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GS SOIL
Assessment and Strategic development of INSPIRE compliant Geodata-Services for European Soil Data

D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe

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D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe

Author’s Note
This document was jointly developed in the framework of the eContentplus-project GS SOIL “Assessment and strategic Development of INSPIRE compliant Geodata-Services for European Soil Data” in the working package 2 on “Content Provision Framework”.

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### Abbreviations

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<th>Description</th>
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<tr>
<td>DEM</td>
<td>Digital elevation model</td>
</tr>
<tr>
<td>FSCC</td>
<td>ICP Forests Soil Coordinating Centre, Geraardsbergen, Belgium</td>
</tr>
<tr>
<td>FSEP</td>
<td>Forest Soil Expert Panel (ICP Forests)</td>
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<tr>
<td>GSDBE</td>
<td>Georeferenced Soil Database for Europe (1:250,000)</td>
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<tr>
<td>INSPIRE</td>
<td>Infrastructure for Spatial Information in the European Community</td>
</tr>
<tr>
<td>ICP</td>
<td>International Cooperative Programme on assessment and monitoring of air pollution effects on forests in the UN/ECE region (1985)</td>
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<tr>
<td>IPR</td>
<td>Intellectual Property Rights</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>OGC</td>
<td>Open Geospatial Consortium</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>OGC® Observations and Measurements</td>
</tr>
<tr>
<td>RSG</td>
<td>Reference soil group (in WRB)</td>
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<tr>
<td>SMU</td>
<td>Soil mapping unit</td>
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<tr>
<td>SGDBE</td>
<td>Soil Geographical Database of Europe (1:1Mio)</td>
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<tr>
<td>SPADE</td>
<td>Soil Profile and Analytical Database for Europe</td>
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<tr>
<td>STU</td>
<td>Soil typological unit</td>
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<td>WRB</td>
<td>World Reference Base for Soil Resources</td>
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For further technical terms see ‘Reference Terminology’ (GS Soil D4.3 Data Harmonization Best Practice Guidelines).
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Foreword

Population growth and increasing land use intensity leads to growing demands and exploitation of natural resources. The soils are among the most important and most endangered natural resource entities. In order to plan and implement sustainable soil management practices and to facilitate the rational exploitation of the soil resource, more detailed information on the occurrence of soils, its particular characteristics, potential risks and hazards is needed. Soil conservation and its sustainable use are implemented through political initiatives such as the Common Agricultural Policy, Nitrate Directive, Soil Thematic Strategy, and other initiatives and programmes (Maljean et al. 2004\(^2\) provides an overview of European political activities with respect to soil organic matter).

In order to cope with this need for soil information, an increasing amount of data about soils must be made accessible and across disciplines, such as climate, land use and environment observation. The exchange of soil information has already intensified with increasing amounts of digital data and GIS-processing becoming available in the frame of European integration activities and raised awareness, and new natural resource management approaches being developed. The exchanged data must be interoperable so that data users can process and combine soil information with digital information from neighbouring disciplines. Harmonization is needed so that information from different sources can be understood, compared and interpreted across administrative borders.

Within the INSPIRE directive, the theme soil is explicitly addressed as an individual theme and besides that, soil-related environmental, agricultural and forestry aspects are also addressed. Political activities are very often accompanied by research and development. In the case of INSPIRE and soil, the GS Soil project has been implemented under the eContentplus programme. It aims at establishing a European network to improve the access to spatial soil data. The project considers aspects of data organisation, data harmonisation as well as semantic and technical interoperability in order to produce seamless geospatial information on soil.

In order to achieve the GS Soil goals, the first step is to assess the current status of existing soil data across Europe, and to propose best practice content standards. Such standards shall provide harmonisation of spatial and non-spatial soil data. Both steps - status compilation and analysis, and best practice recommendations - were the task of Work Package 2 “Content Provision Framework”. This us achieved on the basis of the following deliverables:

1. Compilation of a Soils Inventory and Theme Catalogue which documents the current status and ability of soil and which allows conclusions about the challenges of harmonisation of data resources (Deliverable D2.3).
2. Consideration of Intellectual Property Rights of available soil data (D2.4). On that basis the distribution policies and existing access restrictions can be analysed, so that security services can be better designed in Work package 5.
3. Definition of Content-Framework Standards and Best Practice Guidance (D2.5; this report). This work has been split into two parts: part I includes the definition of content-framework standards, part II on the development best practice guidelines. The main focus of part II is on soil typological data as represented in maps. Those data types are discussed which are deemed relevant for the transport of soil information from the level of EU member states rather than region-specific high-resolution data.

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a content framework for interoperable soil data in Europe

Following the INSPIRE specifications will mainly allow the technical fit of data (description of data sets through metadata, projections, gap filling along borders, structures for XML-coded data sets). However, comparability of data from different sources and mapping projects is only achieved if data products are harmonized to an agreed level among data providers. Therefore, work packages 2 and 4 have developed a strong focus on the content of soil data: definitions of mapping units, nomenclature and classification, stratification, parameter definitions. Existing systems and standards are analysed, and recommendations developed and presented as best practice.

The results of this report (D2.5) are also intended to serve as input to other project activities, especially on harmonization (D4.3 Data Harmonization Best Practice Guidelines). D4.3 will test practical steps to implement the recommendations provided here. On that basis, data providers will find solutions to provide harmonized soil data in Europe. Additionally, data providers could estimate the possible cost involved with implementing recommendations for harmonization. The results will also support the discussion process about a new European high-resolution soil map data base, which is currently under discussion.

Part I was developed by partner 31 (Agricultural Institute of Slovenia, AIS), part II by partner 11 (Federal Institute of Geosciences and Natural Resources, BGR).
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GS SOIL
Assessment and Strategic development of INSPIRE compliant Geodata-Services for European Soil Data

D2.5 Part I
Review and analysis of soil content framework for development interoperable soil data
SUMMARY OF PART I

This report describes a current availability, organisation and accessibility of soil related data in Europe. It was done based on available information to authors and with a goal to overview the current practices in soil data collection, description, analysis and data base management. It also describes current efforts to establish common national soil databases around Europe as well as attempts of the European commission for a more unified and harmonised European soil data base.

It attempts to review and suggest the best possible solutions, for a uniform approach to soil data collection, analysis and presentation. Based on good practice examples, it proposes additional guidance to unify and better define the approach for defining a minimum soil quality indicator data, presenting current systems in use. Improved table of the most important soil quality indicator data is also proposed. It describes the common approaches for filling data gaps and map applications and the most used PTFs in Europe, their weaknesses and strengths. It further more describes the soil data harmonisation issues, listing all main European soil related data bases as the source of already collected and partly harmonised soil data. In terms of usability this report reviews the technical interoperability of data and different soil classifications in use. It recognises WRB classification as the classification system already in place that could unify the national classifications. It recognises some difficulties that some of the countries with more specific national resources might encounter during WRB harmonisation process. It furthermore suggests additional improvements and best practice guidance for a smoother adaptation of the WRB classification.
1. Review of the content framework for existing soil data in Europe

1.1 Soil maps

Soil maps contain important information about the spatial distribution of country’s soil types and other soil properties such as horizon’s depth, pH, texture, organic matter content etc. Soil data retrieved from the field sampling campaigns are usually shown on maps at various scales (state, region, municipality level etc.). These maps are then used for various decision making processes, e.g. to evaluate soil suitability for agricultural, spatial planning and to direct activities in urban development and infrastructure planning.

Existing soil maps are usually not in digital formats, so researchers cannot always use them in their scientific work. Nevertheless, they still contain very important information for present and future scientific work. Soil maps and their databases can be used also to monitor land degradation, to improve land use and water resources and to predict environmental and climatic changes. It is important to preserve older soil data, because there is a lack of new soil data production. In many countries (especially in developing and transitional countries) soil maps are being lost because of bad storage. Therefore, it is important to digitize old soil map before they are completely lost. Digitization process can be a good practice to improve national soil information.

Presently, soil maps are still initially being digitalized and stored in adequate Soil Information System (SIS) and in that way made useful for different applications. Usually they are consisted of vector polygons (Soil mapping units – SMU) and points ((soil profiles, etc.) which are linked to corresponding attribute tables with a range of analytically and field based measured data.

Joint Research Centre of the European Commission (JRC) and the International Soil Reference and Information Centre (ISRIC) established a platform (EuDASM – European Digital Archive on Soil Maps) for the storage of soil and related maps in scanned raster format. The platform is freely accessible for the global community (scientists, researcher, policy makers, students, etc.). Such platform on one side significantly improves the accessibility and preserves the old soil maps. JRC and ISRIC have also developed a detailed metadata for some European soil maps. These can be viewed, downloaded and further used by users in different formats (JPEG, PDF).

Figure 1: Example of accessible soil maps: Czech Republic and Slovakia (EuDASM 2010)
Figure 2: Example of accessible soil maps: Austria (EuDASM 2004)

1.1.1 Map elements

Soil maps represent the spatial distribution of soil types. In general, two types of soil information are presented:

- **Polygons**, such maps are the most common way to present distribution of soil types in a certain area. Each polygon represents the defined soil mapping unit (SMU). They cover the area (e.g. municipality, region, country, state etc.). The main weaknesses of such thematic maps are:
  
  o Subjectivity: definition of soil polygon borders is based on subjective evaluation of the field surveyor/soil expert who defines the boundaries of each individual soil mapping unit-SMU (soil polygon).
  
  o Spatial accuracy: each soil polygon (soil mapping unit-SMU) usually consists of several soil types. Therefore the location of individual soil types within the polygon is not known.
  
  o Transition between different soil types in nature usually is gradual, the polygon borders are decision represented by a discrete line which artificially dividing gradual changes.

- **Point data** on location of soil sampling or soil observation.

1.1.2 Soil thematic maps

Soil thematic maps are used to represent spatial distribution of a certain soil property. In general, key soil properties are presented such as soil depth, texture, water capacity, pH, soil quality etc.

Commonly soil thematic maps are derived from pedological maps, therefore these are polygon based. Each polygon represents an quantitative estimation, often an average of the individual soil property within the SMU borders (e.g. soil erodibility, average topsoil pH or OM content, soil parent material development, soil water holding capacity, etc.). However, the main weaknesses of polygon based thematic maps are:
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

- Accuracy of soil properties is based on subjective spatial and semantic definition of soil mapping units.
- Soil properties in nature change gradually while the border of each polygon is discrete.
- Each SMU originally consists of several soil types. Therefore each soil property is somehow estimated (e.g. averaged) for the entire SMU. The estimation / generalization is frequently based on estimated proportion (%) of area of each soil type.

Raster based soil thematic maps are next but less common/frequent type of soil maps. They present estimated soil properties based on the available digital geospatial data. The quantitative estimation is based on mathematical and statistical methods, algorithms/pedotransfer functions, simple expert based judgement and decision tree based algorithms. Additionally the development of GIS technology, algorithms and better digital geographical data on soil forming factors enable advanced and cheaper techniques for spatial estimation of physical and chemical soil properties.

1.2 National soil map examples

1.2.1 Soil maps of Austria

There are three main soil survey institutions in Austria:

- The Federal Forest Research Centre responsible for Forest Soil Survey,
- And The Austrian Agricultural Soil Survey (Institute for Applied Soil Science Federal Office and Research Centre for Agriculture)

Most of the Austrian soil maps use 1:25,000 scale, however the field maps scale is larger for instance the Austrian Agricultural Soil Survey field maps use 1:10 000 scale. The Soil Taxation Survey uses the scale of the Austrian Cadastre, i.e. 1:2 000 or 1:2 880 (old cadastre). The newly prepared Austrian soil systematic considers the translation of soil types into WRB, however, this is not always possible. Several soil types, especially those of the alpine regions, are not adequately classified by the WRB system.

