europe' European Commission, 2002) identified eight threats to soil, of which soil compaction is one. The indicator is relevant for the forthcoming Soil Framework Directive European Commission, 2006a,b), which will implement tougher action to mitigate soil compaction, along with the other threats to soil. This will be achieved by harmonised criteria to establish soil compaction status and the indicator CP02 is one such criterion that could be a fundamental component in future monitoring systems.

1.14.1.4 Scientific background

Air capacity is an important measure of the degree of soil compaction, but estimates of the air-filled pore volume require sampling undisturbed cores (e.g. 222 cm^3) of soil to be equilibrated on a sand-suction bath (Smith and Thomasson, 1982; Hall *et al.*, 1977, p.6-18). This is a relatively time-consuming and thus expensive process, both in the field and in the laboratory.

Air capacity (C_a) can be calculated from the equation 1:

$$C_a = T - \theta_v(5) \quad \text{....................Equation 1}$$

where T = total pore space (%, w w^{-1})
θ_v (5) = Volumetric water content at 5 kPa

Total pore space (T) is determined from equation 2

$$T = (1 - D_b/D_p).100 \quad \text{....................Equation 2}$$

where D_b = bulk density
D_p = particle density

Thus, by measuring bulk density from undisturbed soil cores, and then equilibrating these cores on a sand-suction bath at 5 kPa suction to measure the volumetric water content (at 5 kPa), the air capacity can be determined using a known value for D_p, usually in the range 2.55 – 2.65 t m^{-3} for mineral soils. Air capacity is closely related to organic matter and, in some soils, to the clay content (see Figure 1.14.2)

1.14.1.5 Data availability

Soil: A European Soil Database at 1:1,000,000 scale (1:250,000 scale would be preferable when available), to provide spatial data on soil type, surface and subsurface texture, depth, physical structure and bulk density (derived using pedotransfer rules – PTRs; Van Ranst *et al*. 1995). Soil organic carbon (SOC) content is available at 1 km resolution (Jones *et al*., 2005). The European Soil Database also contains a soil profile analytical database (Breuning-Madsen and Jones, 1995; Hiederer *et al.*, 2006) and pedotransfer functions derived from the HYPRES database (Wösten *et al.*, 1998). Other databases, containing soil bulk density and water retention data for Europe, are the WISE database (Batjes, 1995) and the IGBP Global Soils Data Task database (Scholes *et al.*, 1999).

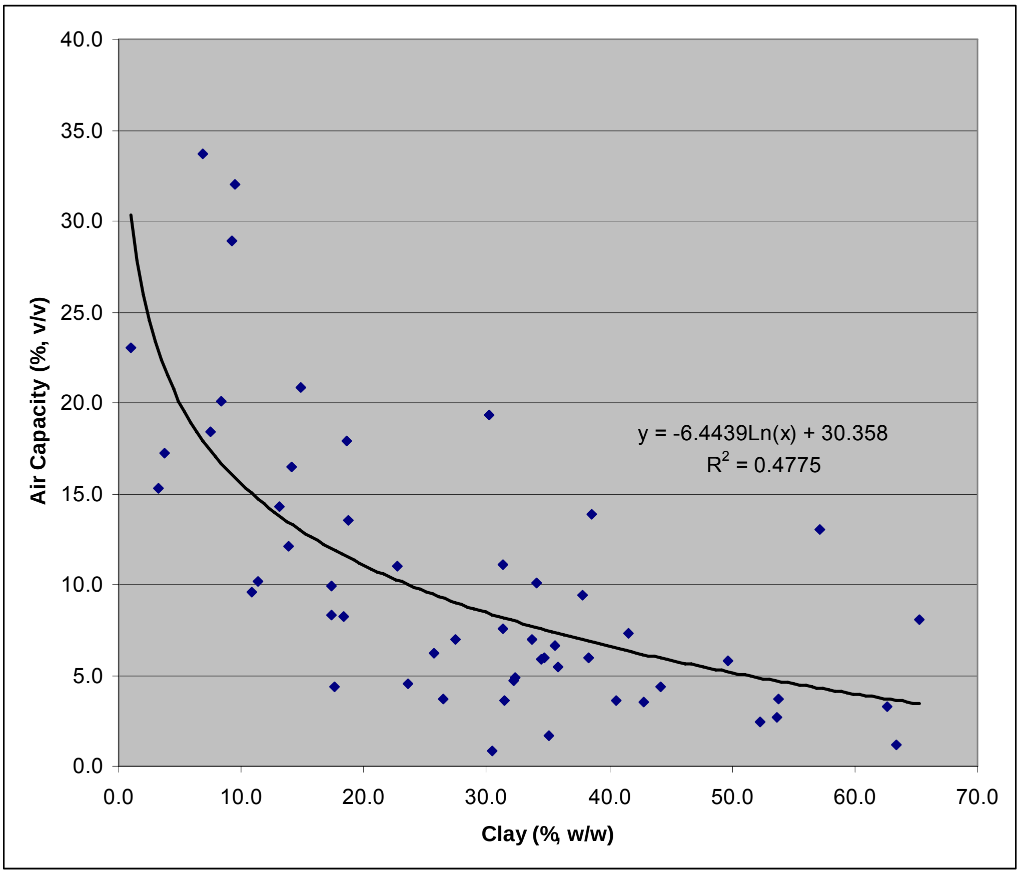


Figure 1.14.2 Air capacity (Ca) related to clay content

Land use/land cover data: land use affects the air capacity of soil such that the same soil type under grassland, woodland or forest normally has larger volumes of air-filled pores than under arable agriculture (except immediately after cultivation). Thus CORINE Land Cover (CLC) at 100 or 250 m resolution provides a historic data set on land use that can be used to help estimate spatial variations in air capacity and bulk density.

Geographical coverage of data sets: Europe

1.14.1.6 Assessment of results

Measuring air capacity is a standard procedure in which the uncertainty attached to measured values is known. Because of the relatively slow and expensive procedure for measuring the water content at 5 kPa suction, a sound method that estimates air capacity would be valuable for applying this indicator (CP02).

1.14.2 Meta data

1.14.2.1 Technical information

i) **Data sources:** several sources provide relevant Europe-wide data (see above).

ii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries and Neighbouring States in the Mediterranean Basin;

iii) **Spatial resolution:** from local to national scale, although water retention measurements for European soils are generally the scarce physical measurements.

iv) **Temporal coverage:** soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; soil physical databanks in Europe were only compiled to any great extent during the past 30 years; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).

v) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at five year intervals using updated climatic and land cover data.

vi) **Methodology of indicator calculation:** procedures for measuring volumetric water content at a specified suction (e.g. 5 kPa) and soil bulk density are well known and fully documented. Procedures for estimating air capacity from texture, structure and land use have been developed over the past 30 years and, although the values obtained are less reliable than direct measurements, these procedures enable spatial data on air capacity and soil bulk density to be generated for areas where no direct measurements have been made and/or where such data are unlikely to be forthcoming in the near future.

vii) **Availability of baselines and thresholds:** a general baseline exists and thresholds are proposed.

1.14.2.2 Quality information

i) **Strengths and weaknesses:** detailed information is available for some countries although spatial and temporal coverages differ. The data are mainly reliable but there is currently a dearth of data on soil physical properties throughout Western Europe, yet these data are of crucial importance for assessing soil compaction.

ii) **Data comparability:**
Comparability over time: current data sets originate from different periods and been determined by different analytical techniques.
Comparability over space: spatial coverage is insufficient at the present time.

1.14.3 Further work required

The main tasks for future improvement of the approach described for this indicator (CP02) are:

i) Many more measurements of soil water retention properties are needed for the full range of soil types in Europe;

ii) Existing databases of soil physical properties need further analysis to explore the possibilities of determining pedotransfer functions for more accurate estimation of air capacity than is possible at present.

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1.15 CP06 Vulnerability to compaction

Key issue: Vulnerability to compaction
DPSIR classification: State

Main information: Soil compaction occurs when soil is subjected to pressure through the use of heavy machinery or dense stocking with grazing animals, especially under wet soil conditions. Compaction reduces the pore space (between soil particles), increases bulk density and the soil's absorptive capacity is reduced or lost. Compaction can occur at the surface or in subsurface soil horizons. The worst effects of surface compaction can be rectified relatively easily by cultivation, and hence it is perceived to be a less serious problem in the medium to long-term. On the contrary, once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate. Furthermore, remedial treatments usually need to be repeated.

1.15.1 Example

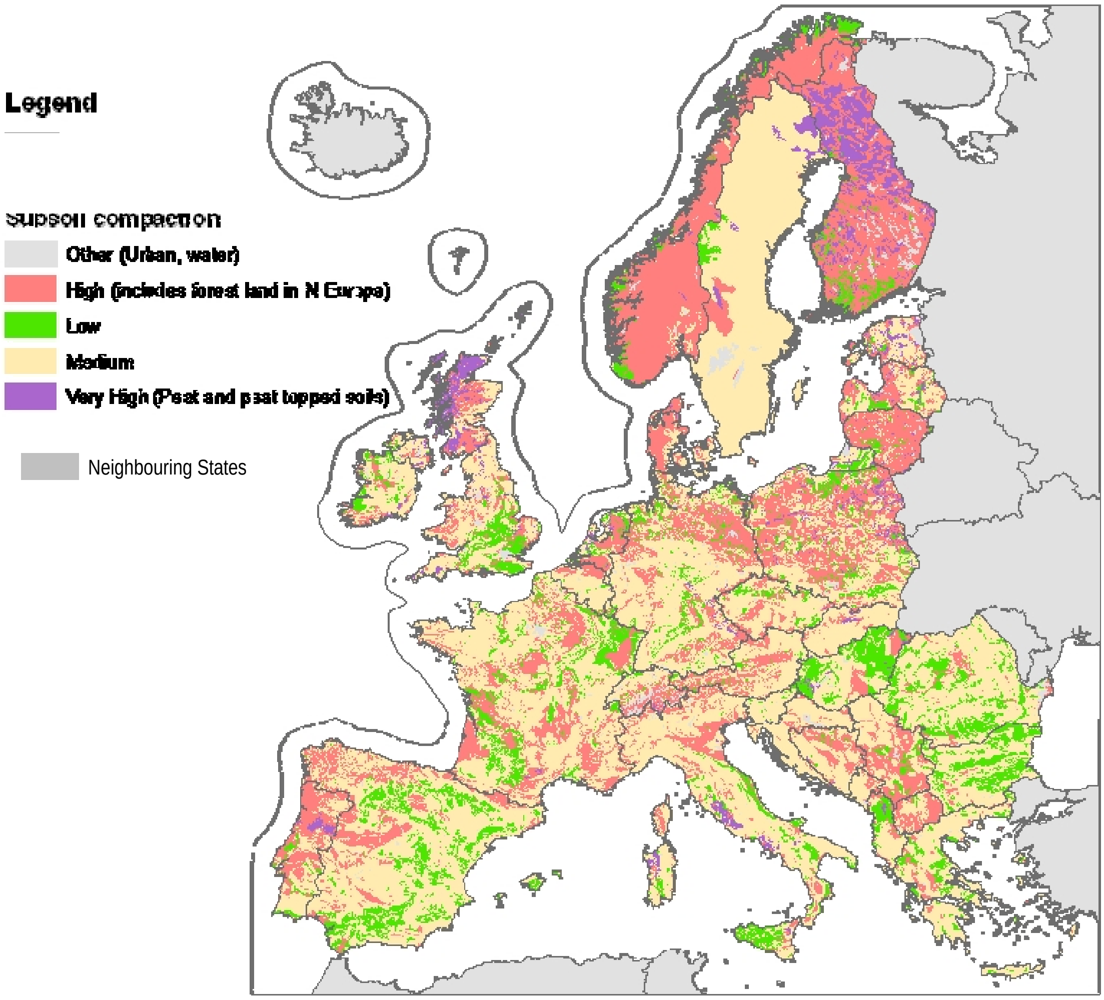

Figure 1.15.1 Susceptibility of subsoils in Europe to compaction, based on soil properties (Jones et al., 2003)

Knowledge concerning the vulnerability of subsoils to compaction in Europe is now an increasingly important requirement within agriculture and for planning environmental protection measures. Subsoil compaction has been the subject of two recent EU funded Concerted Actions (Van den Akker, 1999; Van den Akker and Canarache, 2001) and under these projects a database of experimental results on subsoil compaction has been compiled (see Van den Akker *et al.,* 2003). Ideally, subsoil vulnerability to compaction should be assessed by direct measurement of soil bearing capacity, but currently no direct practical tests are available. Similarly, soil mechanics

principles are not advanced enough to allow extrapolation of likely compaction damage from experimental sites to soils in general.
This indicator is based on a simple classification system for subsoil vulnerability to compaction, based for field use on local soil and wetness data at the time of critical trafficking, and, for Europe as a whole, on related soil and climatic information. A two-stage methodology is proposed: i) assessing the inherent susceptibility on the basis of the relatively stable soil properties of texture and packing density, and ii) combining this soil susceptibility with an index of climatic dryness/subsoil wetness, or actual subsoil moisture status, to determine the vulnerability class. A highly susceptibility soil is one that has properties that make it likely to compact, given the appropriate compactive forces and the moisture contents above field capacity (5 kPa).

1.15.1.1 Significance

Once subsoil damage occurs, it can be extremely difficult and expensive to alleviate. Subsoil compaction risks are increasing with growth in farm size, and associated increased mechanisation and equipment size, caused by the drive for greater productivity. The response of the engineering industry to the demands of agriculture has been impressive over the past 30 years. Larger and larger machines have been developed but, from the soil standpoint, the result has been a significant increase in axle loads not always matched by reductions in ground contact pressures (e.g. by using wider tyres) to prevent or minimise compaction. (Hakansson, 1994; Renius, 1994; Tijink *et al.*, 1995). Compaction, particularly in subsoils, has ceased to be a problem associated solely with agriculture; the environmental impacts that can ensue are now causing serious concern (Van den Akker, 1999). Assessing the vulnerability of different subsoils to compaction is, therefore, an increasingly important issue. This is not only so that appropriate measures can be identified for its avoidance in different situations, but also to determine the extent of actual and potential problems within Europe (Jones *et al.*, 2003).

1.15.1.2 Policy context

The official 'Communication on a Thematic Strategy for Soil Protection in Europe' (European Commission, 2002) 179) identified eight threats to soil of which soil compaction is one. The indicator is relevant for the forthcoming Soil Framework Directive (European Commission, 2006a,b)), which will implement tougher action to mitigate soil compaction, along with the other threats to soil. This will be achieved by harmonized criteria to establish soil compaction status and the indicator CP06 is a candidate upon which to base monitoring systems. Jones *et al.* (2004a) briefly described the extent of subsoil compaction in Europe.