1.2.2 Soil maps of Czech Republic

The territory of the Czech Republic is covered with 1:10,000, and 1:50,000 soil maps; soil ecology maps (1:5,000) maps (land under agriculture), and forest typological maps (1:5,000) from which soil maps can be derived.

Maps of soil associations at scales 1:1 000 000, 1:500 000 and 1:200 000 were compiled by the generalization of large-scale maps. The Soil Map at scale 1:1 million has been used for international cooperation with Dudal, Tavernier and Jamagne. A 1:200 000 map was published by the RISWC, (Ministry of Environment). Soil regions and corresponding soil type interactions (combinations) of the soil map 1:500 000 were characterized in “Geography of soils in the Czech Republic” (1983).

Soil maps at large scale (1:10 000) are based on a taxonomic approach. Soil mapping units of agricultural land reflect pure soil units, their combinations and contrasting accessory soils. Soil maps at medium and small scales are based on soil type interactions (combinations reflecting the dominant, co-dominant, accompanying compounds and accessory soils at scale 1:200 000).
1.2.3 German soil maps

German federal institutes, such as the Federal Institute for Geosciences and Natural Resources (BGR, Hannover) and the Federal Environmental Agency (UBA, Berlin), as well as environmental and soil survey institutes at individual state level, have strengthened their activities to improve and extend a joint soil information system for Germany.

A 1994 documentation of existing soil maps in Germany, showing the availability of 1:25 000 to 1:200 000 soil maps, emphasized the problem of incomplete coverage. Besides these scales, several state soil surveys published soil maps at scales of 1:5 000 and 1:10 000 and soil maps of the entire state at scales of 1:300 000 to 1:500 000. Although some state soil surveys could improve soil information, the availability of soil maps at identical scales and quality is still unsatisfactory with respect to national requirements.

For national need, maps at scale 1:2,000,000 and 1:1,000,000 are available, maps at 1:200,000 scale are in preparation. They have all been compiled applying the 4th Edition of the German Soil Mapping Guide KA 4.

1.2.4 Soil maps of Hungary

A large amount of soil information is available in Hungary as a result of long-term observations, various soil surveys, analyses and mapping activities on national (1:500 000), regional (1:100 000), farm (1:10 000 – 1:25 000) and field level (1:5 000 – 1:10 000) during the past seventy years.

1.2.5 Soil maps of Italy

In Italy, overall soil survey activity has increased considerably in the last few years, but the organization of knowledge on Italian soil is still in its infancy. The main institutional framework for soil mapping and pedological information is the National Observatory for Pedology and Soil Quality of the Ministry for Agricultural Policies. Soil maps that have been produced in Italy vary in classification system, mapping methodology, and scale, because origins, aims and purposes of the various surveys were often different. There are some 433 maps in Italy, of which only 126 (29 %) have been digitized.

1.2.6 Soil maps of Poland

There are 3 aspects of soil classification and the associated soil maps in Poland: (i) soil quality/productivity classes, (ii) soil agricultural maps (soil suitability classes) and (iii) soil taxonomy classes (based on soil genesis). Soil quality class maps at scale 1:5 000 cover the whole agricultural area. Soil agricultural maps (soil suitability classes) are available for Poland’s agricultural area at scales 1:5 000, 1:25 000 and 1:100 000. Soil maps at a scale of 1:25 000 demonstrating spatial variability of soil types (genetic map) covered 60 percent of the entire Polish agricultural land in 2000.

1.2.7 Soil maps of the UK

There is approximately 25 percent of the land covered by maps at the 1:25 000, 1:50 000 or 1:63 360 scale in England and Wales, whereas in Scotland nearly half of the country, including most of the arable land, is covered at the 1:63 360 scale. Northern Ireland has complete coverage of soil maps at the 1:50 000 scale. On all these maps, the basic unit of soil classification and mapping is the soil series (Clayden and Hollis 1984). Each large-scale map (at scale 1:25 000 to 1:63 360) comprises polygons that delineate areas in which the soil characteristics conform to one or more soil series. Although the specific criteria used to identify soil series are somewhat different in England and Wales, Scotland and N. Ireland and have also evolved over the years (Hollis and Avery, 1997), the basic concept of the soil series has remained similar in all four countries.
In addition to the more detailed 1:25 000, 1:50 000 and 1:63 360 scale soil maps, ‘National’ 1:250 000 scale soil mapping programmes have been completed in all four countries. This represents the only complete systematic soil cover information for the UK.

1.2.8 Soil maps of Slovenia

Systematic soil mapping in Slovenia started in the 1960s under the direction of Centre for Soil Science and Environment from Ljubljana, while collection of soil data started in 1930s. In 1981 the initial mapping scale of 1:50,000 was changed to 1:25,000. By the end of 1986 about 50% of Slovenian territory had been covered with soil maps, partly at scale 1:50,000 and partly at scale 1:25,000. The 1:50,000 map territories were additionally inspected and the soil map was upgraded to 1:25,000 scale. Currently the whole territory of Slovenia is covered by maps in scale 1:250,000 and detailed soil maps in 1:25,000 (DSM25). DSM25 represents the core of digital soil data brought together into the Soil Information System (SIS), providing a wealth of information on Slovenian soils. Beside DSM25 two important soil information layers associated with DSM25 are included in SIS (Vrščaj, et.al, 2005):

- soil profile data (SP/PP) → measured data on ~1,700 soil profiles
- data on points of soil pollution monitoring in Slovenia (MSPS/MOTS)

Soil maps of Slovenia are built up of soil mapping units (SMU) and soil typological units (STU). According to the percentage of representation of STU's in each SMU, soil parameters are estimated/calculated for the whole area of SMU.

Because of the great variability of Slovenia's landscape, there is a great need to improve existing soil map of 1:25,000 to a better scale. Therefore making of new soil map in larger scale would be reasonable.

1.2.9 Overview of existing national soil maps in Europe

Eastern Europe
- Belarus
- Bulgaria (8 maps)
- Czech Republic (19 +/- maps)
- Hungary (57 maps)
- Moldova
- Poland (32 maps)
- Romania (32 maps)
- Russian Federation (97 maps)
- Slovakia (19 +/- maps)
- Ukraine

Northern Europe
- Denmark (7 maps)
- Estonia (1 map)
- Faroe Islands
- Iceland (1 map)
- Ireland (13 maps)
- Latvia (1 map)
- Lithuania
- Norway (18 maps)
- Sweden (9 maps)
- Finland (25 maps)
- Greenland
- United Kingdom (108 maps)
Southern Europe
- Albania
- Bosnia and Herzegovina
- Croatia (5 maps)
- Cyprus (17 maps)
- Greece (5 maps)
- Italy (166 maps)
- Former Yugoslav Republic of Macedonia
- Malta (1 map)
- Portugal (33 maps)
- Serbia (former Yugoslavia)
- Slovenia (200 map sheets - 1 digital map)
- Spain (47 maps)
- Turkey (19 maps)

Western Europe
- Austria (8 maps)
- Belgium (19 maps)
- France (33 maps)
- Germany (273 maps)
- Luxembourg (4 maps)
- Netherlands (351 maps)
- Switzerland (9 maps)

1.2.10 Europe-wide soil maps

1.2.10.1 The European Soil Database v2.0

The Soil Geographical Database of Eurasia at Scale 1:1M is part of the European Soil Information System (EUSIS) which is under jurisdiction of the JRC in Ispra, Italy. The database is a simplified representation of soil types and their properties of Europe and neighbouring countries. Soil types are defined according to FAO legend for the Soil Map of the World at Scale 1:5M.

The database contains a list of soil typological units (STU). STU table also contains information on soil properties for each STU. Because the geographical data scale (1:1M) is too coarse it is not feasible to delineate the STUs. That is why STUs are grouped in soil mapping units (SMU). Some examples of soil thematic maps are shown below (Internet1, 9.7.2011).

1.2.10.2 Soil thematic maps derived from the SGDB

According to the common practice, each soil attribute gets the estimation structured. The combinations of categories (surface soil, subsurface soil, dominant and secondary) are made for each soil property estimation. For example, soil texture is described using four attributes:

1. Dominant surface textural class of the SMU (TEXT-SRF-DOM)
2. Secondary surface textural class of the STU (TEXT-SRF-SEC)
3. Dominant sub-surface textural class of the STU (TEXT-SUB-DOM)
4. Secondary sub-surface textural class of the STU (TEXT-SUB-SEC)

List of the most important soil properties available as EU soil thematic map layers (Internet2, 2011).

---

http://eusoils.jrc.ec.europa.eu/ESDB_Archive/raster_archive/sgdbe_display_attributes.html#
<table>
<thead>
<tr>
<th>Property</th>
<th>Attributes</th>
<th>No. of attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>• TEXT-SRF-DOM: Dominant surface textural class of the STU</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• TEXT-SRF-SEC: Secondary surface textural class of the STU</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• TEXT-SUB-DOM: Dominant sub-surface textural class of the STU.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• TEXT-SUB-SE: Secondary sub-surface textural class of the STU.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• TEXT-DEP-CHG: Depth class to a textural change of the dominant and/or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>secondary surface texture of the STU</td>
<td></td>
</tr>
<tr>
<td>Parent Material</td>
<td>• PAR-MAT-DOM: Code for dominant parent material of the STU</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>• PAR-MAT-DOM1: Major group code for the dominant parent material of the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STU</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PAR-MAT-SEC: Code for secondary parent material of the STU</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PAR-MAT-SEC1: Major group code for the secondary parent material of the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>STU</td>
<td></td>
</tr>
<tr>
<td>Primary properties</td>
<td>• TEXT: Dominant surface textural class (completed from dominant STU)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• OC_TOP: Topsoil organic carbon content</td>
<td></td>
</tr>
<tr>
<td>Chemical properties</td>
<td>• DIFF: Soil profile differentiation</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>• CEC_TOP: Topsoil cation exchange capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CEC_SUB: Subsoil cation exchange capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BS_TOP: Base saturation of the topsoil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BS_SUB: Base saturation of the subsoil</td>
<td></td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>• DR: Depth to rock</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>•VS: Volume of stones</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• STR_TOP: Topsoil structure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• STR_SUB: Subsoil structure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PD_TOP: Topsoil packing density</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PD_SUB: Subsoil packing density</td>
<td></td>
</tr>
<tr>
<td>Hydrological properties</td>
<td>• AWC_TOP: Topsoil available water capacity</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>• AWC_SUB: Subsoil available water capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>SUM</strong></td>
<td><strong>24</strong></td>
</tr>
</tbody>
</table>

1.2.10.1 SGDB thematic maps - examples

More information and maps for each soil property described above can be found on:
Figure 3: Topsoil organic carbon content (Europe and Russia).

European Soil Data Centre also enables to view different geographical soil properties/data with web Map Viewer (http://eussoils.jrc.ec.europa.eu/wrb/).

Figure 4: Dominant surface textural class for Europe in MapViewer.
1.3 Soil profile data

Soil profile is a vertical section through the soil. Soil profile description is basic part of every field observation and sampling and is the most common way to acquire measured soil data. There is no unique or harmonized methodology for sampling and describing soil profile. In general, soil survey institutions have their own version of soil description forms which are similar but not harmonized. Nevertheless basics of soil sampling, description, field measurements and estimation of soil properties are more or less alike and this, comparable to a certain extent. Guidelines for soil sampling and soil profile description are published by FAO (2006).

1.3.1 FAO Guidelines for soil profile description

The 4th Edition Guidelines for soil description is available on: ftp://ftp.fao.org/agl/agll/docs/guidel_soil_descr.pdf. This further text has been cited from this cover document.

Figure 6: The process of soil description, classification, and site quality and suitability evaluation
1.3.1.1 General site information, registration and location

The first step in actual soil description, collection of relevant information is related to the registration and identification of the soil. The key information each soil profile should initially get:

Profile number – The letter code should consist of “sub” codes merged together. International Organization for Standardization (ISO) provides some good examples of coding, where the name of location of sampling is included in the code. Example: DE/ST/HAL -0381 = Halle in Saxony-Anhalt in Germany, profile 381.

Description status - The status of the soil profile description refers to the quality of the soil description and the analytical data. Date of description - The date of description is given as: yymmdd (six digits). Location - It should be as precise as possible. Could be in the terms of distance from features recognizable in the field.

Elevation - Elevation is given in metres. Map sheet number - The number or code of the topographic map sheet should be given. Preferably sheets should be at 1:25 000 or 1:50,000 scale. Grid reference - The latitude and longitude of the site. They should be given as accurately as possible (in degrees, minutes, seconds and decimal seconds) and can be derived from GPS or from topographic map.

Also important are the soils forming factors which should be included in the description. The information may be derived from a combination of field observations, field measurements, climate records and evaluation, topographical, geological and geomorphologic maps and documents. For land use and vegetation, the present conditions are reported. Description should be made for atmospheric climate, weather conditions and soil climate. Soil surveyor should define major landform, position, slope form, slope gradient and orientation, land use, crops, human influence, vegetation, age of the land surface and information about parent material.

1.3.1.2 Comprehensive Soil Description

Within the soil description procedure morphological and other soil characteristics during the field sampling are recorded. At the begging the surface characteristics are recorded. In the continuation the soil description is done horizon by horizon, starting with the uppermost one. Mainly there are two types of soil data:

One type is measured soil profile data and the other is estimated/described soil profile data. There are many methods and techniques how to measure or estimate certain soil property during the field sampling. Nevertheless many soil properties (especially chemical) can’t be measured accurately on the field (percentage of different mineral fragments of the soil, percentage of organic matter, pH, content of CaCO₃, CEC, bulk density etc.), therefore analytical methods are necessary. Some soil and location related properties can be measured or estimated only during the field surveying. Such properties are: slope gradient, slope aspect, rocky outcrops, surface cracks, root depth, number of horizons and depth of horizons, colour of horizons, the shape of soil structural aggregates etc. Some soil properties can be estimated on the field as well as accurately measured with analytical methods (organic matter, pH, texture etc.).

Each soil property is described by a variable. There are three basic types of variables used:

- Nominal (examples: soil horizon type, soil horizon colour, land use, parent material, landform type etc.)
- Ordinal (examples: rock outcrops estimation, estimation of degree of erosion, estimation of organic matter on the field, estimation of CaCO₃ on the field, etc.)
- Numerical (examples: soil depth, horizon, soil infiltration rate, bulk density, CEC, pH, % of organic matter, etc.)

Most profile soil data are nominal or ordinal type (numerical are rare), while analytical methods are numerical. Nominal variables we can be used in basic statistic operations, with ordinal some more complex statistics, while with numerical offer all possible and complex statistic analyses.

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1.3.1.3 Soil forming factors
The chapter provides the guidelines for description of factors that defines kind and intensity of soil formation processes. **Atmospheric climate and weather conditions**: present and former (in last month) weather conditions are registered. **Soil climate** - soil moisture and temperature regime information is not always applicable and thus represents optional information. **Landform and topography** is described by four categories: the major landform, the position of soil description site within the landscape, the form of the slope and the slope angle. **Land use and vegetation** set of soil observation parameters comprehends land use, crops - cultivated plants and human influence. All three descriptions have to be made using detailed coding tables. **Parent material** - the material where the soil has been derived is defined on the basis of the hierarchical lithological / geological classification. **Age of the land surface** is re order as well using the 14 briefly described potential classes of influences to soil formation.

1.3.1.4 Soil description

**Surface characteristics**
Surface characteristics are ordinal type of variables and belong to the estimated soil profile data.

**Rocky outcrops** are described in terms of percentage surface cover, together with additional relevant information on the size, spacing and hardness of the individual outcrops. **Coarse surface fragments** are described by the percentage of surface coverage and of size of the fragments. **Erosion** is classified by type (category: water or wind), by the area affected by erosion, and by the degree and activity. **Surface sealing** used to describe crusts that develop at the soil surface after the topsoil dries out. **Surface cracks** develop in shrink–swell clay-rich soils after they dry out. The width (average, or average width and maximum width) of the cracks at the surface is recorded in centimetres. The average distance between cracks may also be indicated in centimetres. A number of other **surface characteristics** such as the occurrence of salts, bleached sands, litter, worm casts, ant paths, cloddiness and puddling, may be added to the surface description.

**Description of soil horizons**

**Horizon boundaries - depth and horizon distinctness.** The depth of the upper and lower boundaries of each horizon is given in centimetres, measured from the surface (including organic and mineral covers) of the soil downwards. If the boundary between horizons is transitional and not a sharp line, the rounded value should be entered. In case the boundary/topography of horizons varies or is irregular or not horizontal, average horizon depth should be defined (FAO guidelines for soil description, 2006).

**Primary constituents.**
**Texture** refers to the proportion of the particle size classes. It can be estimated on the finger test. For this, the soil sample must be in a moist to weak wet state while gravel and other constituents > 2 mm must be removed. Texture class is a subjective observation estimate based entirely on surveyor’s experience. Soil texture classes can be determined using well structured and comprehensive key to the soil textural classes (Table 1, FAO 2006).

Texture estimated during the field observation is in general confirmed my accurate measurements in soil laboratory.
Table 1: Presentation of a key to the soil textural classes as a good practice example

Rock fragments and artefacts. The presence of rock fragments and mineral fragments (> 2 mm) and artefacts are described according to abundance, size, shape, state of weathering, and nature of the fragments. Degree of composition and humification of peat and the aeromorphic organic layers in forest soils can be determined.

The soil colour defines the colour of the soil matrix of each horizon in the moist condition (or both dry and moist conditions where possible) using the notations for hue, value and chroma as given in the Munsell Soil Colour Charts. Where there is no dominant soil matrix colour, the horizon is described as mottled and two or more colours are given. Mottles - spots or blotches of different colours or shades of colour interspersed with the soil matrix - dominant colour of the soil. Mottles indicate that the soil has been subject to alternating wet (reducing) and dry (oxidizing) conditions. Colour, abundance, size, contrast and boundary of mottles are estimated on the field.

Soil redox potential and reducing conditions is an important parameter characterizing the soil moisture status and availability of nutrients. For measuring redox potential (DIN/ISO Draft, DVWK, 1995) require special equipment composed of at least two electrodes should be installed for each soil depth being measured. Redox potential is measured with a millivolt meter against a reference electrode. The measured voltage (Em) is related to the voltage of the standard hydrogen electrode by adding the potential of the reference electrode. For interpretation, the results are transformed to pH values according the calculation pH = 2pH + 2Eh/59 and interpreted using the provided table.

The presence of carbonates / calcium carbonate (CaCO₃) is on-field estimated by adding some drops of 10-percent HCl to the soil. The degree of effervescence of carbon dioxide gas indicates the amount of calcium carbonate present. Gypsum is estimated in the field by measurements of electrical conductivity in soil suspensions of different soil–water relations.
In a similar way as gypsum content also other readily soluble salts can be measure in the field using field conductometer.

**Soluble salt** usually in coastal or desert soils can be roughly estimated from an EC (in dS m-1 = mS cm-1) measured in a saturated soil paste or a more diluted suspension of soil in water.

In the field, the pH is either estimated using indicator papers, indicator liquids, or measured with a portable pH meter in a soil suspension and interpreted using the classification. Field soil pH measurements should be correlated with laboratory determinations where possible.

The presence of smell of soil horizon **soil odour** can be classified in three classes. The procedure for determination of **andic characteristics and volcanic glasses** is presented. Two alternate methods are described.

The **organic matter content** of mineral horizons is estimated from the Munsell colour of a dry and/or moist soil, taking the textural class into account. This estimation is based on the assumption that the soil colour (value) is due to a mixture of dark coloured organic substances and light coloured minerals. FAO (2006) presents the OM estimations table.

Table 2: **Estimation of organic matter content based on soil colour and texture**

<table>
<thead>
<tr>
<th>Colour</th>
<th>Munsell value</th>
<th>Moist soil</th>
<th>Dry soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>LS, SL, L</td>
<td>Sil, Si, SICL, CL, SICL, SC, MC</td>
</tr>
<tr>
<td>Light grey</td>
<td>7</td>
<td>&gt; 0.3</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>Light grey</td>
<td>6.5</td>
<td>&gt; 0.4</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>Grey</td>
<td>6</td>
<td>0.6-1</td>
<td>0.6-1</td>
</tr>
<tr>
<td>Grey</td>
<td>5.5</td>
<td>1-1.5</td>
<td>1-1.5</td>
</tr>
<tr>
<td>Grey</td>
<td>5</td>
<td>&gt; 0.3</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>Dark grey</td>
<td>4.5</td>
<td>&gt; 0.4</td>
<td>0.3-0.6</td>
</tr>
<tr>
<td>Dark grey</td>
<td>4</td>
<td>&gt; 0.4</td>
<td>0.3-0.6</td>
</tr>
<tr>
<td>Black</td>
<td>3</td>
<td>0.9-1.5</td>
<td>1-2</td>
</tr>
<tr>
<td>Black</td>
<td>2.5</td>
<td>1.5-2</td>
<td>1-2</td>
</tr>
<tr>
<td>Black</td>
<td>2</td>
<td>&gt; 2</td>
<td>&gt; 2</td>
</tr>
</tbody>
</table>

Note: If chroma is 2.5–6, add 0.5 to value; if chroma is > 6, add 1.0 to value.
Source: Adapted from Schnitzler, Blume and Stege, 1996.

**Organisation of soil constituents**

For the **description of soil structure**, a large lump of the soil should be taken from the profile, from various parts of the horizon if necessary, rather than observing the soil structure in situ. It is suggested to describe the structure when the soil is dry or slightly moist. Soil structure can be described by **type**, **grade** of their development and their **size**. The classification of structure for pedal soil materials and soil structure types is available. as well as codes for types of soil structures.

**Consistence** of soil horizon is required for dry, moist and wet (stickiness and plasticity) states. Where applicable, the smeariness and fluidity may also be recorded. For routine descriptions, the soil consistence in the natural moisture condition of the profile may be described. In case of dry conditions the wet and/or moist consistence can be described by adding water to the soil sample.