1.15.1.3 Scientific background

Knowledge of soil physical properties and moisture status can be particularly helpful in assessing the likely magnitude of the soil shearing resistance and hence the inherent vulnerability of a subsoil to compaction. The most closely related properties are:

- Soil texture, estimated from the proportion of sand, silt and clay (% w w^{-1}), and expressed as a texture class.
- Nature of clay fraction and associated ions
- Bulk density, t m^{-3} (g cm^{-3})
- Soil organic matter content, often expressed as percentage soil organic carbon (w w^{-1})
- Soil structure, the type, size and degree of ped or clod development which strongly influence porosity, permeability and nature of macro-pores
- Soil moisture (water) content (% vol.).
- Soil moisture potential (kPa).

With the exception of information on clay mineral type and soil moisture content/potential, all the other properties are reported in, or can be inferred from, soil survey records and databases. In some situations, clay mineralogy can also be inferred from geology or soil parent material or soil structural properties.

Soil: European Soil Database at a 1:1,000,000 scale (1:250,000 scale would be preferable when available), to provide spatial data on soil type, surface and subsurface texture, depth; physical structure and bulk density (derived using pedotransfer rules – PTRs; Van Ranst *et al*. 1995). Soil organic carbon (SOC) content is available at 1 km resolution (Jones *et al*., 2004b,c, 2005).

Climatic/Meteorological data: Ideally, climatic data are needed at the same resolution as other model input factors. Therefore, to match the soil data, this would be at a 1 km resolution. Climatic data are not generally available, nor may they exist, at such a detailed scale for Europe. The MARS agroclimatic data are calculated for 50 km x 50 km grid squares across Europe and other data are at 0.5° or 10' intervals. However, it is possible to generate interpolated data at higher resolutions than these by using geostatistics (Ragg *et al*., 1988). The soil moisture deficit is needed to assess vulnerability to compaction.

Agroclimatic data – rainfall, temperature, evapotranspiration are available from a number of sources: MARS agroclimatic database (Vossen and Meyer-roux, 1995) – using an inverse spline function for rainfall and an average adiabatic lapse rate (decline of 6°C per 1000 m rise in altitude) for temperature, the MARS data (rainfall and evaporation were interpolated onto a 1 km x 1 km raster for the PESERA Project (Gobin *et al*., 2003; Kirkby *et al*., 2004); Global Historical Climatology Network – GHCN (Easterling *et al*., 1996); The Tyndall Centre for Climate Change Research (Mitchell *et al*., 2003; New *et al*., 2002). Average climatic data are needed, preferably for a recent international standard period of 30 years, for example 1961-90 or 1971-2000.

Land use/land cover data: CORINE Land Cover (CLC) at 250 m resolution provides a historical data set on land use. These data define the areas likely to be subjected to passage of heavy agricultural machinery and areas where forestry machinery is used, less frequently but sometimes with equally damaging results.

1.15.1.4 Assessment of results

The map of soil susceptibility to compaction, and the transformation of these assessments into vulnerability (Jones *et al.* 2003) could be improved (see 'Further work required'). However, the relevance of this type of modelling, applied through a soil map at 1:1,000,000 scale, may be questioned. It may be more appropriate at scales of 1:50,000 or larger, where real crop performance in specific fields, or where detailed management interventions, are being evaluated. It is clear that the basic data to run such models at scales larger than 1:1,000,000 will be lacking for some parts of Europe for many years to come. In the absence of these data however, the approach described above offers the best chance of achieving results that are satisfactory enough for broad scale policy-making in the immediate future.

1.15.2 Meta data

1.15.2.1 Technical information

i) **Data sources:** several sources provide relevant data Europe-wide (see above).

ii) **Data description:** see above (scientific background)

iii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring States in the Mediterranean Basin and the Former Soviet Union;

iv) **Spatial resolution:** 1 km x 1 km to 50 km x 50 km for various data sets (see above)

v) **Temporal coverage:** soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; Climatic data are available for international standard periods, for example 1961-90, 1971-2000; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).

vi) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at five year intervals using updated climatic and land cover data.

vii) **Methodology of indicator calculation:** calculation of the vulnerability to subsoil compaction: although considered to be mainly a problem of arable agriculture, modern forestry practices can severely compact the soil. For most countries, the measurements of compaction are very scarce.

viii) **Availability of baselines and thresholds:** a general baseline exists and thresholds are proposed.

1.15.2.2 Quality information

i) **Strength and weakness**: detailed information is available for some countries though spatial and temporal coverages differ. The data are mainly reliable but better resolution (e.g. for climate) and more recent (for soil) are needed; there is a dearth of data on soil bearing strengths in Europe yet these data are of crucial importance.

ii) **Data comparability**:
Comparability over time: current data sets originate from different periods.
Comparability in space: spatial coverages are the same but resolutions of the different data sets differ.

1.15.3 Further work required

The main tasks for future improvement of the approach described for this indicator (CP06) have been identified by Jones *et al.* (2003) as:

i) Combine existing climatic data (at 50 km x 50 km intervals) with inherent soil susceptibility data to produce estimates of subsoil vulnerability to compaction.
ii) Improve the resolution of the agro-meteorological data at European scale, preferably to 25 km x 25 km;
iii) Incorporate the quantitative results from recent soil mechanics research (Van den Akker, 1999, Van den Akker and Canarache, 2001);
iv) Use pedotransfer functions based on the latest research, for example those computed by Horn and Fleige (2000).

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1.16 BI01 Earthworm diversity

Key issue: Decline in biodiversity
DPSIR classification: Impact

Main information: Measuring this indicator will provide information on the species diversity of earthworms. Together with other biodiversity indicators and complementary information (e.g. land use, soil type, climate) it will provide information on the decline of biodiversity.

1.16.1 Example

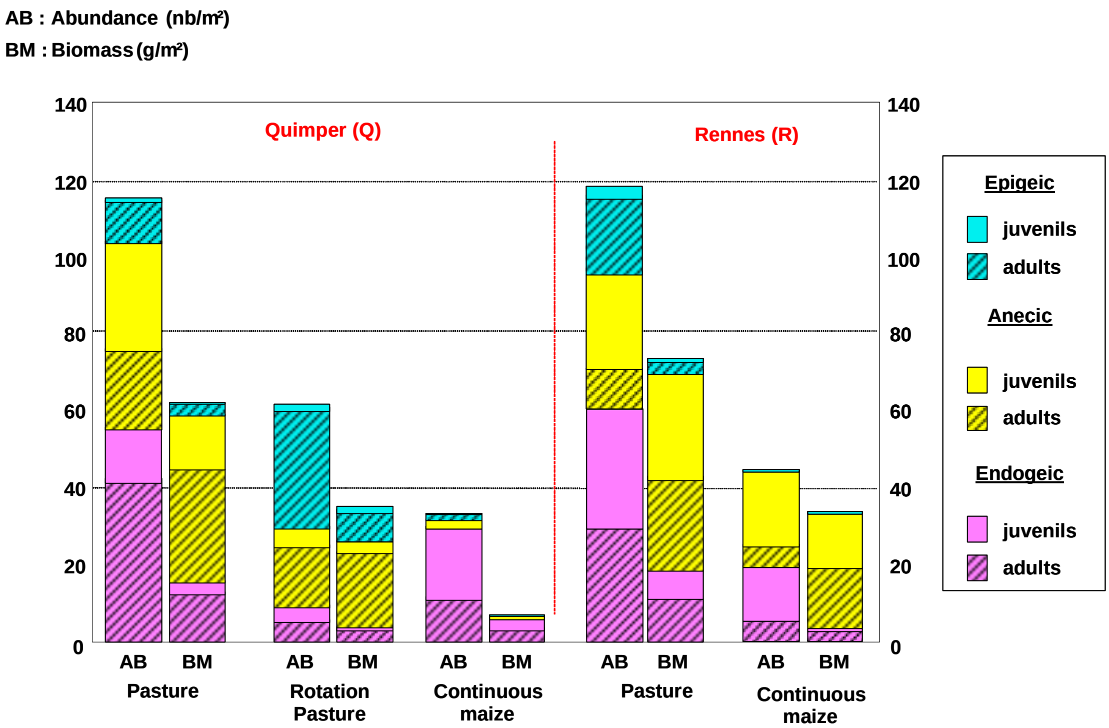

Figure 1.16.1 Example for indicator presentation - Abundance and biomass of earthworms in 2 locations (Quimper and Rennes, France) with different land-uses

Earthworm counts (density and biomass) may be converted into ecological groups (see chapter "Scientific background") which appeared to be inversely proportional to the anthropogenic pressure:

In continuous maize (ploughing each year, use of pesticides) the lowest earthworm density and biomass ($p<0.05$) is found, with a domination of endogeic (Q) or a mixture of endogeic and anecic (R) species; this difference is related to the different agricultural practices within the maize crop. By contrast, the permanent pastures present the highest earthworm density and biomass ($p<0.05$) and the three ecological categories are always observed. The intermediate situation, i.e. rotated pasture, presents intermediate biomass and abundance values, and is dominated by epigeic and anecic species, showing the speed of colonisation by the different species.

Furthermore, all ecological categories are very perturbed by the agricultural practices in the maize crop, but the impact is different according to the categories:

Epigeic and large individuals (anecic, endogeic adults) are the most affected,

Depending on the soil cover (which is reduced in maize) and mechanical actions (tillage) sensitivity of the species differs.

1.16.1.1 Significance

This indicator will provide information on the diversity of earthworms. Together with other indicators for biodiversity and other information (e.g. land use, soil type, climate) it will provide information on the decline of biodiversity.

1.16.1.2 Policy context

The importance of soil biodiversity is acknowledged in international treaties (UN-CBD, UNFCCC, UNCCD), by international organisations (OECD, FAO, UNEP, CGIAR) and by national governments. The UN treaties are implemented through national policies, strategies and action programmes, in which the role and protection of (soil) biodiversity is addressed. However, the scope of attention to this issue in each country depends on awareness by decision makers, human capacities and knowledge, financial resources and priorities. Soil biodiversity needs to be protected because of its intrinsic value, and its ecological functions in the soil. Moreover, through support for appropriate land use systems and management practices, soil biological functions can be enhanced with multiple benefits in terms of increased productivity, increased efficiency of resource use and hence reduced costs of external inputs, increased sustainability and reduced erosion and pollution.

1.16.1.3 Scientific background

Earthworms are without any doubt the most important soil invertebrates in temperate regions (Bretscher, 1896; Graff, 1953; Stöp-Bowitz, 1969; Bouché, 1972; Rundgren, 1975) and, to a lesser extent, in tropical soils (Satchell, 1983; Lavelle, 1984; Lee, 1985; Anderson, and Ingram, 1993; Römbke *et al.*, 1999). Since Darwin (1881) their influences on soil properties via their burrowing activities and organic matter feeding are acknowledged, and their impacts on soil functions, such as soil aeration, water holding capacity, litter decomposition and nutrient cycling, are increasingly documented (Petersen and Luxton, 1982; Edwards and Bohlen, 1997; Nuutinen *et al.*, 2001). Their activities are strongly related to the three main ecological groups:

Epigeic species, live on soil surface, create no or few burrows,

Anecic species, live in semi-permanent burrows more or less vertical, and mixe organic matter that they have collected on soil surface to mineral soil

Endogeic species dig extensive and very branched systems of ephemeral subhorizontal burrows and feed evoluated organic matter found in soil. Furthermore, studies have also shown the high diversity of activities within the different ecological groups (BBodSchG, 1998; Blakemore, 2002; Edwards and Bohlen, 1997).

Furthermore, they are also important in many terrestrial food-webs due to their very high biomass.

1.16.1.4 Assessment of results

Several sampling methods for earthworms have been developed and compared (Zicsi, 1958; Raw, 1959; Thielemann, 1986; Gunn, 1992; Vetter, 1996; Dunger and Fiedler, 1997; Lawrence and Bowers, 2002; Zaborski, 2003). In order to harmonise future data, earthworms will be extracted from soil samples with the standardised method ISO 23611-1 (2006). The following measurement endpoints can be used for the bio-classification of a soil (including bio-indication or bio-monitoring for, e.g., anthropogenic stress) as well as the evaluation of effects of chemicals on earthworms in the field:

Abundance (number of individuals per area or volume);

Biomass (fresh or dry weight of the population per area or volume);

Species (Bouché, 1972; Ljungstrom, 1979) or other taxonomically or ecologically defined groups;

Dominance spectrum of species or ecological groups (in percentage of the population);

Age structure of the population (e.g. the adult/juvenile ratio);

Morphological alterations in individuals.

Firstly the number and biomass of worms are quantified and expressed as individuals per sample and gram per sample (separately for hand-sorting and formalin samples). Secondly both values (hand sorting, formalin) are added in order to determine the total abundance and biomass of earthworms. This number is then multiplied by a factor in order to achieve the number of worms per square meter. Additionally, the age structure (juveniles and adults are differentiated by the presence of a clitellum) can be determined with the help of the dissecting microscope. Earthworm species can be classified into ecological groups. The species dominance structure is expressed in terms of species richness, species diversity by using indices (e.g. Shannon or Simpson index or the equitability index (measured species diversity/maximal species diversity)). Other indices may also be calculated as SOILPACS (Spurgeon *et al.*, 1996; Weeks *et al.*, 1997).