**Soil - water status** term is used for the moisture condition of a horizon at the time the profile is described. FAO (2006) shows the possible soil moisture status descriptions.
Table 3: Classification of moisture status of soil

<table>
<thead>
<tr>
<th>Classification</th>
<th>Forming (to a ball)</th>
<th>Moistening</th>
<th>Rubbing (in the hand)</th>
<th>Moisture</th>
<th>pHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dusty or hard</td>
<td>Not possible, seems to be warm</td>
<td>Going very dark</td>
<td>Not lighter</td>
<td>Very dry</td>
<td>5</td>
</tr>
<tr>
<td>Makes no dust</td>
<td>Not possible, seems to be warm</td>
<td>Going dark</td>
<td>Hardly lighter</td>
<td>Dry</td>
<td>4</td>
</tr>
<tr>
<td>Makes no dust</td>
<td>Possible (not sand)</td>
<td>Going slightly dark</td>
<td>Obviously lighter</td>
<td>Slightly moist</td>
<td>3</td>
</tr>
<tr>
<td>Sticky</td>
<td>Finger moist and cool, weakly shiny</td>
<td>No change of colour</td>
<td>Obviously lighter</td>
<td>Moist</td>
<td>2</td>
</tr>
<tr>
<td>Free water</td>
<td>Drops of water</td>
<td>No change of colour</td>
<td>Wet</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Free water</td>
<td>Drops of water without crushing</td>
<td>No change of colour</td>
<td>Very wet</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

* pH (p E potential, F = free energy of water) is log hPa.

Additionally to two not often described soil horizon properties are suggested to be described: soil stickiness (quality of adhesion of soil particles to other objects) and the soil plasticity - the ability of soil material to change shape. For both properties classification tables are given.

**Bulk density.** According the guide the field determinations of bulk density is obtained by estimating the force required to push a knife into a soil horizon exposed at a field moist pit wall. The bulk density for mineral soils is estimated using the estimation key. In case of organic matter content > 2% the estimations values are reduced by the 0.03kg-3 for each 1% increment increase in OM content.

**Porosity / voids** is an indication of the total volume of voids discernible with a ×10 hand-lens measured by area and recorded as the percentage of the surface occupied by pores. Estimation of porosity can be supplemented with analytical methods. Pores or voids are described in terms of type, size and abundance. In addition, continuity, orientation or any other feature may also be recorded.

**Concentrations** of soil materials include secondary enrichments, cementations and reorientations are widely described:

- **coatings** are described in detail by five parameters: abundance, contrast, nature, form and location
- **cementation and compaction** are described by four parameters: the continuity, structure, nature and degree of cementation
- **mineral concentrations** describing by six parameters: abundance, kind, size and shape, hardness, nature and colour

**Biological activity.** The recording of both the size and the abundance of the roots are determined to characterize the distribution of roots in the profile. The abundance of roots can be compared within the same root size class. The abundance of fine and very fine roots may be recorded similarly as for voids expressed in the number of roots per decimetre square. Other biological features, such as krotovinas, termite burrows, insect nests, worm casts and burrows of larger animals, are described in terms of abundance and kind.

**Human made materials.** In the past not common but nowadays it is became increasingly important to document the type and degree of human influence. Three different groups of human made materials are defined:

- artefact
- human - transported material
- geomembranes and technic hard rock

Artefacts which are considered as more important soil can be further described and coded according to their abundance, kind, size, hardness, weathering stage and colour.

1.3.1.5 Soil sampling

The guide recommends giving the sample the profile number followed by an additional capital letter and a depth range at which the sample has been collected. Samples are never
taken across the horizons. Horizon symbols should not be used as sample codes due to potential change. Usually, 1 kg is recommended as sample size.

1.3.2 Commonly measured / representative chemical soil analyses

Measurements are called chemical when they involve characterization of the soil solution and of the composition of the organic and inorganic phases in soil.

1.3.2.1 Soil horizon pH

pH affects the availability of soil nutrients, solubility of toxic nutrient elements in the soil, physical breakdown of root cells, biological activity and cation exchange capacity. When the pH values are high the availability of phosphorus (P) and most micronutrients (not boron (B) and molybdenum (Mo) tends to decrease. Usually acid soil can be found in temperate and humid areas and alkaline soils can be found in drier areas. The pH is one of the basic measurements in soil laboratories. For mapping purposes it may be classified, for instance, as the following:

- strongly acid (pH < 5.0)
- moderately to slightly acid (5.0 - 6.5)
- neutral (6.5 - 7.5)
- moderately alkaline (7.5 - 8.5)
- strongly alkaline (> 8.5)

1.3.2.2 Organic matter content

Soil organic matter (OM) consists of plant remains, root material and soil organisms and has a big influence on soil aggregation, nutrient availability, moisture retention, biological activity, etc. While in peat soils the OC is the dominant constituent it is almost absent in some desert soils. Temperate-region soils normally have 3 - 4% OM and semi-arid areas have less than 1%OM. There are different laboratory analyses to measure OM (reduction of potassium dichromate, etc.) and is usually presented as oxidised organic carbon (OC) or multiplied by 1.334 as OC.

1.3.2.3 Calcium Carbonate

Calcium carbonate is found in soils due to parent material or as a result of weathering. Calcium carbonate is an important component in fertilization process. Application of inorganic carbonate in the first fertilization actions enables soil reactions. Calcium carbonate influences the soil pH and only when pH is appropriate the nutrient availability to plants increases.

1.3.2.4 Base cations

Many soil minerals are negatively charged and can therefore attract cations such as:

- calcium (Ca++)
- magnesium (Mg++)
- potassium (K+)
- ammonium (NH4+)
- sodium (Na+)

Different methods and especially extractions are used to measure the cation exchange capacity (CEC) and exchangeable cations in soil:

- the cobalt hexamine chloride method
- the barium chloride method
- the ammonium acetate method
1.3.2.5 Cation Exchange Capacity (CEC)
Cation exchange capacity is a reversible process of the attraction of some cations to the negatively charged soil minerals. CEC is influenced by clay content, organic matter and soil pH. CEC is an important chemical soil property and is used for soil classification, soil fertility assessment and can influence on retaining/leaching of nutrients and pesticides through the profile, etc. It is reported as milli-equivalents per 100 g soil or more recently as cmol (+)/kg soil. Values of CEC are in the range of 1 to 100 meq/100g, least for sandy soils and most for clay soils.

1.3.2.6 Electrical conductivity
Conductivity is needed to measure EC of nutrient solution. While increasing nutrient concentration the conductivity increases too and needs to be regulated. Different plants need different EC according to growth stages (Petelinc, 2006). EC influences on biological productivity and diversity.

1.3.3 Physical and morphological soil properties
Physical and morphological properties of soil are defined during quantitative description of soil and definition of soil horizons in the field work as in the laboratory.

1.3.3.1 Structure
Soil structure is defined as the arrangement of particles into aggregates and can also be described in terms of the size and stability of aggregates. Soil horizons can differ due to the structure type. Soil processes such as freezing and thawing, wetting and drying, animal and root activity influence on the arrangement of the particles in the soil. Some features in the soil cause the cementation of the aggregates (organic matter, wastes, etc) and some of the processes in the soil cause their destruction (depletion of soil organic matter, poor tillage practices, etc.).

1.3.3.2 Texture
Soil texture can be described as the size distribution of primary mineral particles. The texture of soils is described in terms of the percentages of sand, silt, and clay. Particles of 2 to 0.05 mm diameter are called sand; of 0.05 to 0.002 mm diameter are silt; and the <0.002 mm particles are clay. Different soil texture can be a good indicator of different soil horizon. Soil texture can be estimated by feeling and manipulating a moist sample, or can be determined accurately by laboratory analysis.

1.3.3.3 Consistence
Consistence describes the behaviour of the soil to mechanical stress. It is a physical condition and can be described as hard, loose, friable, plastic, firm, sticky, etc. The consistence of soil is determined by the texture of soil, organic matter and clay minerals.

1.3.3.4 Soil organic matter
When plant residues are returned to the soil, various organic compounds undergo decomposition. Decomposition is a biological process that includes the physical breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules (Juma, 1998). The continual addition of decaying plant residues to the soil surface contributes to the biological activity and the carbon cycling process in the soil (FAO, 2005). Dark soil colour indicates larger organic matter content and spherical structural aggregates form only when organic matter (humus) is present.
1.3.3.5 Soil moisture

Water held in the spaces between soil particles is called soil moisture. Water in the first 10 cm of soil is considered to be surface soil moisture and the water available to plants is considered to be root zone soil moisture (upper 200 cm of soil).

Well branched root system is developed in a fertile soil, containing organic matter (humus) and have appropriate air-water regime (suitable soil structure). Due to soil compaction, soil water, rock fragments in soil poor root system develops.

1.3.3.6 Colour

Soil colour is an important diagnostic feature, which helps us explain soil genesis processes and also indicates on the conditions in which the soil was created.

Different colours of soils indicate different soil properties. In general surface soils are darker than sub-soils. Also moisture and organic components influences on soil colour and make soils darker.

Oxidation and hydration states of iron oxides reflect as red, yellow and gray hues of sub-soils. Good aeration and drainage reflects as red and yellow hues in sub-soils.

Transition between well and poorly drained zones can appear in the form of mottled zones, splotches of one or more colours in a matrix that is in a different colour. Gray hues indicate bad aeration properties in sub-soils.

The colour is in general determined by the use of a colour atlas of the 'Munsell Soil Colour Charts'.

1.3.3.7 Rock and other fragments

Rocks and other fragments are considered as particles larger than 2mm (Schoeneberger, P. J. et al., 1998). The proportion of rock fragments is usually determined in the field. In this procedure we estimate volume proportion (vol. %), maximum size and shape (very angular, angular, sub-angular, sub-rounded, rounded, well rounded). Larger rock fragments can influence tillage (harder or even impossible).

1.3.3.8 Soil temperature and plant growth

Soil temperature and soil moisture control the biological processes for nutrient transformations and their availability. It influences seed germination, nutrient uptake, roots and crop growth. Factors that control the soil temperature are soil moisture, soil colour, vegetative cover and land slope.

We can control the soil temperature by regulating soil moisture, organic soil content, with good management practices (good drainage, etc.) and keeping the soil warm enough to enable chemical and biological activities in the soil.

1.3.3.9 “New features”

New features appear as the result of soil formation processes and can be defined as coatings, mottles, concretions and splotches. Coatings are developed when small particles are transferred down the profile. In this case very fine particles or organic matter are leached from upper horizons. Leached substances are suspended as coatings on structural aggregates and crack walls in lower soil horizons.

Concretions are formed due to different mineral concentration in soils. In older soils where water filtering is slower iron and iron-manganese concretions are formed. In semi-humid and semi-arid climates carbonate coatings and concretions are formed.
Splotches (of one or more colours) are in some case formed as precursors of concretions. Their formation is usually associated with alternating oxidation and reduction conditions in soils.

1.3.3.10 Soil organic carbon content

Soil organic carbon (SOC) is composed of different substances containing carbon. Organic substances derive from animal manure, compost, crop residues and other organic materials. The quantity of SOC defines the health state of soil and its reduction can cause the land degradation. It is a major contributor to soil fertility and acts as a reservoir for soil nutrients (nitrogen, phosphorus and sulphur). SOC supports the structure of the soil, reduces the risk of erosion, and improves the water holding capacity of the soil and the physical environment for roots, so that they can easily penetrate through the floor. The SOC content is influenced by climate, soil composition, hydrology, land use and vegetation.

1.3.4 Rarely measured soil properties

1.3.4.1 Microbial biomass

Microorganisms maintain soil fertility due to their ability to sustain nutrient cycling and therefore support plant life and enables food production. The majority of soil microbial activity is located in rhizosphere. Microbial communities in soil are heterogeneous (fungus, algae, protozoa and viruses); in one gram of soil we find from 106 to 109 bacteria. Microorganisms follow the plant, nutrient (OC, N, P) and water distribution. Micro-organisms presence around the roots is particularly important to operate soil system.