1.16.2 Meta data

1.16.2.1 Technical information

i) **Data source:** There are already several EU datasets identified (e.g. Netherlands, France, Germany). The Dutch approach appears to be the most developed monitoring approach (Schouten *et al.*, 1999). For example, a field monitoring approach has been developed in vineyard systems in France. It records biological parameters (earthworms, microbial biomass) and basic physico-chemical characteristics. Other datasets are available from transect or field studies. Nevertheless all the available data can be used later to define baseline/threshold values across the EU.

ii) **Description of data:** For each dataset, the raw data usually consists of the names of the species with their respective numbers (and/or biomass).

iii) **Geographical coverage:** Up to now, only the Netherlands has a complete monitoring network with data on earthworms. In France it is limited to some vineyard regions (Champagne, Burgundy, Beaujolais) while in Germany mainly the North-Western part is covered.

iv) **Spatial resolution:** Nearly all EU monitoring networks are stratified according to land use (including land management)

v) **Temporal coverage:** The Dutch network started with biological sampling in 1997, the French one in 1990 and the German one in 1992.

vi) **Methodology and frequency of data collection:** In the Netherlands samples are taken every 6 years (three samples are collected and earthworms are extracted by hand sorting. In France, samples are taken every 3-4 years (in March) and three samples are collected and extracted by a combination of the formaldehyde method and hand-sorting. It should be noted that the methods used for sampling are partly different from the ISO method published in 2006. In all countries in which earthworms are sampled, detailed information concerning the site (soil pedological variability, land use and land management) is required. The sampling is done during favourable climate periods of the year (and the sampling day).

vii) **Methodology of indicator calculation:** Survey of abundance (and/or biomass) of individuals. This information is converted into diversity indices or compared with other data sets using multivariate methods.

viii) **Availability of baselines and thresholds:** Up to now baselines are only available for certain regions and land uses within the EU while thresholds are not yet available. However, a methodology can be proposed in order to define such values. In any case baselines are different according to land uses: in pastures their number should be between 60-80 ind/m², and in vineyards between 40-50 ind/m² (French data). Furthermore, the relative or absolute abundance of the different ecological groups should also be used, in relation to the functional impacts of these groups. For example, the absence of anecic species in pastures or crop systems is considered to have a strong impact on the soil ecosystem.

1.16.2.2 Quality information

i) **Strength and weakness**: Up to now data for all regions of the EU are not available. Nevertheless several datasets already exist. The quality of data in these datasets is different as the sampling was generally performed with different methods. This situation will change as for new measurements an ISO method is now published.

ii) **Data comparability**:
Comparability over time: Data are comparable if samples are taken during the same period (e.g. sampling in spring or in autumn). Variations may occur if land use changes or if climatic conditions before sampling are strongly different from the previous sampling. *Comparability over space*: As the distribution of soil organisms depends on soil characteristics their variability will be considered by the sampling strategy.

1.16.3 Further work required

The following work is required to make the use of this indicator simpler:

i) Develop new datasets by using a harmonised approach at different locations across the EU integrating different climates, soil types, land uses and agricultural practices
ii) Simplify identification by developing e-tools/software
iii) Compare datasets from different countries, land uses and agricultural practices in order define threshold values and baselines

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1.17 BI01A Enchytraeid diversity

Key issue: Decline in biodiversity
DPSIR classification: Impact

Main information: Measuring this indicator will provide information on the species diversity of enchytraeids. This indicator is to be measured if earthworms are not available in the soils. Together with other biodiversity indicators and complementary information (e.g. land use, humus form, climate) it will provide information on the biological state of the soil and on changes in soil biodiversity.

1.17.1 Example

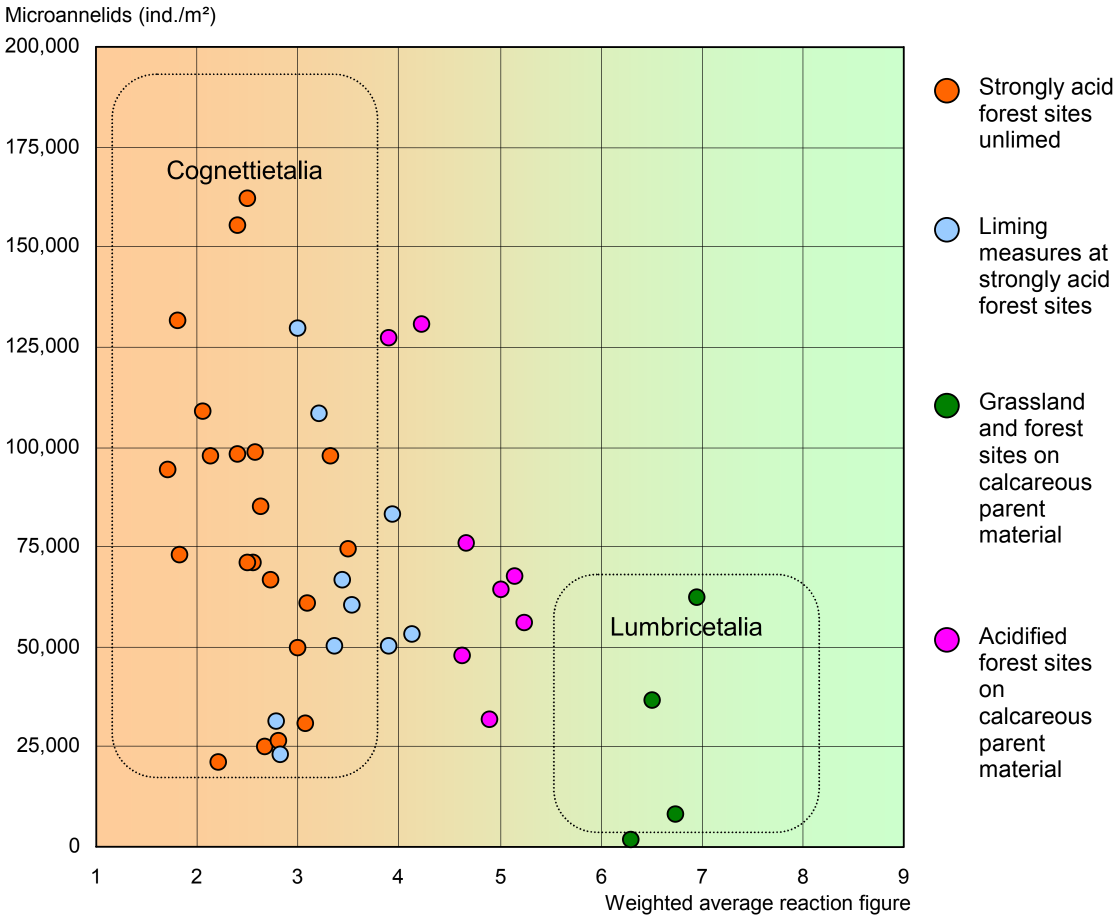

Figure 1.17.1 Biological condition of soils at permanent soil monitoring sites in North Rhine-Westphalia - Diagram with two biological indices: the total abundance of enchytraeids and the weighted average reaction figure of the annelid community

The species are classified with respect to their occurrence along the gradient of soil pH into indicator value groups figured from 1 (indicator of extreme acidity) to 9 (indicator of basic reaction). The average reaction figure is the calculated mean of indicator values of all species within a given community. The weighted average reaction figure is the mean of indicator values multiplied by a factor 1 to 5 for the abundance class of the species. (Beylich and Graefe, 2002; Beylich *et al.*, 1995; Graefe, 1997, 1998; Graefe *et al.*, 1998, 2001, 2002; Graefe and Schmelz, 1999; Graefe and Beylich, 2003, 2006).

There are two distinct groups corresponding to different soil community types. Lumbricetalia are dominated by anecic and endogeic earthworms. Cognettietalia are dominated by enchytraeids. Owing to the absence of soil mixing earthworms soil life in Cognettietalia is largely restricted to the humus layer. In terms of humus forms Cognettietalia corresponds to Moder/Mor and Lumbricetalia to Mull. Species diversity is increasing from Mor to Mull. Liming has shifted the species composition from indicators of strongly acid condition in the direction to indicators of moderately acid condition, but has not resulted in switching to another community type. High abundances of enchytraeids in Mor/Moder indicate high biological activity through the eutrophying effect of high nitrogen deposition.

1.17.1.1 Significance

This indicator will provide information on the diversity of enchytraeids. Together with other indicators for biodiversity and other information (e.g. land use, soil type, climate) it will provide information on the decline of biodiversity.

1.17.1.2 Policy context

The importance of soil biodiversity is acknowledged in international treaties (UN-CBD, UNFCCC, UNCCD), by international organisations (OECD, FAO, UNEP, CGIAR) and by national governments. The UN treaties are implemented through national policies, strategies and action programmes, in which the role and protection of (soil) biodiversity is addressed. However, the scope of attention to this issue in each country depends on awareness by decision makers, human capacities and knowledge, financial resources and priorities. Soil biodiversity needs to be protected because of its intrinsic value, and its ecological functions in the soil. Moreover, through support for appropriate land use systems and management practices, soil biological functions can be enhanced with multiple benefits in terms of increased productivity, increased efficiency of resource use and hence reduced costs of external inputs, increased sustainability and reduced erosion and pollution.

This indicator is measured in the context of the biological classification of soils including soil quality assessment (Beylich *et al.*, 1995; Jänsch and Rombke, 2003), terrestrial bioindication and long-term monitoring (Graefe and Schmelz, 1999) as well as for the evaluation of the effects of chemicals on soil animals (Römbke *et al.,* 2002). Right now, most studies are performed in the context of scientific research but enchytraeids are increasingly used in governmental programs (e.g. in the Netherlands, Germany or Austria).

1.17.1.3 Scientific background

Enchytraeids are small soil-inhabiting worms (few mm to several cm in length) belonging to the family Enchytraeidae, order Oligochaeta, class Clitellata, phylum Annelida. In acidic soils (e.g. in coniferous forests) they can replace earthworms as ecosystem engineers. Their influence on soil functions like litter decomposition, soil pore structure or nutrient cycling, is well known (Graefe, 1997, 1998, 1999, 2004; Römbke, 1991). Due to their often very high number (and population biomass) they are also important in many terrestrial food webs (Didden 1993; Graefe and Beylich, 2006).

1.17.1.4 Assessment of results

Enchytraeids are extracted from soils samples with the standardized method ISO 23611-3 (2006) and identified in the laboratory. The name and number of species are determined. These results can be used to calculate either diversity indexes or to compare the respective data set with a reference data set, for example by using multivariate statistics.

1.17.2 Meta data

1.17.2.1 Technical information

i) **Data sources:** There are several data sets from monitoring systems in Austria (A) (Bauer, 2000, 2003) Germany (D) (Graefe *et al.*, 1998; Barth *et al.*, 2000; Graefe, 2005) and the

Netherlands (NL) (Rutgers *et al.*, 2005). Other data sets come from transect or field studies. All the available data can be used to define baseline/threshold values across EU.

ii) **Description of data:** The raw data usually consist of the names of the species with their respective numbers. Then this information is converted into diversity indices.

iii) **Geographical coverage:** D: Schleswig Holstein, Hamburg, Nordrhein-Westfalen, Hessen, Mecklenburg-Vorpommern (partly), Brandenburg (partly). A: Land Salzburg. NL.

iv) **Spatial resolution:** A, D and NL monitoring network is stratified according to land use.

v) **Temporal coverage:** Enchytraeid sampling at German soil monitoring sites started in 1992, at Austrian sites in 1996. NL network started biological sampling in 1997.

vi) **Methodology and frequency of data collection:** In D samples are taken in intervals of 5 (Nordrhein-Westfalen) to 10 years (Hamburg), in Salzburg 3 to 6 years, in NL every 6 years. In D and A 10 replicates are collected at each sampling occasion. Soil cores are divided in 4 vertical subsamples and extracted by wet funnel method (ISO 23611-3, 2006).

vii) **Methodology of indicator calculation:** The species are classified with respect to their occurrence along the gradients of soil pH, soil moisture, and salinity, as well as to their reproductive strategy, stress tolerance, and their occurrence in the continuum of humus horizons and humus forms. Multiple species information is aggregated to one value per site and inventory by calculating average indicator values and life-form ratios.

viii) **Availability of baselines and thresholds:** Baselines and thresholds according to soil parameters as pH are published in numerous papers (Healy, 1980, Didden, 1993; Graefe, 1993, 2005; Graefe *et al.*, 2001, 2002, Beylich and Graefe, 2002, Graefe and Beylich, 2003; Jänsch and Römbke, 2003; Jänsch *et al.*, 2005)..

1.17.2.2 Quality information

i) **Strength and weakness***:* Up to now data for all EU are not available. Nevertheless several datasets already exist and may be available. The quality of data in these data sets is different as the sampling was generally performed with different methods. This situation will change as for new measurements an ISO method is now published.

ii) **Data comparability**:
Comparability over time: overtime data are comparable if samples are taken at the same period (e.g. sampling in spring or in autumn). Variations may occur if land use changes or if climatic conditions before sampling are strongly different from the previous sampling.
Comparability over space: as the repartition of soil organisms depends on soil characteristics their variability will be considered by the sampling strategy.

1.17.3 Further work required

The following work is required to make the use of this indicator simpler:

Develop new datasets by using an harmonized approach on different locations across EU integrating different climates, soil types, land uses and agricultural practices.

Datasets from various countries (in particular Germany and the Netherlands) have to be compiled in order to define threshold values and baselines.

Research is progressing to develop software and/or technical guides allowing an easy identification step. Furthermore identification of soil species with DNA extracts is also a matter of research and will maybe produce DNA arrays within 10 years.

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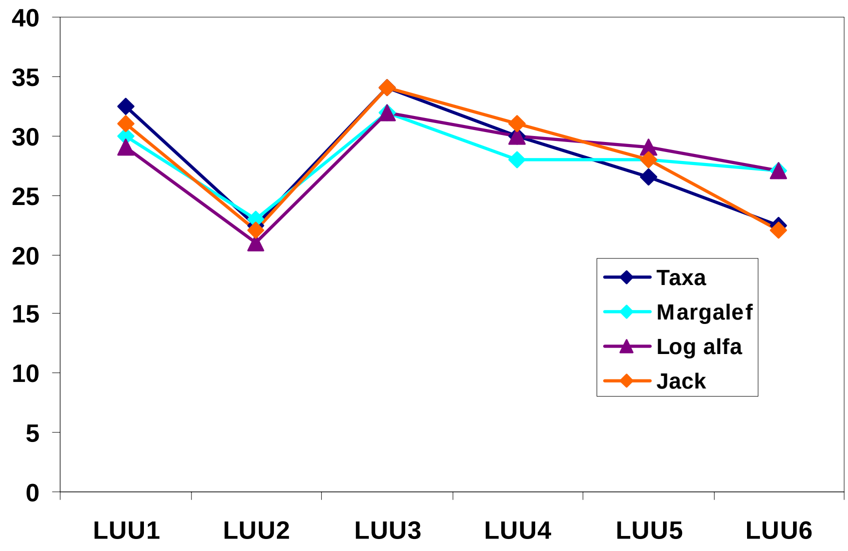
1.18 BI02 Collembola diversity

Key issue: Decline in biodiversity
DPSIR classification: Impact

Main information: Measuring this indicator will provide information on the species diversity of collembola. Together with other biodiversity indicators and complementary information (e.g land use, soil type, climate) it will provide information on the decline of biodiversity.