The majority of microorganisms according to their metabolic plasticity can survive without plants, but significantly less active. On the other hand the absence of this interaction is often fatal for plants. Microbial oases in the soil are therefore places where hot spots activities are present (David Stopar, 2010). The microbial biomass and enzyme activities can also be used to indicate changes in biological soil properties induced by changed tillage.

1.3.4.2 Abundance and biomass of earthworms

Earthworms find in soil the energy, nutrient resources, water and buffered climatic conditions that they need. According to the food resource they exploit and the general environmental conditions, earthworms can be grouped into different functional categories which differ essentially in morphology, size, pigmentation, distribution in the soil profile, ability to dig galleries and produce surface casts, demographic profiles and relationships with the soil micro flora. Soil characteristics are both the determinant and the consequence of earthworm activities, since these animals greatly influence the functioning of the soil system. When present, they build and maintain the soil structure and take an active part in energy and nutrient cycling through the selective activation of both mineralization and humification processes. By their physical activities and resultant chemical effects, earthworms promote short and rapid cycles of nutrients and assimilable carbohydrates. Thus earthworms represent a key component in the biological strategies of nutrient cycling in soils and the structure of their communities gives a clear indication of the type of soil system that they inhabit (P. Lavelle, 1988).

Earthworms have been documented to be major driving forces for belowground processes. Due to their large body size, high consumption rates and burrowing activity they are keystone organisms forming the habitat of soil biota (Scheu, 2003). Also, it has widely been appreciated that earthworms affect decomposition processes and nutrient dynamics in the soil (Scheu, 2003). However, as outlined above, the implications of these effects for the aboveground system are strongly biased towards agricultural systems and focused on a single parameter, the yield of crop plants. It appears that earthworms have been treated largely as agents for improving agricultural production rather than as components of natural ecosystems.
The lack of integration of studies on effects of earthworms on plant performance and the whole aboveground system opens a large scope for future research. The imperative for future research is adopting an ecological rather than an agricultural perspective in studying earthworm-plant interrelationships and viewing earthworms as driving factors of the aboveground food web. Earthworms not only modify nutrient availability to plants but may alter the whole rhizosphere environment. The mechanisms by which earthworms affect plant growth include direct effects such as root feeding and transposal of plant seeds. However, plant growth is modified mainly indirectly by changing soil structure, mineralization processes, hormone-like effects, dispersal of plant growth stimulating microorganisms and dispersal of microorganisms antagonistic to root pathogens. As stressed by Scheu and Setälä (2002), belowground interactions may not only affect plant growth and vegetation structure but further propagate into the herbivore and even predator/parasitoid community.

It has been realized in early studies that the presence of earthworms may alter the structure of plant communities. Hopp and Slater (1948) documented that the dominance ratio between grasses and legumes shifts towards the latter in experimental grassland systems with earthworms.

Obviously, earthworms not only modify plant biomass production but also the growth form of plants. This certainly also applies to their belowground parts.

Another ignored topic in experiments on how earthworms affect plant growth is the physiological response of plants. It has been documented frequently that the presence of earthworms results in increased nutrient concentrations in plant tissue (Scheu, 2003).

As the major limiting element for plant growth the availability of nitrogen drives plant physiology. Earthworms therefore likely affect the concentrations of primary and secondary metabolites in plants and this may have important consequences for the susceptibility of plants to pathogens, parasites and herbivores. In fact, early observations by Kollmannsperger (1952) indicate that earthworm faeces increase the resistance of cress seedlings to fungal pathogens which he ascribed to the uptake of antibiotics produced in the rhizosphere.

1.3.4.3 Enzyme activities
All biological transformations are in fact enzyme transformations. Basically they happen even without enzymes but much more slowly.
2 Soil Quality

Soil quality is often believed to be an abstract soil characteristic hard to define since it depends also on external factors (i.e. environmental interactions, socioeconomic and political priorities, soil management practices etc.). The perception of soil quality - what constitutes good and bad soil varies with respect to the functions performed by soil (Doran and Parkin, 1994). Different definitions of soil quality have been proposed, some of which are rather complex:

- The capability of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem (Larson and Pierce, 1991);
- The capability of soil to produce safe nutritious crops in a sustained manner over a long-term period, to enhance human and animal health without impairing the natural resource base or harming the environment (Parr et al., 1992).
- Soil quality is an assessment of to what extent and how well the soil performs its functions and how they are preserved for the future use (USDA SQG, 2004).
- The shortest definition of soil quality is simply Fitness for use given by Pierce and Larson (1993).

For some authors the definition of soil quality is elusive and value-laden. To overarch this problem they suggest emphasizing quality soil management instead of soil quality management (Sojka et al., 2003). For Harris (1994) and Doran (2002) soil quality equals soil health. The term soil quality and soil health tend to be used interchangeably. The term soil quality focuses on quantitative and analytical properties and seems to be preferred by soil scientists. The characterization soil health, used by farmers, is focused on the qualitative/descriptive properties of soil which are directly judged (Agriculture and Agri-Food Canada, 2005). Soil quality is also a necessary but insufficient indicator of sustainable land management (Herrick, 2000; Doran, 2002). A characteristic common to all the definitions is that soil quality is a long-term capacity of soil to perform its functions effectively.

Changes in the priorities of society in the last decade of the 20th century, together with demands and pressures on soil resources, redefined views of soil quality in order to follow the needs of non-agricultural stakeholders. The adoption of a approach where the multifunctional role of soil is fully considered was called for (National Soil Resources Institute, 2001). The quality of soil is largely defined by the priority of the functions the soil performs and represents a composite of chemical, physical, and biological soil properties. The major issues or components defining soil quality:

- Productivity – the ability of soil to enhance plant and biological productivity
- Environmental quality – the ability of soil to attenuate environmental contaminants, pathogens, and offsite damage
- Health – the relationship between soil and plant, human and animal health.

A theoretical definition for soil quality, which included the above listed issues is: Soil quality is the capacity of soil to function within ecosystem boundaries in order to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994).

2.3 Soil quality assessment

Soil quality has been assessed for many different purposes, however, soil being a complex medium it is often difficult to evaluate its properties. In the agricultural context the evaluation of soil quality was biased towards indicators designed to monitor the soil capacity to support agricultural production rather than the broad range of functions and services it performs. Soil quality was integrated in different land capability or land suitability classifications or soil potential ratings. Systems, such as the FAO Land Capability system (FAO, 1981; Helms, 2006),
were based on soil properties that could more or less limit crop yields. The _USDA Land Capability Classification_ was developed to bridge the gap between soil classification and soil fertility. It ranks soil mapping units according to their ability to support a general kind of land use for farm planning (Rossiter 1995). The _Fertility Capability Soil Classification System_ was also based on soil parameters that could directly or indirectly influence cultivation and employed a coded system that eased the transmission of information on soil capacity/quality (Rossiter 1995; Young, 2000). The _Soil Potential Rating_ developed by the US Department of Agriculture features classes that indicate the relative quality of soil for a particular use compared with the soils of a given area (Beatty et al., 1979). Subsequently, the soil quality evaluation concept was introduced, which entailed a wider recognition of the environmental role of soil (Doran and Parkin, 1994). A better understanding and greater awareness of the fact that soils are a living natural body with physical, chemical, and biological properties and processes (Andrews et al., 2003), performing vital ecosystem functions that cannot be separated, helped to widen the operative definition of soil quality to follow the needs of non-agricultural stakeholders (National Soil Resources Institute, 2001). The urban environment in particular needs a wide framework for evaluating soil quality.

The procedure used for soil quality evaluation should be based on a mechanism by which the land user/owner could obtain:

- information about the capacity of the soil to perform the desired functions and service and to provide goods, and
- information related to the sustainable use of the soil resources. The operative framework needs to be structured and it should be used at a high level without necessarily expert knowledge of soil science. Equally important, it should identify the points at which a soil scientist’s expertise should be involved (National Soil Resources Institute, 2001).

### 2.4 Soil quality indicators

The term soil quality is also often assigned to specific soil attributes (i.e. pH, soil structure stability, organic matter content, and nutrient supply). However, soil quality cannot be measured directly; it cannot be determined by the evaluation of a single measured parameter or measured by the crop yield, water quality, or any other single factor. It is assessed through an evaluation of several soil quality indicators (SQI). SQI are measurable physical, chemical, biological, and functional soil and soil-related parameters and characteristics that can be expressed in terms of numeric values. The principles of soil evaluation that come from the agricultural use of soil were mentioned above. The same evaluation concepts based on the same (or very similar) soil quality indicators are applicable for soil quality evaluation in all soil-associated ecosystems (National Soil Resources Institute, 2001).

Indicators, and the values assignable to them, can be determined by exact science (laboratory analysis) or expert opinion. The value of each indicator depends on the function it explains. The same indicator can have different optimal values for different functions, e.g. the optimal pH for food and fibre production (a corn field) is very different from the optimal pH for an ornamental garden with the species _Erica_ or a blueberry plantation; soils with high clay content can be evaluated better when planning chemical industry facilities compared with assessing the quality of an agricultural field or pasture for such use; or, optimal soil depth and nutrient content can be very different in the case of an orchard as compared with a dry Karst grassland - a high-biodiversity semi-natural ecosystem.

To evaluate soil quality, soil indicators have been developed or identified for many different specific, mostly agricultural, and general environmental purposes. The National Soil Resource Institute (2001) identified 60 different soil quality indicators from which one awareness indicator and nine functional indicators have been selected which, due to their usefulness, act as _immediate_ indicators of soil quality.
2.4.1 Minimum soil quality indicator data set

The Minimum Data Set (MDS) is a list of the most important and essential soil quality indicators. As an example, an MDS for the monitoring of soil quality was presented by Larson and Pierce (1991). Their MDS comprises well-known and generally accepted soil quality indicators (See Table 4). Although the list was presented in an agricultural context, it can be considered to be the list of measured and observed parameters suitable for the most general characterization of soil quality.

Table 4: Minimum soil quality indicator data.

<table>
<thead>
<tr>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient availability</td>
</tr>
<tr>
<td>Total organic C</td>
</tr>
<tr>
<td>Labile organic C</td>
</tr>
<tr>
<td>Particle size distribution</td>
</tr>
<tr>
<td>Plant-available water capacity</td>
</tr>
<tr>
<td>Soil structure, form</td>
</tr>
<tr>
<td>Soil strength</td>
</tr>
<tr>
<td>Maximal rooting depth</td>
</tr>
<tr>
<td>Soil surface condition</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>Electrical conductivity</td>
</tr>
</tbody>
</table>

In the UK, the minimum national indicator set as defined by the National Soil Resource Institute (2001) is considered to give the greatest amount of information about soil quality in all contexts and is regarded as an idealised target (Table 5). It is composed of one awareness indicator and nine function-related indicators. The criteria for indicator selection were wide-ranging:

- Clear link to soil function
- Wide applicability
- Robustness
- Resonance with a wide audience
- Ascertaintable within a reasonable time frame

Beside the 10 indicators composing the minimum dataset, they identified an additional 50 different soil quality indicators.