1.18.1 Example



LUU1 old-growth forest, LUU2 managed forest, LUU3 forest / woodland-dominated landscape, LUU4 mixed-use landscape, LUU5 pasture-dominated landscape, LUU6 arable crop-dominated landscape (from Sousa *et al.*, 2006).

Figure 1.18.1 Concordance analysis based on Collembola diversity and richness measures (at landscape scale) related to landscape composition

Species richness at landscape level (gamma diversity) presented higher and similar values in natural old-growth forests (LUU1) and mixed-use landscapes (LUU4), than in heavily managed forests (LUU2) or crop areas (LUU6). A decrease in forest cover did not cause a decrease in gamma diversity, since the loss of forest species was compensated for with species typical from open areas.

1.18.1.1 Significance (target or objective)

This indicator will provide information on the diversity of collembola. Together with other indicators for biodiversity and other information (e.g land use, soil type, climate) it will provide information on the decline of biodiversity.

1.18.1.2 Policy context

The importance of soil biodiversity is acknowledged in international treaties (UN-CBD, UNFCCC, UNCCD), by international organisations (OECD, FAO, UNEP, CGIAR) and by national governments. The UN treaties are implemented through national policies, strategies and action programmes, in which the role and protection of (soil) biodiversity is addressed. However, the scope of attention to this issue in each country depends on awareness by decision makers, human capacities and knowledge, financial resources and priorities. Soil biodiversity needs to be protected because of its intrinsic value, and its ecological functions in the soil. Moreover, through support for appropriate land use systems and management practices, soil biological functions can be enhanced with multiple benefits in terms of increased productivity, increased efficiency of resource use and hence reduced costs of external inputs, increased sustainability and reduced erosion and pollution.

1.18.1.3 Scientific background

The widespread use of Collembola in soil ecological studies is connected to the good taxonomic knowledge of the group and to their representativity in the soil system. Reaching high diversity and density levels (Hopkin, 1997), Collembola can have an important contribution to soil fauna biomass (12-13%) and to total soil fauna respiration, depending on the ecosystem considered (Petersen, 1994). Collembola act mainly as catalysts of the organic matter decomposition process (Petersen, 2002),contributing to an increase in surface area for microbial attack, and acting as dispersal agents of fungal spores and bacteria.

Moreover, acting as selective grazers, Collembola may promote fungal succession in decomposing plant material. These characteristics allowed their use as indicator organisms in several research programmes dealing with the impacts of forest practices (Huhta, 2002; Lindberg and Persson, 2004; Lauga-Reyrel and Deconchat, 1999; Ponge *et al.*, 1993, 2003; Sousa *et al.*, 1997, 2000, 2006) or crop management practices (Dekkers *et al.*, 1994; Filser *et al.*, 1995, 1996; Heisler and Kaisser, 1995; Loranger *et al.*, 1999; Frampton and Van den Brink, 2002). These features make them suitable organisms to be used as bio-indicators of changes in soil quality, especially due to land use practices and pollution (Van Straalen, 1997, 2004).

1.18.1.4 Assessment of results

Collembola will be extracted from soils samples with a standardized method (ISO 23611-2, 2004) and identified in the laboratory. The name and number of species will be determined. These results can be used to calculate several indicators as diversity and richness measures, taxonomic profiles and indicator species (e.g., using IndVal software).

Species richness and species diversity measures can be used to assess effects of different drivers on changes on soil biodiversity by comparing the obtained values with baseline values of the same land-use type under the same eco-climatic conditions. Similar comparative approach can also be adopted by comparing community composition (or taxonomic profiles) of the different sites over time using multivariate methods (several methods are available and some include the possibility to attach statistical significances to the comparisons and also to verify which species, or other taxonomic units, are responsible for observed changes).

A different approach to assess changes in soil quality can be the use of integrative indexes. Several approaches can be adopted. Most of them are based on the comparison of the community composition of impacted sites against the one found on reference sites under similar eco-climatic conditions; these were developed for soil macrofauna but the concept can be adopted for soil mesofauna (e.g., SoilPacks). Another approach is based on the use of life traits (the QBS index) and rating the presence of individuals according to certain morphological traits. This approach has been used to compare soil quality in grassland and crop areas (with good correlation with land-use intensity), but more work is needed to use it successively in forested areas.

1.18.2 Meta data

1.18.2.1 Technical information

i) **Data sources:** There are already several EU datasets identified but only one concerns an EU country, the Netherlands (NL), in a monitoring system. Other datasets came from transect or field studies. Nevertheless all the available data can be used later to define baseline values across EU.

ii) **Description of data:** The raw data usually consists on the names of the species with their respective numbers. Then this information is converted into diversity indices.

iii) **Geographical coverage:** Up to now, only NL has a complete monitoring network with data on collembola.

iv) **Spatial resolution**: NL monitoring network is stratified according to land use.

v) **Temporal coverage:** NL network starts biological sampling in 1997

vi) **Methodology and frequency of data collection**: In NL samples are taken every 6 years and 3 samples are collected and extracted by hand sorting for earthworms. It should be noted that the method used for sampling is different from the ISO method published in 2006.

vii) **Methodology of indicator calculation**: In general terms, several approaches can be used. (1) biodiversity descriptors (richness and diversity measures) can be calculated at land-use or landscape level, and changes in these parameters can be monitored through time (e.g., reporting always in relation to the existing baseline value); (2) significant changes in community composition over different sites within the same land-use type (e.g., comparing impacted and reference sites) can be monitored on a spatial and temporal basis using available multivariate tools; (3) indicator species for a pre-defined habitat typology (e.g., each land-use type within a certain geographical area) can be selected and monitored through time, again comparing to a possible baseline value (this last option can be more difficult because indicator species are, most of the times, more region dependent than land-use dependent, or an interaction between the two).

viii) **Availability of baselines and thresholds:** Up to now baselines or thresholds are not available but a methodology can be proposed in order to define such values.

1.18.2.2 Quality information

i) **Strength and weakness**:
At present data for all EU member states are not available. Nevertheless several datasets already exit and may be available. The quality of data in these datasets is varied as the sampling was generally performed with different methods. This situation may change as for new measurements a draft ISO method is now published.

ii) **Data comparability:**
Comparability over time: data are comparable if samples are taken during the same period or season (e.g. sampling in spring or in autumn). Variations may occur if land use or climatic conditions are very different from that present during the previous sampling.
Comparability over space: as the distribution of soil organisms is influenced by soil characteristics their variability will be considered by the sampling strategy.

1.18.3 Further work required

The following work is required to make the use of this indicator simpler:

i) Develop new datasets by using an harmonized approach at different locations across EU integrating different climates, soil types, land uses and agricultural practices.
ii) Simplify identification by developing e-tools.
iii) Assess the use of surrogate taxonomic groups (e.g., genera or family) for the number of species
iv) Adapt the strategies adopted for soil macrofauna to derive soil quality indexes
v) Compare existing datasets in order define threshold values and baselines for different land-use types under similar eco-climatic conditions

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1.19 BI03 Soil microbial respiration

Key issue: Decline in biodiversity
DPSIR classification: Impact

Main information: By measuring the soil microbial respiration an integrated measure of microbial biomass and activity and soil organic matter quantity and quality is obtained. Hence, this indicator will give a measure of the soil biological functioning. This soil functioning is based on the diversity and activity of all individual players in the soil.

1.19.1 Example

Soil samples were taken from the upper 10 cm surface layer in the Demmerikse Polder (NL) (Boivin *et al.*, 2006). Chemical and biological parameters were measured. Correlations between metals and CO_2 production are presented in the following table. In this example CO_2 production is strongly correlated negatively with total metal concentrations.

Table 1.19-1 Example for data presentation – Correlation between CO_2 production and the total concentration of trace elements

		Total concentrations			
	n	Pb	Zn	Cu	Cd
$C0_2$ production (mg C/kg)	18	-0.74***	-0.63**	-0.66**	-0.83***

n: number of values used for the analysis; significance level: **P = 0.01; ***P = 0.001.

1.19.1.1 Significance

By measuring the soil microbial respiration an integrated measure of microbial biomass and activity, and soil organic matter quantity and quality is obtained. Hence, this indicator will give a measure of the soil biological functioning. This soil functioning is based on the diversity and activity of all individual players in the soil.

1.19.1.2 Policy context

The importance of soil biodiversity is acknowledged in international treaties (UN-CBD, UNFCCC, UNCCD), by international organisations (OECD, FAO, UNEP, CGIAR) and by national governments. The UN treaties are implemented through national policies, strategies and action programmes, in which the role and protection of (soil) biodiversity is addressed. However, the scope of attention to this issue in each country depends on awareness by decision makers, human capacities and knowledge, financial resources and priorities. Soil biodiversity needs to be protected because of its intrinsic value, and its ecological functions in the soil. Moreover, through support for appropriate land use systems and management practices, soil biological functions can be enhanced with multiple benefits in terms of increased productivity, increased efficiency of resource use and hence reduced costs of external inputs, increased sustainability and reduced erosion and pollution. Soil microbial respiration is a very targeted measure of soil biological functions.

1.19.1.3 Scientific background

Decomposition of organic matter is one of the most important functions of soil as it enables the recycling of dead organic matter and provides minerals for plant growth. Decomposition is the oxidation of carbon to CO_2 and can be measured either by CO_2 release or O_2 consumption. CO_2 release is a more sensitive parameter due to low atmospheric content of CO_2. Soil microbial respiration is correlated with soil organic matter and often with microbial biomass and activity (Winding *et al.*, 2005).

1.19.1.4 Assessment of result

Soil biological respiration should be determined by the ISO standard 16072:2002: “Soil quality – Laboratory methods for determination of microbial soil respiration”. This standard describes:

- measurement of O_2 consumption by static incubation in a pressure-compensation system
- determination of CO_2 release by titration in a static system
- coulometric determination of CO_2 release in a static system
- determination of CO_2 release using an infrared gas analyser in a flow-through system
- determination of CO_2 release using gas chromatography in a flow-through system and in a static system
- determination of soil respiration by pressure measurement in a static system

Which of these methods to choose in the exact situation is dependent on a site and soil specific evaluation.

For soil sampling and characterization of the soil, the ISO standards 10381-6:1993, Soil quality – Sampling – Guidance on the collection, handling and storage of soil for the assessment of aerobic microbial processes in the laboratory, ISO 11274:1998, Soil quality – Determination of water-retention characteristic – laboratory methods, and ISO 11465:1993, Soil quality – Determination of dry matter and water content on a mass basis – Gravimetric method, should be applied.

1.19.2 Meta data

1.19.2.1 Technical information

i) **Data sources:** Existing data sets from A, NL, D, CH. Other data sets might be available from transects and experimental studies.

ii) **Description of data:** Data are usually presented as O_2 consumption or CO_2 release. Conversion between the two measures and also between the different methods for measuring CO_2 release is missing.

iii) **Geographical coverage:** Not available all over Europe, but many EU countries have already integrated the soil microbial respiration in their soil monitoring networks as A, G, NL, UK, CZ.

iv) **Spatial resolution:** Depending on the soil networks (grid vs stratified according to land use)

v) **Temporal coverage:** Sampling in spring or autumn

vi) **Methodology and frequency of data collection:** Every year if possible but no longer than every 5 years

vii) **Methodology of indicator calculation:** Determination of O_2 consumption or CO_2 release

viii) **Availability of baselines and thresholds:** not yet available for all EU

1.19.2.2 Quality information

i) **Strength and weakness***:* up to now data for all EU are not available. Nevertheless several datasets already exit and may be available. The quality of data in these datasets has to be checked according to sampling and analysis methods.

xi) **Data comparability:**
Comparability over time: overtime data are comparable if samples are taken at the same period (e.g. sampling in spring or in autumn). Variations may occur if land use changes or if climatic conditions before sampling are strongly different from the previous sampling.
Comparability over space: as the repartition of soil organisms depends on soil characteristics their variability will be considered by the sampling strategy.

1.19.3 Further work required

Develop new datasets by using an harmonized approach on different locations across EU integrating different climates, soil types, land uses and agricultural practices.
Compare existing datasets in order to define threshold values and baselines for different land-use types under similar eco-climatic conditions.

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1.20 SL01 Salt profile

Key issue: Salinisation
DPSIR classification: State

Main information: The salt profile gives a complete picture of the salinity/sodicity state of the soil, or more exactly the salt-affected area. The salt profile gives the vertical and horizontal distribution as well as the chemical composition of the salts, which are extremely important data regarding the unfavourable impacts of salinisation/alkalisation/sodification.

1.20.1 Example

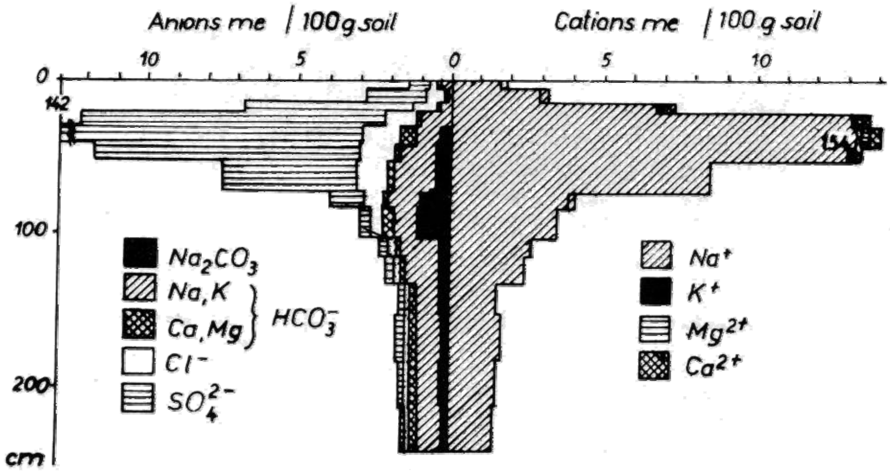

Figure 1.20.1 Salt profile of a shallow meadow solonetz soil in Hortobágy (Hungary)

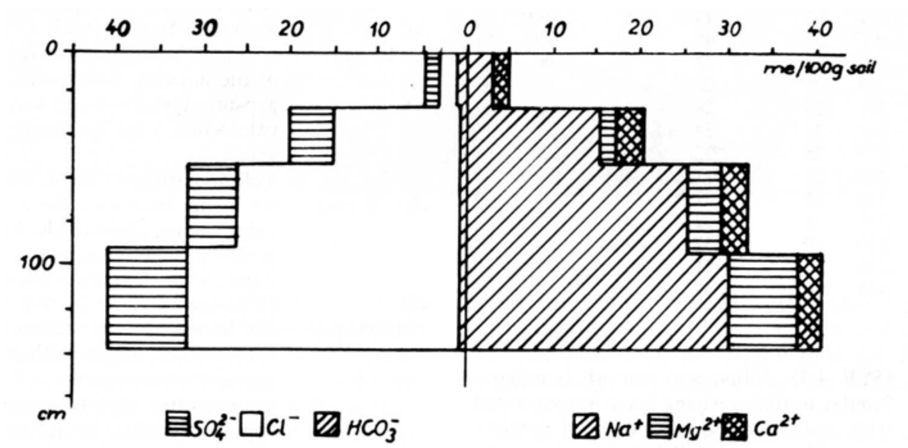

Figure 1.20.2 Salt profile of a saline soil (sulphate-chloride solonchak) in Marismas (Spain)

1.20.1.1 Significance

The salt profile gives a two-dimensional picture on the distribution of water soluble salts (content; vertical distribution; salt composition; quantity and ion composition of salts).

1.20.1.2 Policy context

Salt profiles are important characteristics for managing rational land use and cropping patterns; the amelioration and reclamation of salt affected soils for biomass production, and important parameters for the conservation or rehabilitation of salt affected lands as protected areas, with unique (or rare) flora and fauna. On the basis of salt profiles the necessary preventive measures or management practices can be implemented efficiently.

1.20.1.3 Scientific background

Salt accumulation is a world-wide soil degradation process. The most important ions are Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} cations, and CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} anions. Some of the sodium salts are highly alkaline (e.g. $NaHCO_3$, Na_2CO_3), others (NaCl, Na_2SO_4, calcium and magnesium salts) have a pH closer to neutral. The chemical composition of the salt solution determines soil pH and the exchangeable cations (see indicator ESP). The vertical distribution and chemical composition influence other soil characteristics, including solubility, mobility and availability of other constituents, and the physical–hydrophysical characteristics of the soil and soil moisture regime.

Salt profiles reflect the actual state of salt accumulation processes due to natural factors or human activities and are sensitive indicators and important diagnostic criteria for soil classification.

1.20.1.4 Assessment of results

The salt profile is the consecutive sequence and thickness of various soil layers (including diagnostic soil horizons), which can be measured during the field survey. The salt content of soil can be determined *in situ* in the field by various instruments. The total water soluble salt content is determined in most cases by measuring electrical conductivity (EC). For the determination of ion composition, ion selective electrodes can be used in the field.

The water soluble salt content can be determined from collected samples in laboratory. In this case the electrical conductivity measurement is carried out in the saturated soil paste and the salt composition is determined from the saturation extract or 1:5 water extract. The cations and anions are determined using a standard procedure. If the salt profiles are of adequate density, three-dimensional salt profiles can be constructed and if it combined with consecutive or continuous measurements (monitoring), conclusions can be drawn on the temporal variability as well.

1.20.2 Meta data

1.20.2.1 Technical information

i) **Data sources:** EU and national field measurements and laboratory analysis for salt-affected areas.

ii) **Description of data:** Vertical distribution of total soluble salt content and the vertical distribution of salt composition, including both anions and cations.

iii) **Geographical coverage:** Salt-affected regions in Europe.

iv) **Spatial resolution:** 1:100,000 scale for salt-affected areas

v) **Temporal coverage:** 1 to 3 years.

vi) **Methodology and frequency of data collection:** Either *in situ* field measurement or laboratory measurement from collected soil samples. Open profile at the beginning and boring in the next years from a sampling area with a diameter of 10 metres. Frequency of data collection: 1–3 years. The required sampling depth depends on a preliminary soil salinity test (*in situ*) from the soil surface to the salt accumulation horizon or to the groundwater table.

vii) **Methodology of indicator calculation:** Determination of the salt content in the soil profile

viii) **Availability of baselines and thresholds:** Depends on land use, e.g. arable land; intensive and extensive grasslands; permanent plantations (e.g. vineyards or orchards); nature protected areas. The characteristics of a 'normal' soil without any specific influence of salts and sodium is considered a baseline, i.e. the total amount of soluble salts is less than 0.05% or the electrical conductivity (EC) is less than 2 dS m^{-1} in the saturated soil paste. As a general threshold above which salt concentrations should be considered excessive, the following figures can be used: 0.15% total salt content or 6 dS m^{-1} EC in the 0–30/50 cm soil layer (depending greatly on ion composition and pH).

1.20.2.2 Quality information

i) **Strength and weakness:** The accuracy and uncertainty of data depend on the sampling strategy, sampling density and the representativity of the observation point or the collected samples. Reliability and accuracy depend on the main objective of the survey and on the reliability and accuracy of the applied methodology (including instrumentation). The main weakness is the limited availability of measured data, which can only be partly substituted by models, even after careful and precise field validation. Pedotransfer functions can be applied but only after careful validation.

ii) **Data comparability:**
Comparability over time: For the separation of spatial variability and time dynamism a precise sampling strategy must be elaborated and implemented which is specific for each situation.
Comparability over space: Point information needs to be upscaled and interpolated to regional or national scales (using any technique such as remote sensing, geostatistics, GIS); or *in situ* measurements and soil sampling in a time series. Temporal variability will then determine the frequency of measurements.

1.20.3 Further work required

More work is needed in salt-affected areas and areas at risk of salinisation (see SL03 indicator) to extend salt profiles in space (3D maps) and time (salt dynamics, salt balances).

Concerning existing ‘hot spots’ for salinisation/sodification, further work should focus on the preparation of 1:10,000–1:25,000 scale maps and the registration of annual changes. Sampling should be carried out preferably in the same season of the year to enable the distinction between spatial and temporal variability. In addition to the total salt content, the analysis of the saturation extract is advisable (especially in the case of high total salt content), determining exchangeable cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, anions CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-}. It enables measurement and calculation of ESP.

1.20.4 References

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1.21 SL02 Exchangeable sodium percentage (ESP)

Key issue: Sodification
DPSIR classification: State, Impact

Main information: The most important indicator selected for Sodification is exchangeable sodium percentage (ESP) which, together with Sodium Adsorption Ratio (SAR), quantify the the main processes in solonetz formation. Sodification results in unfavourable changes in the physical/hydrophysical soil properties and moisture regime of the affected areas, increasing the hazard (frequency, duration and ecological consequences) of extreme moisture situations.

The selected most important parameters: pH and exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) in the saturation extract.

1.21.1 Example

Hungary

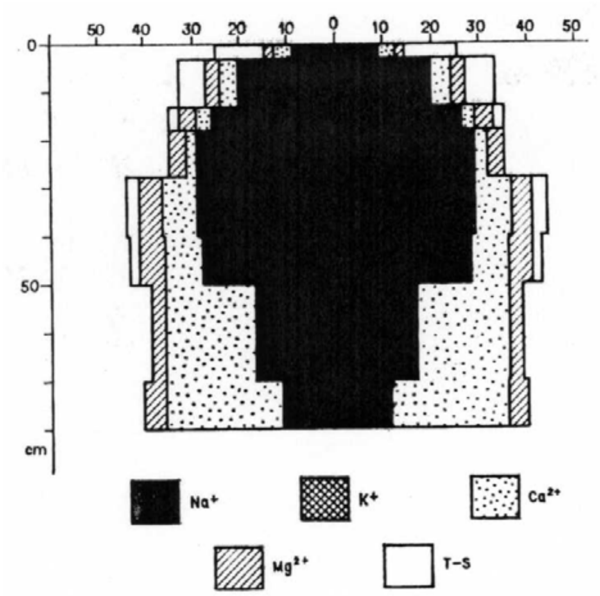

Figure 1.21.1 Profile of exchangeable cations (me/100 g soil) in a solonetz soil, Hortobágy region.

1.21.1.1 Significance

Sodium ions may occur in the solid and/or liquid phases of soil. Exchangeable cations are in the solid phases. Exchangeable sodium is – to a certain limit – responsible for the unfavourable physical, chemical, biological and agronomical characteristics of salt-affected soils. ESP is a widely accepted indicator of sodic or alkali soils and sodification (solonetz) processes.

1.21.1.2 Policy context

ESP and pH are important characteristics for rational land use and cropping pattern, the amelioration and reclamation of salt affected soils for biomass production and are significant parameters for the conservation, protection or rehabilitation of salt-affected areas with unique (or rare) flora and fauna. ESP is used for the calculation of the required dosage of amendments for sodic soil reclamation (e.g. gypsum requirement).

1.21.1.3 Scientific background

Exchangeable cations are in dynamic equilibrium with the ion composition of the soil solution. That is the reason why sodic soils with highly alkaline reaction can be saturated with sodium. In such soils, calcium and magnesium compounds are not soluble and do not release Ca and Mg ions into the soil solution. In many sodic soils, the $CaCO_3$ content is 20% or more, and no (or very few) Ca ions are in the soil solution due to the low solubility of $CaCO_3$ under alkaline reaction. The theory of the radical amelioration of sodic soils is to add Ca ions to the soil solution: giving soluble Ca compounds (gypsum, calcium nitrate) or to mobilize the $CaCO_3$ reserves in the soil using acidic material (e.g. sulphur, mineral acids, acidic industrial by-products, sulphur-containing lignite etc.). There is a close relationship between ESP and SAR (as described in Chapter 10) of the saturation extract.

1.21.1.4 Assessment of result example

Exchangeable cations and exchangeable sodium percentages (ESP) are determined by standard methods. The standardization of the procedure, however, is complicated because the traditional methods do not give accurate results when alkalinity is high (pH > 10). ESP is usually determined from the same soil sample as the salt content and salt composition, but with the use of different extractants.

1.21.2 Meta data

1.21.2.1 Technical information

i) **Data sources:** European and national field measurements and laboratory analysis for salt-affected soils.

ii) **Description of data:** Vertical distribution of exchangeable sodium percentage (ESP), pH and sodium adsorption ratio (SAR)

iii) **Geographical coverage:** Salt-affected regions in Europe

iv) **Spatial resolution:** 1:100,000 scale for salt-affected areas

v) **Temporal coverage**: 1–3 years

vi) **Methodology and frequency of data collection:** Cation exchange capacity (CEC) and exchangeable cations are determined by modified standard procedures 1–3 yearly.

vii) **Methodology of indicator calculation**:

Exchangeable sodium percentage: $ESP = \frac{Exch\ Na^{+}}{CEC} \cdot 100$

Where:

CEC = Exch ($Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$)

Sodium adsorption ratio (SAR) in water or saturation extract:

$$SAR = \frac{Na^{+}}{\sqrt{0.5\ (Ca^{2+} + Mg^{2+})}}$$

For sodicity hazard prediction, the following empirical relationship is used between SAR and ESP:

$$ESP = \frac{(1.475(SAR) - 1.26)}{(1 + (0.01475(SAR) - 0.0126))}$$

viii) **Availability of baselines and thresholds**: The baseline for ESP is 5%; SAR in the saturation extract is less than 4; pH is in a range of 5 to 8. The thresholds for Sodification are: ESP > 15; SAR > 10 and pH more than 8.5 in the accumulation horizon.

For practical purposes we use the following thresholds:

ESP < 5	no sodification symptom
ESP 5–15	slightly sodic (solonetzic) soil
ESP 15–25	strongly sodic (solonetzic) soil
ESP > 25	sodic (solonetz) soil

Depth of ESP accumulation:

< 7 cm	shallow sodic soil (solonetz)
7–15	medium sodic soil (solonetz)
> 15 cm	deep sodic soil (solonetz).

In sodic soils the pH in the eluvial A horizon can be neutral or even acidic, but the illuvial B horizon is always alkaline, in most cases highly alkaline.

1.21.2.2 Quality information

iii) **Strength and weakness**:
The accuracy and uncertainty of data depends on the sampling strategy and sampling density, the representativity of the observation point or the collected samples. Reliability and accuracy depends on the main objective of the survey and on the reliability and accuracy of the applied methodology (including instrumentation). The main weakness, however, is the limited availability of measured data. However, ESP can be estimated by calculation from the SAR value of the saturation extract and saturation percentage (SP).

iv) **Data comparability**:
Comparability over time: A precise sampling strategy must be elaborated and implemented that is specific for the given situation.
Comparability over space: Point information needs to be upscaled and interpolated to regional or national scales (using any technical possibility, like remote sensing, geostatistics, GIS); or *in situ* measurements and soil sampling in a time series, from which temporal variability can be used to determine the frequency of measurements.

1.21.3 Further work required

More work is needed in salt-affected areas and areas at risk of salinisation (see SL03 indicator) to extend ESP and pH profiles in space (3D maps) and time (pH and ESP dynamism).

Concerning existing ‘hot spots’ for salinisation/sodification, further work should focus on the preparation of 1:10,000–1:25,000 scale maps and the registration of annual changes. Sampling should be carried out preferably in the same season of the year to enable the distinction between spatial and temporal variability. In addition to the total salt content, the analysis of the saturation extract is advisable (especially in the case of high total salt content), determining exchangeable cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, anions CO_3^{2-} , HCO_3^{-}, Cl^{-} and SO_4^{2-}. It enables measurement and calculation of ESP.

1.21.4 References

Darab, K., Ferencz, K. (1969). Soil Mapping and Control of Irrigated Areas. OMMI. Budapest.