Table 5: The national UK minimum soil quality indicator set related to soil functions.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness</td>
<td>/</td>
</tr>
<tr>
<td>Total above-ground biomass production</td>
<td>Food and fibre production</td>
</tr>
<tr>
<td>Total below ground soil organic carbon</td>
<td>Food and fibre production</td>
</tr>
<tr>
<td></td>
<td>Habitats and biodiversity</td>
</tr>
<tr>
<td>Topsoil pH</td>
<td>Environmental interaction</td>
</tr>
<tr>
<td>Buffering capacity</td>
<td>Environmental interaction</td>
</tr>
<tr>
<td>Keystone species</td>
<td>Habitat and biodiversity</td>
</tr>
<tr>
<td>Soil microbial diversity</td>
<td>Habitat and biodiversity</td>
</tr>
<tr>
<td>Soil surface condition</td>
<td>Providing a platform</td>
</tr>
<tr>
<td>Extent and depth of ploughing</td>
<td>Protection of cultural heritage</td>
</tr>
<tr>
<td>Area of land taken for mineral workings</td>
<td>Providing raw material</td>
</tr>
</tbody>
</table>
The indicators listed in Table 5 require intensive data collection in order to make them operative. For operative work, the SQI have to be supported by clearly defined technical soil parameters and properties. Schipper and Sparling (2000) defined a reduced SQI set in order to characterize the general soil condition of New Zealand. The set comprises SQI selected on the basis that:

- They provide information on the chemical, psychical, and biological condition of soil
- They contribute significantly to the soil characterization using the principal component analyses method performed in the research study, and
- They are readily measurable

Table 6: New Zealand soil indicators for assessing soil condition on a national scale (Schipper and Sparling, 2000)

<table>
<thead>
<tr>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Potentially mineralizable N</td>
</tr>
<tr>
<td>2. pH</td>
</tr>
<tr>
<td>3. Bulk density</td>
</tr>
<tr>
<td>4. Total C</td>
</tr>
<tr>
<td>5. Olsen P</td>
</tr>
<tr>
<td>6. Macroporosity</td>
</tr>
</tbody>
</table>

The identification of the appropriate SQI represents the initial step in a soil quality evaluation. Yet it has only limited value if the methods used for the determination of separate SQI are not fully defined and/or standardised. A comparison of soil evaluation data, e.g. on the determination of the heavy metals in the soil, shows that they vary considerably depending on the analytical method used (Duncan et al., 1995). Thus, the soil quality evaluation methods should include detailed information on sampling, sample storage, and pre-treatment, as well as the analytical methods used to determine the separate SQI.

2.4.2 Grouping and selection of soil quality indicators

In terms of their complexity, soil quality indicators can be divided into three categories (National Soil Resources Institute, 2001; Nortcliff, 2002):

- The measured physical and chemical properties of the soil linked to the soil’s function(s) (pH, HM conc., CEC, texture, structure, etc.)
- The environmental properties which affect soil function, and
- High level indicators which reflect the soil functioning.

Nortcliff (2002) grouped the SQI into four groups:

- Physical attributes indicators
- Chemical attributes indicators
- Biological attributes indicators
- Visible attributes indicators

and an additional SQI demonstrating the importance of organic matter:

- Soil organic matter as an indicator

According to Hoosbeek and Bouma (1998) soil and land quality indicators may be classified by three characteristics:

- Scale level
- Complexity
- Transferability
The SQI should also be sensitive to changes in management and climate (Doran and Parkin, 1994; National Soil Resources Institute 2001). Nortcliff (2002) suggests that the final selection of the SQI should be based on:

- Land use
- The relationship between soil function and indicator
- The ease and reliability of measurements
- Variations in the soil’s spatial and temporal distribution
- The sensitivity of the measurement to changes in soil management
- Comparability with routine sampling and monitoring programs
- The skills required for the use and interpretation of indicators

### 2.4.3 Selected examples of soil quality indicators used and recommended for the soil quality evaluation in general, agricultural and urban context

Table 7 presents a list of selected soil quality indicator sets as recommended or defined by different authors within different soil evaluation contexts, soil uses, or primary functions.

### Table 7: The list of selected sets of soil quality indicators

| SQI set No. | 1G | 2G | 3G | 4G | 5A | 6A | 7A | 8A | 9U | 10U | 11U | 12U | A |
|-------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| **Chemical indicators** |    |    |    |    |    |    |    |    |    |     |     |     |
| pH          | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Organic matter content | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Total organic C | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Labile organic C | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Polysaccharides | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| CEC         | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | MP  |
| Total N     | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Mineralizable N | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| C / N ratio | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Ext. P      | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Ext. K.     | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Plant nutrients | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Electrical conductivity (salinity) | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Sodium adsorption ratio | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Exchangeable N | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Microbial biomass C | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Microbial biomass N | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Heavy metal concentrations | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Pesticides, solvents, petroleum derivatives | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Buffering capacity | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |
| Base saturation | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | M   |

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**Biological indicators**

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**Observation indicators – visible attributes**

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<td>✓</td>
<td></td>
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<td></td>
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<td>O</td>
</tr>
</tbody>
</table>

<sub>g</sub> describes the general soil quality;
<sub>a</sub> is used to assess soil quality in an agricultural context;
<sub>u</sub> is used for an urban soil quality evaluation;
<sub>A</sub> indicates the data acquisition method.
<sub>M</sub>: the indicator is predominantly measured;
<sub>P</sub>: the indicator is predominantly assessed using a specific PTF;
<sub>O</sub>: the indicator is predominantly observed.

### 2.4.4 The summary of the presented SQI

From Table 7 it can be concluded which soil quality indicators can be regarded as the most relevant for the soil quality evaluation for agricultural, urban and general purposes.
The acquisition of data for SQI marked with \( M \) is done predominantly through national or international (standardised) analytical procedures. The others, marked with \( P \), are assessed by the application of specific pedotransfer functions (PTF) on measured or observed data; the latter are marked with an \( O \).

The high number of measured indicators confirms the importance of accurate measurements and analytical procedures and denies the value of data gathered on the basis of visual assessment. Such an oversimplification as it was encountered in some research project materials (i.e. evidence of pollution on the basis of plant growth) cannot represent a firm or a scientific foundation for the development of a soil quality evaluation technique.

The selection of the (analytical) methods for determining SQI varies between countries/regions; it mainly depends on the data availability and is often defined by national legislation.

A close look at the soil quality indicators reveals their grouping and rating according to the importance of specific indicators for different purposes (Table 8).

**Table 8: Selection of the most important soil quality indicators**

<table>
<thead>
<tr>
<th>SQI set</th>
<th>General</th>
<th>Agriculture</th>
<th>Urban</th>
<th>Sum</th>
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<tr>
<td>Texture/particle size distribution</td>
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<td>6</td>
<td>12</td>
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<tr>
<td>Organic matter content; Organic C</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>12</td>
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<tr>
<td>pH</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Plant nutrients &amp; Ext. P; Extr. K; Total N</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Bulk density</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Electrical conductivity (salinity)</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>8</td>
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<tr>
<td>CEC</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Depth of soil; rooting depth, topsoil depth</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Porosity and macropores, infiltration rate</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Structure (aggregate strength and stability)</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Heavy metal concentrations/pollution</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
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</table>

**Ranking:**
1. texture/particle size distribution
2. organic matter content
3. pH
4. plant nutrients, including N

The second group is composed of equally represented SQI: 5) bulk density, 6) electrical conductivity/salinity; 7) cation exchange capacity (CEC); 8) soil depth (depth of topsoil or rooting depth); 9) porosity, 10) information on soil structure, and 11) heavy metal (HM) pollution.

The low ranking of heavy metals in soil can be explained with the high cost of the HM measurements and analytical procedures and low awareness of soil pollution at the time when the SQI sets listed in Table 7 were defined. These are expected to be the main reasons for the low number of HM pollution measurements in the data collections and consequently in the SQI sets. As regards the growing importance of heavy metals and their relation to environmental health and the development of analytical techniques and procedures, it can be concluded that heavy metals have only started to become standard indicators.

Several other authors have presented their SQI sets for different purposes or have specified alternate SQI. Some SQI sets are adapted to regional conditions, i.e. the Central High Plains of the Midwestern USA; (Hanks and Lewandowski, 2003). In order to assess soil quality in the context of soil fertility, soil enzyme activity was used as an indicator (Dick, 1994; Brejda and Thomas, 2001). Hankard et al. (2005) describe earthworm reproduction tests as a soil quality indicator. The authors reported that chemical analyses are not enough to characterize the
quality of urban soils and confirm the value of biological assays for the risk assessment of potentially contaminated soil. Doran and Zeiss (2005) suggested the use of other soil organisms and biotic parameters to assess soil quality. Soil microbial activity reflects microbiological processes in soil and is a potential indicator of soil quality (Bloem and Breure, 2003; Chen et al., 2003). According to Linden et al. (1994) the numeration and identification of burrowing soil fauna should be included in a minimum dataset for assessing changes in soil.

The conclusion of the above review of the SQI use is that no universal set exists; only suggestions of suitable SQI sets, some for general others for specific evaluation purposes can be proposed. All of them have to be adapted and fine-tuned by local soil experts to best meet the local conditions the most. The SQI selection criteria depend on the purpose of the evaluation, e.g. the primary functions of the soil. With regard to the fact that an extensive list of soil SQI sets can be generated, each of them best suits the selected soil evaluation purpose, diverse local conditions and data availability. Additionally, various analytical methods and measurements are used for the determination of soil properties; in view of this, a significant proportion of the SQI cannot be directly compared. Wherever possible the suggested SQI should already be a part of existing data sets.

2.5 Soil data exchange quality standard

The purpose of this International Standard is to provide a general procedure to record all kinds of soil related data and to exchange them. Soil related studies are usually conducted by specialized departments and their results have then to be forwarded to the requesting parties or to the administration. Official services are solicited to put the soil data online to become available to the public and they have to be crossed with other environmental, land-use or statistical data sources and using GIS is consequently essential.

This International Standard contains information on how to encode soil data and also contains basic principles to read/decode information provided in a clear and retrievable manner. In addition it also allows the interactive application of evaluation methods building on the development and successful implementation of harmonization procedures. The Standard proposes an Extensible Markup Language (XML) schema definition and associated data dictionaries. It includes XML platform, which is the standard for data transfer over the internet. There are several software tools and programming interfaces for processing and querying XML files, to transform XML into other data formats for further processing or display and to transform XML to/from relational databases. A specific form of XML for the exchange of geographic information is called GML. As such it promotes their exchange and their use in combination with other environmental data.

Soil data are stored in XML file which is structured text file that follows a specific set of rules and that embeds data between tags. The set of special rules to be followed are encoded into special types of XML files called XSD schema files that describe the names and definitions of data elements, their structure, attributes and relation. As such, XSD files are used for the validation of XML data files.

2.5.1 Normative references

In most soil quality projects there are several sets of data exchanged. The most common soil data exchanges are:

- ISO 1000, SI units and recommendations for the use of their multiples and of certain other units
- EN ISO 3166-1, Codes for the representation of names of countries and their subdivisions
- ISO 10381 series, Soil quality – Sampling
- ISO 11074, Soil quality – Vocabulary
- ISO 15903, Soil quality – Format for recording soil and site information
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

- ISO 19109, *Geographic information – Rules for Application Schemas*
- ISO 25177, *Soil quality – Field soil description*
- ISO 19118, *Geographic Information – Encoding*
- ISO/TS 19139, *Geographic Information – Metadata – XML schema implementation (Encoding of Metadata)*
- ISO 19156-2

All soil quality information shall refer to a specific place (point, location, mapping unit) in or under the surface of the earth. For all geographical information the ISO 19100 series is used.