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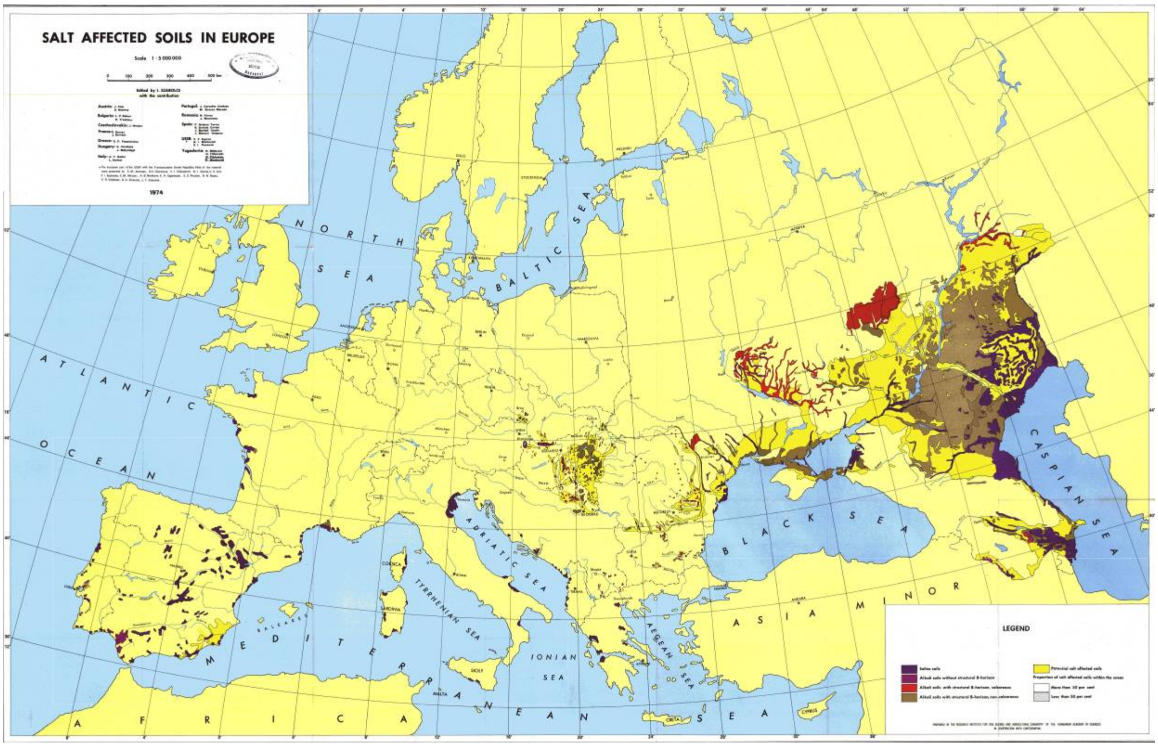
1.22 SL03 Potential salt sources (irrigation water, groundwater, seepage water) and vulnerability of soils to salinisation/sodification

Key issue: Potential salinisation/sodification
DPSIR classification: Pressure

Main information: Potential salinisation/sodification is the risk of saline or brackish irrigation water combined with inappropriate irrigation practices; salt accumulation from the rising water table with high salt content and unfavourable ion composition; the salt movement from the deeper horizons to upper layers or to the active root zone by capillary action; salt water inundation or subsurface intrusion from the sea.

1.22.1 Example



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

Figure 1.22.1 Distribution of salt-affected soils in Europe

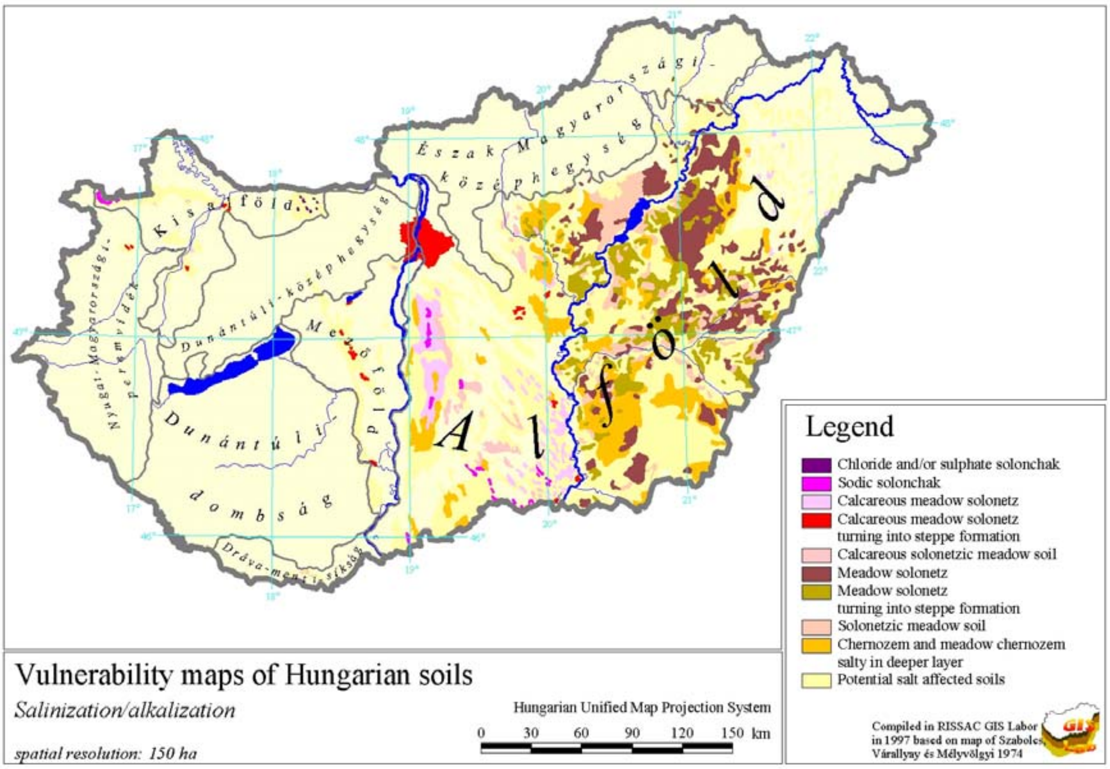


Figure 1.22.2 Map of soil vulnerability of salinization/sodification in Hungary.

1.22.1.1 Significance

The formation of saline and sodic soils is the result of the accumulation of salts from certain natural sources or as a consequence of human activities. Consequently, we propose the evaluation of potential salt sources (quantity of soluble salts and their ion composition) as indicators for this assessment.

1.22.1.2 Policy context

Secondary salinisation/sodification – as a result of human activities – has vital importance in many parts of the World. The extension of irrigated farming, combined with saline irrigation waters and soils vulnerable to salinisation/sodification, is increasing secondary salinisation/sodification. Agricultural production in such areas is the precondition of acceptable living conditions. At the same time, the strict quality control of irrigation water is opposed sometimes by the local population, because it is not understood that the favourable effects of irrigating with saline water only lasts for the first few years, with dire consequences in the long-term. Strict quality control is necessary both for sustainable production and for environmental conservation.

1.22.1.3 Scientific background

The preconditions of salt accumulation are as follows:

i) Presence of salt sources from local weathering, surface waters, subsurface waters and human activities;
ii) Presence of transporting agents (wind or water) that help the horizontal transportation of soluble salts from a large watershed with a small accumulation area or the vertical transportation of salts from a thick geological strata to a relatively thin accumulation horizon (maybe to the root zone);
iii) Presence of a driving force for solution movement (relief, hydraulic gradient, suction gradient, concentration gradient);
iv) Negative water balance (ET > P);

v) Limited drainage conditions (poor vertical drainage of soil profile and poor horizontal drainage of the threatened area).

Human-induced salt accumulation may take place under the following circumstances:

i) Salt accumulation from surface waters (areas with poor natural drainage);
ii) Salt accumulation from poor-quality irrigation water;
iii) Salt accumulation from rising groundwater with capillary solute transport to the overlying horizons, to the root zone or to the soil surface (salt efflorescence). The rise in water table can be the result of improper irrigation technology (as over-irrigation, uneven distribution of irrigation water; seepage from the water reservoir and unlined earth canals), bypass flow through cracks and biological channels.
iv) Limited leaching of accumulated salts during a frost-free vegetation season: lack of drain water reservoir; no water available for leaching (leaching requirement, leaching fraction). The latter is the real danger for irrigated orchards and vineyards using water saving technologies (as drip irrigation, etc.) in the Mediterranean Basin and in many other semi-arid and arid parts of the World.

Human-induced salinisation can be prevented or at least moderated to a tolerable degree by fitting the requirements of a strict irrigation water quality norm, not licensing the use of saline irrigation water in sensitive areas, and irrigation water quality control at the irrigated fields, because the good quality water may become enriched with salts, during the water transport in unlined earth canals from the pumping station to the irrigated plots.

1.22.1.4 Assessment of results

In Hungary, a precise water quality norm was introduced. Waters not fitting these criteria cannot be used for irrigation. The illegal use of poor quality irrigation water or the rising saline groundwater table has resulted in secondary salinisation in some areas. For the assessment of the vulnerability of soils to salinisation/alkalisation various chemical and biological soil characteristics have to be evaluated.

1.22.2 Meta data

1.22.2.1 Technical information

i) **Data sources:** EU and national field measurements and laboratory analysis for potential salt-affected areas.
ii) **Description of data:** Salt concentration and ion composition (including SAR and sodium percentage of irrigation water and groundwater); vulnerability of soils to salinisation/sodification in respect of irrigation technology (with or without drainage establishment).
iii) **Geographical coverage:** Potential salt-affected regions: areas where there is a potential risk of salinisation/sodification processes from irrigation water or from the rising saline water table (approx. 1.4 Million hectares in Europe).
iv) **Spatial resolution:** 1:100,000 scale for threatened (potential) salt-affected areas
v) **Temporal coverage:** yearly, for early warning and for the efficient prevention of salinisation /sodification in the threatened areas (‘hot spots’).
vi) **Methodology and frequency of data collection:** Permanent control of irrigation water at the pumping station and the irrigated field. Continuous or frequent measurement of the depth of the groundwater table and groundwater chemistry.
vii) **Methodology of indicator calculation**: Assessment of vulnerability of soils to salinisation/sodification in respect of irrigation technology based on salt concentration and ion composition (including SAR and sodium percentage of irrigation water and groundwater).
viii) **Availability of baselines and thresholds:**
The baselines for irrigation waters is less than 500 mg L^{-1} salt content or 0.5 $dS \cdot m^{-1}$ EC, less

than 4 SAR. The salt quantity threshold for irrigation water greatly depends on the chemical composition of salts (cation and anion composition, SAR, soda equivalent) and pH; the salt tolerance of vegetation and cultivated crop; and the method and practice of irrigation (less quantity of applied water than the leaching requirement or leaching fraction, e.g. water-saving irrigation practices such as drip irrigation). The baselines can be taken as thresholds, because in the case of baseline exceedance the water cannot be used for irrigation without special precaution measures, e.g. dilution or chemical improvement technologies.

The criteria are formulated precisely in the Hungarian irrigation water quality norm, which is a national standard set up by Ministerial Decree. In the Hungarian irrigation water quality norm five factors are taken into consideration (Source: Darab and Ferencz, 1969):

- dominant cations and anions (chemistry classes)
- total salt content
- sodium percentage (SAR)
- alkalinity against phenolphtalein
- soda (Na_2CO_3) equivalent

Depending on these characteristics irrigation water is classified into the following groups:
Irrigation water can be used:

- in all cases
- only for special soils and drainage classes
- only for ameliorated soils
- only for special land use practices (salt tolerant grasslands and crops)
- only after chemical improvement (dilution, with chemical amendments).

The water must fit these quality norms even in irrigated fields, because the salt content may increase during the water transport in unlined earth canals from the pumping station to the point of application.

Groundwaters accumulate the water soluble salts from a large area to a small accumulation territory and from thick geological strata to a relatively thin accumulation layer, in the worst case to the root zone. For the quantification of salt accumulation from groundwater, the following factors must be considered:

- depth and season dynamics of the groundwater table;
- chemistry of the groundwater (concentration and ion composition)
- capilliary transport from the groundwater to overlying horizons.

On this basis, the critical depth or critical regime of groundwater can be quantified (Kovda *et al.*, 1967; FAO, 1975). The rise of the saline groundwater table can be a consequence of seepage from reservoirs, canals, irrigated fields without or with poor natural or artificial drainage; over-irrigation; uneven distribution of water. The critical depth of groundwater depends on the chemistry of groundwater (salt concentration and ion composition), the salinity status of the soil profile and the character of the salt balance.

As a general threshold 1000 mg l^{-1} salt concentration and 10 SAR can be used. A proper early alarm system is a necessary for successful prediction, which is a key factor for the prevention of salinisation/sodification processes in endangered areas.

The thresholds of this key issue greatly depend on the vulnerability of soils to salinisation/sodification, determined by the following soil characteristics:

- Present salinity status of soil (see baselines);
- Physical properties of soil (texture, structure, compaction rate, bulk density, porosity)
- Hydrophysical properties of soil (infiltration rate, permeability, saturated and unsaturated and hydraulic conductivity, water retention)
- Vegetation cover and land use practice.

1.22.2.2 Quality information

i) **Strength and weakness:** The accuracy and uncertainty of data depends on the sampling strategy and sampling density; the representativity of the observation point or the collected samples. Reliability and accuracy depends on the main objective of the survey and on the reliability and accuracy of the applied methodology (including instrumentation). The main weakness, however, is the limited availability of measured data. Models can only be applied partially, even after careful and precise field validation. Pedotransfer functions can be applied only after careful validation.

ii) **Data comparability:**
Comparability over time: Depending on data availability
Comparability over space: Depending on data availability

1.22.3 Further work required

In the European Soil Thematic Strategy, the environmental threat salinisation/sodification has to be approached in two steps:

i) Delineation of actual salt affected areas as ‘hot spots’ and

ii) Identification of potential salt affected areas threatened by the possibility of salinisation/sodification under the influence of changing environmental conditions or various human activities (land use, irrigation, drainage, application of chemicals, waste and waste water management, etc.).

More detailed studies are needed on the delineation of ‘hot spots’ for the precise characterization and quantification of salinisation/sodification. This has to be purpose-specific (production – environment conservation – rural development etc.). These goals will determine the necessary scale of the study:

- spatial and time resolution;
- number and character of indicators;
- baselines and thresholds (preferably defined by numerical limit values).

The detailed observations in pilot studies can be extended to larger areas by similarity analysis and can be used for risk identification. The specific character of salinisation/sodification requires a specific approach in comparison to other soil threats in Europe.

For potential salt affected areas 1:50,000–1:100,000 scale maps should to be prepared, expressing the general soil characteristics determined during a traditional soil analysis. The salt concentration and ion composition of irrigation water must be measured at the pumping station. For the evaluation of groundwater, information is necessary on the depth, seasonal fluctuation, total salt content and SAR.

The required data are included in Table 10.7 in the Soil Salinisation chapter. To fully satisfy the user requirements, more comprehensive observations are needed on ‘hot spots’ (present salt affected land) and threatened areas making efficient land use and nature conservation possible.

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1.23 DE01 Land area at risk of desertification

Key issue: Desertification
DPSIR classification: State

Main information: 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 (Martínez-Fernández 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.

1.23.1 Example

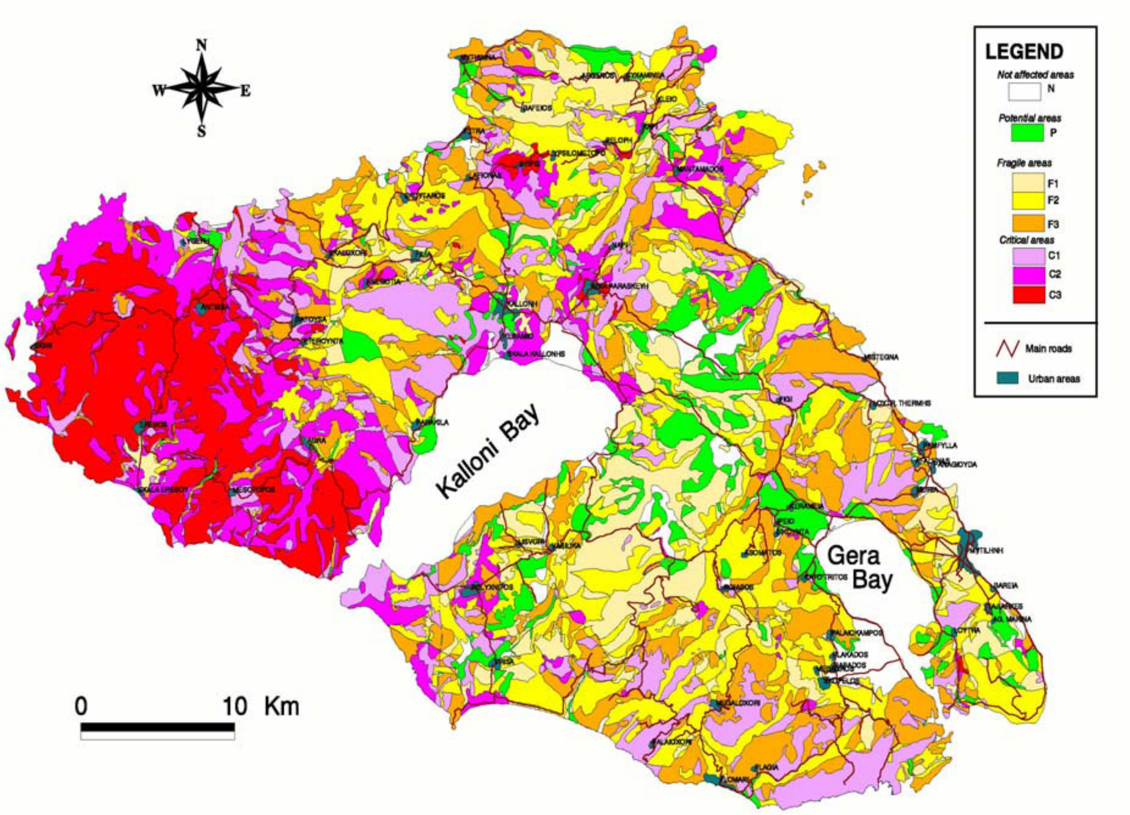

Figure 1.23.1 Map of environmentally sensitive areas to desertification for the island of Lesvos, Greece [After Kosmas *et al*., 1999a]

1.23.1.1 Methodology

Desertification is closely associated with a wide set of degradation processes (Brandt and Thornes, 1996) including decline in soil organic matter, soil erosion, soil salinisation, decline in soil biodiversity, over-exploitation of groundwater, wild fires (forest, scrub and grass 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 most affected are Spain, Portugal, southern France, Greece 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 pronged periods without rainfall follow.

Indicators of desertification have been thoroughly reviewed by the MEDALUS Project (Kosmas *et al.*, 1999b) and this indicator (DE01) emerges as one of the most important for planning the sustainable use of land and soil.

The indicator is defined by climatic, soil, vegetation and human-induced criteria. Climatic criteria, such as the ratio of average annual precipitation to evapotranspiration or to average annual temperature, defines the overall degree of aridity, that can be subsequently redefined using the same criteria should the climate change significantly. The soil and vegetation criteria are a measure of the capacity of the land to withstand aridity and human-induced criteria control the management of the land that can mitigate or exacerbate the effects of desertification.

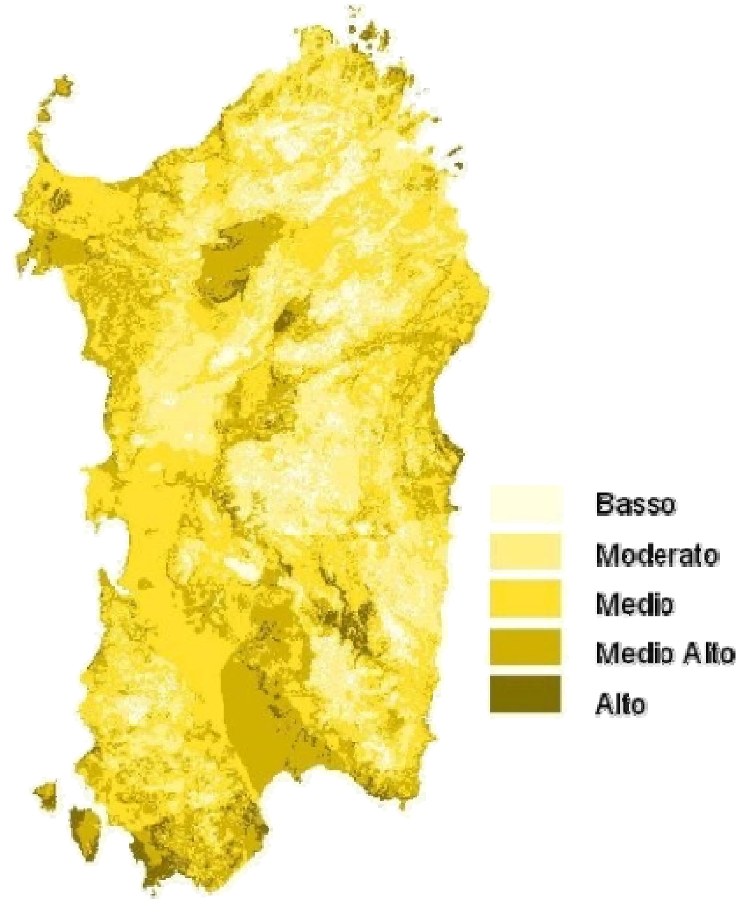

Figure 1.23.2 Areas vulnerable to increasing desertification in Sardinia, Italy [Bianco and Loj, 2000]

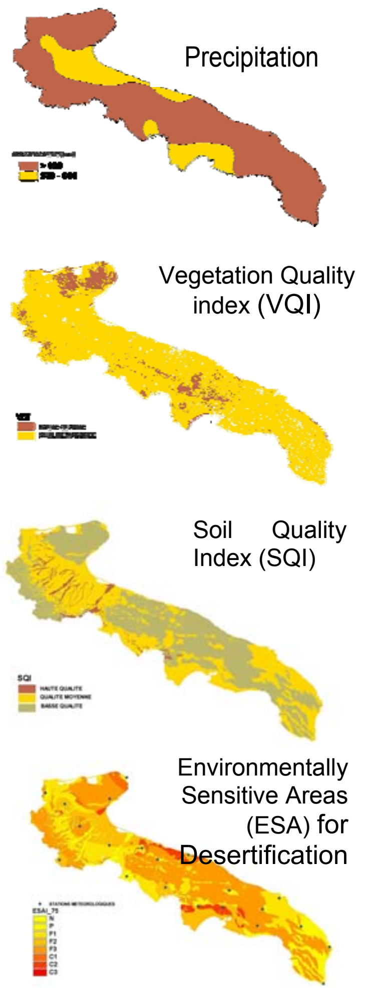

Figure 1.23.3 Application of Medalus methodology to the assessment of desertification risk in Puglia [Montanarella et al., 2001]

1.23.1.2 Significance

Desertification in Europe is increasing partly by human-induced land use change and management practices, but the strongest future driving force is likely to be climate change. The environmental impacts that can ensue from desertification include those identified for soil erosion, decline in soil organic matter, salinisation and decline in soil biodiversity. More precise delineation of areas at risk of desertification in Europe will be an increasingly important requirement for determining the extent (actual and potential) of areas affected (see Rubio *et al.*, 2006).

1.23.1.3 Policy context

Desertification is mainly associated with soil erosion (Martínez-Fernández and Esteve, 2005) but, it is identified separately in the official 'Communication on a Thematic Strategy for Soil Protection in Europe' (European Commission, 2002). However, desertification *per se* is a cross-cutting issue. Therefore, it is relevant for the forthcoming Soil Framework Directive (European Commission, 2006a,b), which will implement tougher action to mitigate the process of 'aridification', which is the main cause of desertification. This will be achieved by harmonized criteria for desertification and DE01 is one indicator that should prove fundamental in future soil monitoring systems in Europe.

1.23.1.4 Scientific background

A number of factors control the process of desertification. Kirkby *et al.* (1996) have defined the different feedback mechanisms controlling desertification. When climatic conditions become more arid, vegetation cover reduces resulting in less organic matter input to the soil, causing decreased water retention capacity, decreased infiltration rates and an increase in runoff and sediment yield (Boix-Fayos *et al.*, 2005). Thereafter, soil structure controls the erosion process.

It is difficult to measure desertification directly, as one would measure soil organic carbon content or soil packing density, but climatic data can be used to identify the areas which are sufficiently arid to be considered suffering from desertification. The area where vegetation has been destroyed by wildfires, mainly in southern Europe, can be a trigger (or a catalyst) for desertification (Baeza *et al.*, 2002) and increased soil erosion (De Luis *et al.*, 2003). Such areas are currently the focus for studies at the Joint Research Centre, Ispra (JRC, 2006), where techniques continue to improve, although errors exist in detecting the degree of destruction of the forest and shrubland cover.

For the island of Lesvos in Greece (Figure 1) and Sardinia and Puglia, in Italy (Figures 2 & 3), a MEDALUS (Kosmas *et al.*, 1999b) procedure was adopted using spatial data sets. A number of indices are combined to produce an overall risk of desertification but the risk according to each set of criteria, such as climate, soil or vegetation, are also produced as spatial data sets.

1.23.1.5 Data availability

Soil: European Soil Database at a 1:1,000,000 scale (1:250,000 scale is preferable when available), to provide spatial data on soil type, surface and subsurface texture, depth, physical structure, and available water capacity. Soil organic carbon (SOC) content is available at 1 km resolution (Jones *et al.*, 2005).

Climatic/Meteorological data: Ideally, climatic data are needed at the same resolution as other model input factors for spatial analysis. Therefore, to match the soil and land use data, this needs to be at a 1 km resolution, but climatic data are not generally available, nor may they exist, at such a detailed scale for Europe. Average values of climatic parameters are also needed, preferably for a recent international standard period of 30 years, for example 1961-90, 1971-2000. The coarse resolution of most climatic data sets, that cover Europe as a whole, can be overcome by interpolation to finer resolutions using geostatistics (Ragg *et al*., 1988).

Consequently, the MARS agroclimatic data, calculated for 50 km by 50 km grid squares across Europe (Vossen and Meyer-Roux, 1995), have been interpolated onto a 1 km by 1 km raster for the PESERA Project, using an inverse spline function for rainfall, and for temperature an average adiabatic lapse rate – 6°C per 1000 m rise in altitude – together with a 1 km digital elevation model (Gobin *et al.*, 2003; Kirkby *et al.*, 2004). Other climatic data at coarse resolution are available at 0.5° or 10' intervals from the Global Historical Climatology Network – GHCN (Easterling *et al.*, 1996) and the Tyndall Centre for Climate Change Research (Mitchell *et al.*, 2003; New *et al.*, 2002).

Land use/land cover data: The most obvious evidence of desertification is a lack of vegetative cover, thus CORINE Land Cover (CLC) at 250 m resolution provides a vital historic data set on land use that can be used to help delineate desertified areas However, CLC data do not cover the whole of Europe and Global Land Cover data are needed to fill in the gaps (Hiederer, pers comm.).

Geographical coverage of data sets: Europe.

1.23.1.6 Assessment of results

The examples in Figures 1-3 are the results of mapping areas at risk of desertification in Greece and Italy using a MEDALUS approach. This defines potential (P), fragile (F) and critical (C) areas. For example in Lesvos, the C3 mapping unit comprises land with very steep slopes (>35%), a semi arid climate (annual average rainfall (AAR) 300-650 mm) and plant cover from 25-50%. The F2 mapping unit comprises variably sloping land (gentle to steep slopes), dry sub-humid climate (AAR>650 mm) and a very dry bioclimatic index, and plant cover usually > 75% (*Kosmas et al., 1999a)*. Precise validation of these various sub-types is not an easy task but Montanarella *et al*. (2001, p.30-31) have attempted this by comparing the results of applying a modified Medalus methodology, to the northern and southern part of Puglia, with Landsat 5 TM images. Some land in the critical (C) classes is already desertified.

1.23.2 Meta data

1.23.2.1 Technical information

i) **Data sources:** several sources provide relevant data Europe-wide (see above).

ii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring States in the Mediterranean Basin;

iii) **Spatial resolution:** regional to national scale.

iv) **Temporal coverage:** soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; Climatic data are available for international standard periods, for example 1961-90, 1971-2000; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).

v) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at five year intervals using updated climatic and land cover data.

vi) **Methodology of indicator calculation:** MEDALUS type calculation combining indices for climate, soil, vegetation and human influences.

vii) **Availability of baselines and thresholds:** baselines exist for aridity, soil properties such as available water capacity and vegetative cover; thresholds are proposed.

1.23.2.2 Quality information

i) **Strength and weakness:** detailed data on water retention properties of soils in the most affected areas are lacking; climatic data are only available at relatively coarse resolution and temporal coverages differ.

ii) **Data comparability:**
Comparability over time: current data sets originate from various sources and for different periods.
Comparability over space: spatial coverage is wholly insufficient at the present time.

1.23.3 Further work required

The main tasks for future improvement of the approach described for this indicator (DE01) are:

i) More measurements of water retention properties for the main soil types in affected areas;

ix) Analyses of vegetation cover and condition using improved techniques on high resolution remotely sensed images;

x) Climatic data at better resolutions than currently exist would allow better risk area identification; more climatic stations are required, particularly for rainfall and evaporation;

xi) Many more harmonised spatial data on human activities – land management and land use change – are needed.

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1.24 DE02 Wild fires – burnt land area

Key issue: Desertification
DPSIR classification: State

Main information: 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 (Martínez-Fernández 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.