2.5.2 Terms and definitions

The terms and definitions given in ISO 11074 and ISO 19109 and the following apply:

- **analysis**: process by which a sample is tested for composition or state according to a described procedure
- **analytical result**: qualitative or quantitative characteristic of a material obtained by an analysis
- **application schema**
- **attribute**: characteristic of a feature
- **borehole**: vertical penetration into the subsurface with removal of soil/rock material using e.g. a hollow tube shaped tool
- **code**: member of a code list
- **data model**: description of the organization of data in a manner that reflects an information structure
- **feature**: abstraction of a real world phenomenon
- **feature catalogue**: catalogue containing definitions and descriptions of the features
- **feature type**: class used in modelling of geographic phenomena
- **horizon**: domain of soil with a certain vertical extension, developed in a parent material layer through pedogenic processes or made up of in-situ sediment organic residues of up-growing plants
- **layer**: domain of soil with a certain vertical extension developed through uniform non pedogenic processes,....
- **metadata**: data that defines and describes other data
- **observation**: act of observing a property, with goal of producing an estimate of the value
- **non-destructive investigation**: application of a set of procedures or techniques to obtain observations on a material without lastingly changing its physical structure and chemical characteristics
- **plot**: elementary area where individual observations are made
- **project**: unique process, consisting of a set of coordinated and controlled activities, undertaken to achieve an objective conforming to specific requirements
- **sample**: solid, liquid, gaseous, or living material extracted from the soil
- **sampling**: process by which a sample is obtained
- **site**: defined area which is subject to a soil quality investigation
- **soil profile**: describable representation of the soil that is characterised by a vertical succession of horizons or at least one or several parent material layers
- **trial pit, test pit, trench, ;**: excavation prepared to carry out profile descriptions, sampling, and/or field tests: ISO 11074
- **well**: hole sunk into the soil for abstraction of water
- **unified modelling language**: UML
- **extensible mark up language**: XML
- **XML schema definition**: XSD
2.5.3 Assumptions

Features covered by this standard (each feature has its own attributes):

- Site
- Plot
- Soil profile
- Layer
- Sample
- Sampling
- Sample handling and transport
- Analysis
- Analytical result

Some additional assumptions accompany the definitions and frame conditions for soil data assessment and storage:

- Metadata for the full data record (soil site, profiles, horizons, sampling, analysis) are needed
- A number of field observations are made for an individual soil site or soil profile or horizon
- One or more profiles are taken per site
- Profiles could be taken at different dates
- A number of field observations are possible per horizon
- Laboratory observations/analyses are made on soil samples from the horizons
- One laboratory could be responsible for the analytic measurement of all horizons or different laboratories could be responsible for different horizons

2.5.4 Soil quality information model

Soil quality data exchange should be based on information model that is based on Observations and Measurements (ISO 19156-2)

The soil quality features of this model are worked out in subclasses:

- A1 Project

...Is the activity that leads to the collection of soil data. It is of importance to exchange project data along with other soil quality data in order to know the aim and circumstances of data collection.

- B1 Site
- C1 Soil mapping unit & C2 Soil typological unit
- D1 Analysis, D2 Analytical result & D3 Observation result
- E1 Sample & E2 Sampling spots
- F1 Layer Horizon
- G1 Observation
- H1 Sampling
2.5.5 Construction of XML files

2.5.5.1 Principles
XML is open for new kinds of data, i.e. the lists of core parameters are not closed, but can be expanded according to rules that guide any user to find a way to transfer soil analytical data according to this International standard.

2.5.5.2 Feature names
They are given as one word with capital letter at the beginning. If the name is composed of several words, any word begins with a capital letter. Abbreviations within names start with an upper case letter. Due to XML naming constraints, names must not begin with “XML” nor a number and the must not contain other character than letters, numbers and underline character “_”.

2.5.5.3 Attribute parameter definition files
Only parameters not covered by GML are defined in parameter definition files. This file provides meta-information to the data files in that they define the attribute parameters, their valid values, etc.

Any feature can be described by properties. Any property has to be defined by a proper parameter definition in the form of a XML-encoded parameter list that holds the following specifications:

- Meta-data for the parameter file
- Releasing institution with name and address
- Date of release
- Release version number
- Name of parameter list
- Character set
- Person / Organisation in charge for parameter list maintenance with address
- Full literature reference, DOI or URN for original publication or list of parameters, if existing
- Specifications for different parameters types
- All:
  - Feature of the feature catalogue to which it relates
  - Parameter name
  - Parameter type (classified, integer, float, text, …)
  - Nillability
  - Metaparameter (gives an additional information on the parameter value)
  - Parameter with code lists:
    - Type of codes
    - Maximum length of codes
    - Minimum length of codes
    - Codes
    - Explanations to codes
  - If codes represent classified numerical values, additionally:
    - Type of classified numerical values (integer, decimal)
    - SI unit of classified values
    - Single or Lower numerical value (class boundary)
    - Upper numerical value (class boundary)
    - Unit for numerical values
    - Interval closure type
    - Free-text parameters
• Alpha-numerical parameters
• Maximum length
• Minimum length
• Numerical values
• Possible SI units
• Analytical parameters
• Value for “not determined”
• Value for “below detection limit”
• Possible SI units
• Multiple value parameters
• Analytical parameters can compromise sub-parameters
• Methods
• Identifier of a standard
• Version of the standard
• Standard organisation

or
• Literature citation, year of publication, title, name of journal, ...
• DOI (Digital Object Identifier)
• or
• Description of unpublished method
• These data have to be given in XML following the XML Schema for parameter lists.
• Analytical parameters
• Sample processing method
• Determination method
• Unit
• Limit of detection
• Precision
• Laboratory
• For calculated values from analytical values
• Calculation procedure (arithmetic mean, median, geometric mean, ...)
• Standard deviation
• Number of parallels
• Sampling
• Number of satellite samples

2.5.5.4 Attribute parameter definition files
A very generic structure has been chosen at the basic element of SoilML for attributes describing a feature:

```
<SoilAttribute>
  <Parameter> name of parameter </Parameter>
  <Parameter><ParameterListName> name of the parameter list</ParameterListName><value>result</value><unit>unit of the result</unit>
</Parameter>
<SoilAttribute>
```
3 Approaches for filling data gaps and map applications

3.1 Pedotransfer functions

Pedotransfer function (PTF) is a term used in soil science which describes a mathematical approach for assessing the missing, usually more complex and harder to measure soil properties using evaluation models or predictive algorithms and more easily available or cheaper to measure soil property data (Doran and Zeiss, 2000). Hoosbeek and Bouma (1986) suggested the use of PTF and hydrological simulation models to calculate soil quality indicators of high complexity from other measured soil data.

Statistical regression equations expressing relationships between soil properties were proposed to be called “transfer functions” (Bouma and Lanen, 1987) and later “pedotransfer functions” (Bouma, 1989). Estimating soil hydraulic property dominates the research field, although soil chemical and biological parameters are also being estimated. Several reviews on PTF development and use have been published (e.g., Rawls et al. 1991; Van Genuchten and Leij, 1992; Timlin et al., 1996a; Pachepsky et al., 1999; Westen et al., 2001, Vereecken et al 2010)). Large databases, such as UNSODA (Leij et al., 1996), HYPRES (Lilly, 1997; Westen et al., 1999), WISE (Batjes, 1996) and NRCS pedon database (USDA Natural Resource Conservation Service, 1994) are established that can be used for purposes of the PTF development (Pachepsky & Rawls, 2004).

A variety of different pedotransfer modules and functions was developed usually for applied, agricultural soil needs. Some of them are simple, while others require large data sets and complex evaluations. Bouma (1998) discusses the use of PTF for calculating hydraulic conductivity and moisture retention for each of soil horizon in order to simulate the water deficit within the soil body. He describes the procedure of using PTF modelling based on the functional similarity of soil horizons for the determination of the CEC and the phosphate sorption capacity. Larson and Pierce (1989) described a limited listing of 15 PTF related to bulk density, porosity, and soil water retention characteristics; some of them are presented in Table 9:

A PTF in the form of a regression equation for predicting bulk density was developed on the basis of 47,000 topsoil and subsoil samples of USA soil types (Heuscher et al., 2005).

Table 9: A selection of pedotransfer functions

<table>
<thead>
<tr>
<th>Predicted soil property</th>
<th>Pedotransfer function</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cation exchange capacity (CEC)</td>
<td>CEC = 3.0 OM + 0.5 Clay Where OM = organic matter content</td>
<td>(Karlen and Stott 1994; RIVM 2001; RIVM 2002; Wader et al. 2002; Hankard et al. 2005; Saxton and Rawls 2005)</td>
</tr>
<tr>
<td>Cation exchange capacity (CEC)</td>
<td>CEC = 1.5 OM + 0.5 Clay Where OM = organic matter content</td>
<td>(Breeuwsma et al. 1986)</td>
</tr>
<tr>
<td>Phosphate sorption capacity (PSC)</td>
<td>PSC = 0.4 (Al_{ox} + Fe_{ox}) Where Al_{ox} = oxalate extractable Al and Fe_{ox} = oxalate extractable Fe.</td>
<td>(Bouma 1989)</td>
</tr>
<tr>
<td>Phosphate sorption capacity (PSC)</td>
<td>PSC = 0.44 x P_{2}O_{5}</td>
<td>(Bouma 1989)</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>BD = b + b1OM + b2S Where b, b1 and b2 are characteristic constants; OM = organic matter; S = median in sand fraction.</td>
<td>(Breeuwsma et al. 1986)</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>BD = b0+b1OC+b2Si+b3M Where b0, b1, b2 and b3 are characteristic constants</td>
<td>(van Keulen and Wolff 1986)</td>
</tr>
<tr>
<td>Predicted soil property</td>
<td>Pedotransfer function</td>
<td>Author</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>$BD = f(OC, Cl)$  Where $Cl = %$ clay; $OC= \text{organic carbon}$</td>
<td>(Larson and Pierce 1994)</td>
</tr>
<tr>
<td>Porosity increase (P)</td>
<td>$P = f(MR, IP, clay, Si, OC)$  Where $MR = \text{moisture ration; IP = initial porosity; Si = % silt; OC= \text{organic carbon}}$</td>
<td>(Larson and Pierce 1994)</td>
</tr>
<tr>
<td>Water retention $(q)$ (water at a specific pressure head)</td>
<td>$q = v_i(Sa) + b_2(%Si) + b_3(%Cl) + b_4 (%OC)$  Where $Sa = %$ sand; $Si = %$ silt; $Cl = %$ clay; $OC= \text{organic carbon}$</td>
<td>(Larson and Pierce 1994)</td>
</tr>
<tr>
<td>Soil pollution threshold values</td>
<td>$Cd_{Max} = 0.4+0.007*(%C+(3<em>OM))$  $Cr_{Max} = 50+(2</em>C)$  $Cu_{Max} = 15+0.8*(%C+(3<em>OM))$  $Hg_{Max} = 0.2+0.0017</em>((2<em>C)+OM)$  $Ni_{Max} = 10+%C$  $Pd_{Max} = 50+%C+OM$  $Zn_{Max} = 50+1.5</em>((2<em>C)+OM)$  $As_{Max} = 15+0.4</em>(%C+OM)$</td>
<td>Dutch soil protection legislation. (Larson and Pierce 1994)</td>
</tr>
</tbody>
</table>

Measuring physical, chemical and hydrological soil properties on the field and in the laboratory is a cumbersome, expensive, time-consuming and labour-intensive process which gives only local scale results. The development of prediction methods that use more accessible secondary information to spatially extend sparse and expensive soil measurements has been a sharpening focus of research (Bishop and McBratney, 2001). Several attempts have been made to estimate indirectly soil properties from more readily available soil properties such as particle size distribution (sand, silt and clay content), organic matter or organic carbon content, bulk density, porosity, etc. Such relationships are referred to as pedotransfer functions (PTFs) (Merroud and Xu, 2006). There are basically two main types of PTFs: point and parametric PTFs. Point PTFs estimate values of soil moisture at fixed pressure head values (e.g., Rawls and Brakensiek, 1982; Puckett et al., 1985), whereas parametric PTFs estimate parameters of functions that describe the observed data across a range of pressure heads (e.g. Cosby et al., 1984; Wösten and van Genuchten, 1988; Vereecken et al., 1989). These two types of PTFs can also be constructed for a specific location and for specific textural groups of soils. In this last case they are called class PTFs.