1.24.1 Example

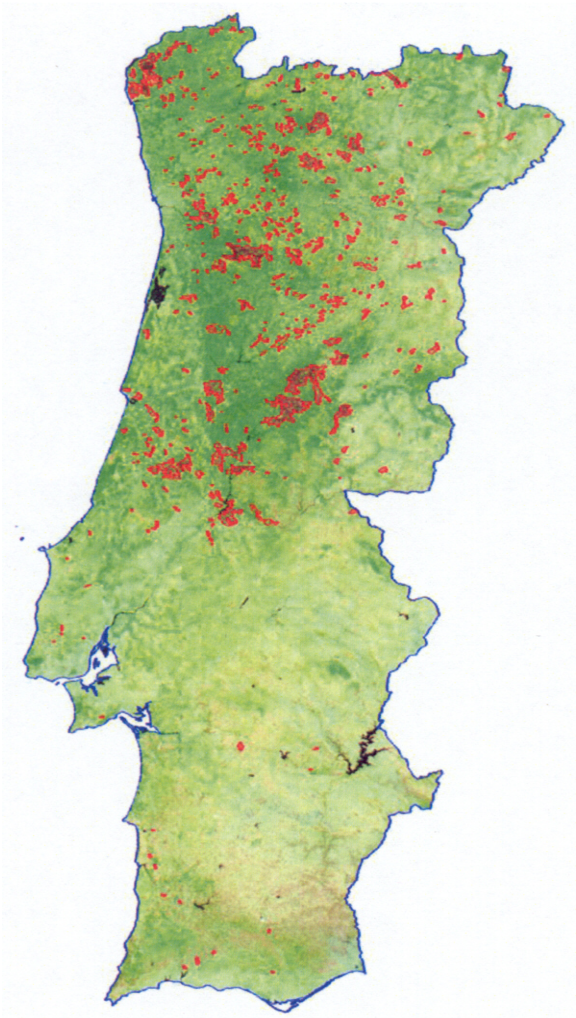


Figure 1.24.1 Areas burnt by forest fires (wild fires) in Portugal, during 2005 (actual burnt areas are in red) – after JRC (2006b

1.24.1.1 Methodology

Desertification is associated closely with a wide set of degradation processes (Brandt and Thornes, 1996) including soil organic matter decline, soil salinisation, soil erosion, decline in soil biodiversity, lowering of the water table by over-exploitation of groundwater, wild fires (forest, scrub and grass fires], soil contamination and even urban expansion (Sommer *et al.*, 1998). Therefore, desertification is a cross-cutting issue and the countries in Europe most affected are Spain, Portugal, southern France, Greece and southern Italy. Some small parts of other countries may meet the criteria of desertification, largely through 'aridification' where the ground water table has been lowered by over-exploitation, or intensive drainage has dried out the land, and prolonged periods without rainfall follow.

Indicators of desertification have been reviewed thoroughly by the Medalus Project (Kosmas *et al.*, 1999). This indicator (DE02) represents the area of wild fires occurring over a fixed timescale, e.g. one year. Wild fires are known to have a devastating effect in the short-term and, in the medium- to long-term, it is clear that they exacerbate the process of desertification by destroying the vegetation cover, increasing surface temperatures, increasing soil erosion and exacerbating other threats such as decline in soil organic matter and decline in soil biodiversity.

1.24.1.2 Significance

Desertification is increasing in Europe partly by human-induced land use change and management practices, but the strongest future driving force is likely to be climate change. The environmental impacts that can ensue from desertification include those identified for soil erosion, soil organic matter decline, salinisation and loss of biodiversity. More precise delineation of areas at risk of desertification in Europe will be an increasingly important requirement for determining the extent (actual and potential) of areas affected (see Rubio *et al.*, 2006). Land burnt by wild fires is often on the semi-humid – semi-arid margins and the areas at risk of future wild fires are increasing as the climate warms up and spring starts earlier (Westerling *et al*., 2006).

1.24.1.3 Policy context

Desertification is mainly associated with soil erosion (Martínez-Fernández and Esteve, 2005), but it is identified separately in the official 'Communication on a Thematic Strategy for Soil Protection in Europe' (European Commission, 2002). However, desertification *per se* is associated with soil organic matter decline, soil salinisation and decline in soil biodiversity, and therefore is a cross-cutting issue. Even so, it is relevant to the forthcoming Soil Framework Directive (European Commission, 2006a,b), which will implement tougher action to mitigate the process of 'aridification', which is a significant cause of desertification. This will be achieved by harmonised criteria for desertification and DE02 is another indicator to accompany DE01 that should prove fundamental in future soil monitoring systems in Europe.

1.24.1.4 Scientific background

A number of factors control the process of desertification, and Kirkby *et al.* (1996) have defined the different controlling mechanisms. When climatic conditions become more arid, vegetation cover reduces resulting in less organic matter input to the soil, causing decreased water retention capacity, decreased infiltration rates and an increase in runoff and sediment yield (Boix-Fayos *et al.*, 2005; Shakesby and Doerr, 2006). Wild fires destroy the vegetation completely and, where these fires occur in semi-arid and arid areas, re-vegetation can be difficult to start and very slow to regenerate.

It is difficult to measure desertification directly but the destruction of vegetation by wildfires can be a trigger (or a catalyst) for desertification (Baeza *et al.*, 2002) and increased soil erosion (De Luis *et al.*, 2003), especially in southern Europe. Areas commonly suffering wild fires are being studied currently at the Joint Research Centre, Ispra (JRC, 2006a). Errors exist in detecting the degree of destruction of the forest and shrubland cover, but techniques are continually improving. It is anticipated that the next generation of satellite borne sensors will greatly enhance the monitoring of burnt areas.

1.24.1.5 Data availability

Soil: European Soil Database at a 1:1,000,000 scale (1:250,000 scale is preferable when available), to provide spatial data on soil type, surface and subsurface texture, depth, physical structure, and available water capacity. Soil organic carbon (SOC) content is available at a 1 km resolution (Jones *et al.*, 2005).

Climatic/Meteorological data: Ideally, climatic data are needed at the same resolution as other model input factors for spatial analysis. Therefore, to match the soil and land use data, this needs to be at a 1 km resolution, but climatic data are not generally available, nor may they exist, at such a detailed scale for Europe. Average values of climatic parameters are also needed, preferably for a recent international standard period of 30 years, for example 1961-90, 1971-2000. The coarse resolution of most climatic data sets, that cover Europe as a whole, can be overcome by interpolation to finer resolutions using geostatistics (Ragg *et al*., 1988).

Consequently, the MARS agroclimatic data, calculated for 50 km by 50 km grid squares across Europe (Vossen and Meyer-Roux, 1995), have been interpolated onto a 1 km by 1 km raster for the PESERA Project, using an inverse spline function for rainfall, and for temperature an average adiabatic lapse rate – 6°C per 1000 m rise in altitude – together with a 1 km digital elevation model (Gobin *et al.*, 2003; Kirkby *et al.*, 2004). Other climatic data at coarse resolution are available at 0.5° or 10' intervals from the Global Historical Climatology Network – GHCN (Easterling *et al.*, 1996) and the Tyndall Centre for Climate Change Research (Mitchell *et al.*, 2003; New *et al.*, 2002).

Land use/land cover data: The most obvious evidence of desertification is a lack of vegetation cover, thus CORINE Land Cover (CLC) at 250 m resolution provides a vital historic data set on land use that can be used to help delineate desertified areas. However, CLC data do not cover the whole of Europe and Global Land Cover data are needed to fill in the gaps (Hiederer, pers comm.). Satellite imagery of areas burnt by wild fires is analysed annually by the Natural Hazards Unit of JRC (JRC, 2006a).

Geographical coverage of data sets: Europe.

1.24.1.6 Assessment of results

The distribution of wild fires in southern Europe shown in Figure 1.24., were produced by the JRC's Forest Fires in Europe – 2005 campaign (JRC 2006b). The results of the previous forest fire campaigns in 2001, 2002 and 2003 are reported in JRC (2002, 2003, 2004).

1.24.2 Meta data

1.24.2.1 Technical information

i) **Data sources:** several sources provide relevant data Europe-wide (see above).

ii) **Geographical coverage:** EU-27, former EFTA countries, EU Accession and Candidate Countries, Neighbouring States in the Mediterranean Basin.

iii) **Spatial resolution:** regional to national scale.

iv) **Temporal coverage:** soil data that comprise the European Soil Database were collected mainly in the period 1950-1980; Climatic data are available for international standard periods, for example 1961-90, 1971-2000; CLC data are available for 1990 and 2000, with additional data available from Global Land Cover (GLC) data sets compiled by JRC (Ispra).

v) **Methodology and frequency of data collection:** modelling (see methodology section), repeated at five year intervals using updated climatic and land cover data.

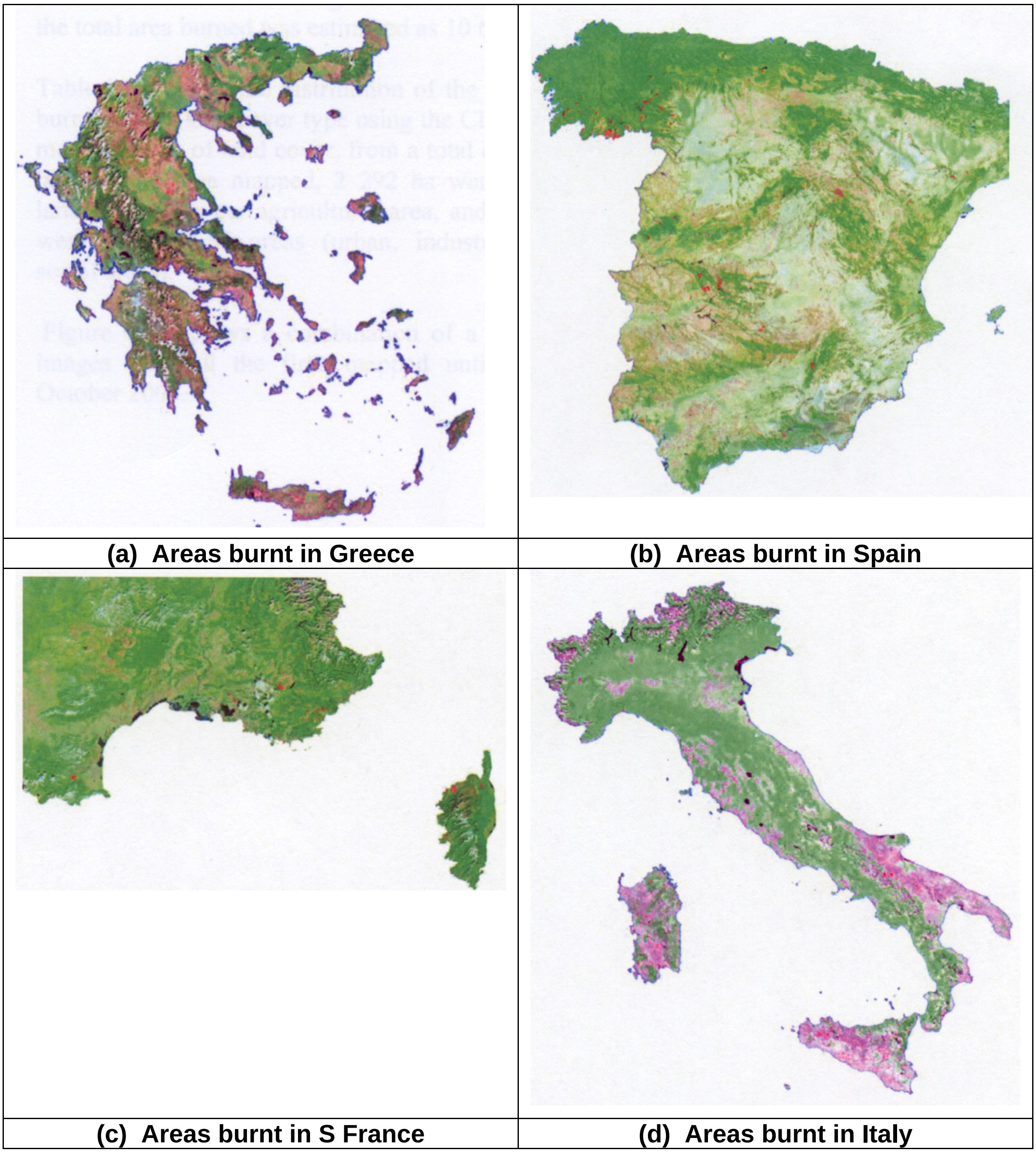
vi) **Methodology of indicator calculation:** MEDALUS type calculation combining indices for climate, soil, vegetation and human influences.

vii) **Availability of baselines and thresholds:** baselines are difficult to establish but thresholds based on the proportion of burnt land in a particular area are proposed.

1.24.2.2 Quality information

i) **Strength and weakness:** detailed data on burnt areas are not easy to find and processing the remotely sensed images is time consuming and expensive. There is some uncertainty over the extent of the damage within the burnt areas.

ii) **Data comparability:** comparability over time: current data sets originate from various sources and for different periods. Comparability over space: spatial coverage is wholly insufficient at the present time.



(a) Areas burnt in Greece | **(b) Areas burnt in Spain**

(c) Areas burnt in S France | **(d) Areas burnt in Italy**

Figure 1.24.2 Areas burnt by Forest Fires (Wild fires) in Southern Europe during 2005 (after JRC, 2006b)

1.24.3 Further work required

The main tasks for future improvement of the approach described for this indicator (DE02) are:

i) More detailed remotely sensed imagery in the semi-arid and arid areas of Europe;
ii) Analyses of vegetation cover and condition using improved techniques on high resolution remotely sensed images;
iii) Climatic data at better resolutions than currently exist would allow better risk area identification; more climatic stations are required, particularly for rainfall and evaporation;
iv) Many more harmonised spatial data on human activities – land management (particularly recreational activities) and land use change – are needed.

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Abstract
The ENVASSO Project (Contract 022713) was funded 2006-8, under the European Commission 6th Framework Programme of Research, 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 soil indicators, identified existing soil inventories and monitoring programmes in the Member States, designed and programmed a database management system to capture, store and supply soil profile data, 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 (I) identifies 290 potential indicators relating to 188 key issues for the following nine threats to soil: erosion, organic matter decline, contamination, sealing, compaction, loss of biodiversity, salinisation, landslides and desertification. Sixty candidate indicators that address 27 key issues, covering all these threats, were selected on the basis of their thematic relevance, policy relevance and data availability. Baseline and threshold values are presented and detailed Fact Sheets describe three priority indicators for each soil threat.

References for citing the other ENVASSO volumes are listed below.
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