There are several methods available for PTFs development. An extensive review was given by Pachepsky and Rawls (2004). Two main categories can be distinguished: statistical regression techniques (linear and nonlinear models) and data mining and exploration techniques (artificial neural networks and group methods of data handling). In general, methods based on artificial neural networks have led to PTFs that performed best in terms of basic indicators such as the RMSR. This is largely due to the fact that this approach does not require an a priori functional form with which to relate PTF input to PTF output (Vereecken, 2010).

The development of pedotransfer functions (PTFs) requires large, good quality data sets comprising measured hydraulic characteristics of a wide variety of soils. An example of such a large data set is the database of hydraulic properties of European soils (HYPRES) (Wosten, 1999).
3.1.1 The use of pedotransfer functions

As the use and development of pedotransfer functions (PTFs) progressed, several problems were detected and addressed. The PTF accuracy remains limited despite the use of predictors and sophisticated tools for data mining with artificial intelligence and machine learning. Additionally the portability of PTFs remained limited; PTFs developed for a specific region or from one database had limited applicability to other regions with specifically different conditions (e.g. Williams et al. 1992; Tietje and Tapkenhinsrichs 1993; Kern 1995; Woesten et al. 2001) (Pachepsky 2005).

Comprehensive reviews of the status of pedotransfer functions have been published (Wosten et al. 2001; McBratney et al. 2002; Pachepsky and Rawls 2004).

Soil hydraulic properties: Quite a number of PTFs have been developed to estimate the hydraulic properties of soils. Eight known and well-accepted predictive PTFs have been compared and evaluated by Wagner (2001). Rawls (1983) studied the effect of soil organic matter on soil water retention using the PTF approach. A PTF developed by Cazemier et al. (2003) estimates the soil water available capacity from an imprecise description of soil classes, a synthesis of soil profiles and statistical functions.

Bulk density was predicted from the existing soil data. The regression equation for predicting bulk density from 47,000 topsoil and subsoil samples was developed for soils from the USA (Heuscher et al. 2005). An independent set of forest soil data (174 samples) was used to compare and evaluate the 12 different PTFs for predicting bulk density in the topsoil and subsoil of Flanders. The study revealed the poor performance of some published PTFs and raised concern regarding the predictive accuracy of others. Two PTFs were recalibrated and validated in order to lower the prediction error (De Vos et al. 2005).

Heavy metal pollution: Scheyer (2001) compared the Cd and Zn availability in a pollution study of soils from Moscow and the USA. He stressed the need to develop a PTF to assess the human dietary risk based on a factor calculated for each soil type and suggested the PTF where the risk factor = f (texture, OM%, CEC, pH, aggregate size, water content).

A PTF for the estimation of the soil capacity for a storm water modelling application was developed in Florida (Gregory et al. 1999).

A list of selected PTFs for predicting physical, mechanical and chemical soil properties using different predictor variables is available in the Table 10.

**Table 10: Pedotransfer functions (PTF) for predicting chemical, physical, and mechanical soil properties (McBratney et al. 2002)**

<table>
<thead>
<tr>
<th>Predicted soil property</th>
<th>Predictor variable</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cation exchange capacity (CEC)</td>
<td>clay content, organic matter content</td>
<td>(Bell and Van Keulen, 1995)</td>
</tr>
<tr>
<td>Critical P level, P buffer coefficient</td>
<td>clay content</td>
<td>(Cox 1994)</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>soil colour</td>
<td>(Fernandez et al. 1998)</td>
</tr>
<tr>
<td>P sorption</td>
<td>pH in NaF</td>
<td>(Gilkes and Hughes 1994)</td>
</tr>
<tr>
<td>pH buffering capacity</td>
<td>organic matter content, clay content</td>
<td>(Helyar et al. 1990)</td>
</tr>
<tr>
<td>Al saturation</td>
<td>base saturation, organic carbon content, pH</td>
<td>(Jones, 1984)</td>
</tr>
<tr>
<td>P saturation</td>
<td>extractable P, Al</td>
<td>(Kleinman et al., 1999)</td>
</tr>
<tr>
<td>K/Ca exchange</td>
<td>clay content, extractable K</td>
<td>(Scheinost et al. 1997)</td>
</tr>
<tr>
<td>Nitrogen-mineralization parameters</td>
<td>CEC, total N, organic carbon content, silt and clay content</td>
<td>(Rasiah 1995)</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>As and Cd sorption</th>
<th>clay content, pH, organic carbon content, dithionite extractable Fe</th>
<th>(Schug et al. 1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous (P) adsorption</td>
<td>clay content, pH, soil colour</td>
<td>(Scheinost and Schwertmann 1995)</td>
</tr>
<tr>
<td>Cd sorption coefficient</td>
<td>clay content, organic carbon content, pH</td>
<td>(Springob and Bottcher 1998)</td>
</tr>
<tr>
<td>Haematite content</td>
<td>soil colour</td>
<td>(Torrent et al. 1983)</td>
</tr>
</tbody>
</table>

**Physical properties**

| Infiltration rate at a given time | initial water content, moisture deficit, total porosity, non capillary porosity, hydraulic conductivity | (Canarache et al. 1968) |
| Soil thermal conductivity | texture, organic matter content, water content | (de Vries 1966) |
| Water repellence | organic matter content, clay content, bulk density, particle size distribution | (Harper and Gilkes 1994) |
| Bulk density | particle size distribution | (Rawls 1983) |
| Infiltration parameters | particle size distribution, bulk density, organic C content, initial water content, root content | (van de Genuchtten et al. 1996) |

**Mechanical properties**

| Soil mechanical resistance | organic carbon content, clay content | (Da Silva and Kay 1997) |
| Volumetric shrinkage, liquid limit, plastic limit, plasticity index | organic matter content, clay content, CEC | (Mbagwu and Abeth 1998) |
| Degree of over consolidation | bulk density, void ratio | (McBride and Joosse 1996) |
| Rate of structural change | organic matter content, clay content, pH | (Rasiah and Kay 1994) |
| Soil erodibility factor | geometric mean particle-size, clay and organic matter content | (Torri et al. 1997) |

### 3.1.2 Frequently used pedotransfer functions (PTF) in Europe

In the further text we are summarising the currently used European PTFs as published and available to the authors.

#### 3.1.2.1 Hydraulic properties

The Mualem-van Genuchten’s equations (van Genuchten, 1980), fitted simultaneously, with, for example, the RETC code (van Genuchten et al., 1991), are the most well known models to parameterise the hydraulic properties (water retention curve and hydraulic conductivity curve).

\[
\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[ 1 + (\alpha h)^n \right]^{-(1-1/n)}
\]

\[
K(h) = K_s \left( \frac{\left( 1 + (\alpha h)^n \right)^{1-1/n} - (\alpha h)^{n-1}}{\left( 1 + (\alpha h)^n \right)^{(1-1/n)(\ell+2)}} \right)^2
\]

where \( \theta \) is the observed volumetric water content (cm\(^3\)/cm\(^3\)), \( h \) is the imposed soil water pressure head (cm water), \( \theta_s \) and \( \theta_r \) are the residual and saturated water contents (cm\(^3\)/cm\(^3\)), \( K \) is the hydraulic conductivity (cm/day), \( K_s \) is the saturated hydraulic conductivity (cm/day) and \( \alpha, n \) and \( \ell \) are empirical shape factors.
D2.5 Best practice guidelines for developing a content framework for interoparable soil data in Europe – PART I

An example of pedotransfer functions for those equations were developed by Wosten et al. (1989), based on the HYPRES database, which are described below:

\[ \theta_s = 0.7919 + 0.001691^*C - 0.29619^*D - 0.000001491^*S + 0.004521^*OM^* - 0.0242^*/C \cdot \left(0.0113^*S - 0.01472^*ln(S) - 0.0000733^*OM^*C - 0.000619^*D^*C - 0.001183^*D^*OM - 0.0001664^*topsoil^*S \right) \]

\[ \alpha_s = -14.96 + 0.03135^*C + 0.0351^*S + 0.646^*OM + 15.29^*D - 0.192^*topsoil - 4.671^*D^2 - 0.000781^*C^2 - 0.00687^*OM^2 + 0.0649^*OM^*D + 0.0663^*ln(S) + 0.1482^*ln(OM) - 0.04546^*D^*S - 0.452^*D^*OM + 0.0073^*topsoil^*C \]

\[ n_s = -25.23 - 0.02195^*C + 0.0074^*S - 0.1940^*OM + 45.5^*D - 7.24^*D^2 - 0.0003658^*C^2 + 0.002885^*OM^2 - 12.81^*D^2 - 0.1524^*S^2 - 0.01958^*OM^*D - 0.2876^*ln(S) - 0.0709^*ln(OM) - 44.6^*ln(D) - 0.02264^*D^*C + 0.0896^*D^*OM + 0.00718^*topsoil^*C \]

\[ \theta_s = 0.0202 + 0.0006193^*C^2 - 0.001136^*OM^2 - 0.2316^*ln(OM) - 0.03544^*D^*C + 0.00283^*D^*S + 0.0488^*D^*OM \]

\[ K_s = 7.755 + 0.0352^*S + 0.93^*topsoil - 0.967^*D^2 - 0.000484^*C^2 - 0.000322^*S^2 + 0.011^*S^1 - 0.0748^*OM^*D - 0.643^*ln(S) - 0.01398^*D^*C - 0.1673^*D^*OM + 0.02986^*topsoil^*C - 0.03305^*topsoil^*S \]

Where C is the percentage of clay (i.e. percent <2 μm), S is the percentage of silt (i.e percent between 2 μm and 50 μm), OM is the percentage of organic matter, D is the bulk density, topsoil and subsoil are qualitative variables having the value of 1 or 0 and ln the natural logarithmic.

Pedotransfer functions only for water retention curve or hydraulic conductivity curve can also be found in the literature.

**Water retention curve**

An example of PTFs for the water retention curve are those developed by Vereecken (1989) for the parameters of van Genuchten model

\[ \theta_r = 0.015-0.005^*C + 0.0139^*C \] \[ \theta_r = 0.838-0.283^*D_b + 0.0012^*C \]

\[ \theta_r = -2.486+0.025^*S_a-0.351^*C-2.617^*B_d-0.023^*C \]

\[ \theta_r = 0.053-0.009^*S_a+0.0015^*C^2 \]

Bd: bulk density (g.cm\(^{-3}\)) C: carbon content (%), Cl: clay content (%), Sa the sand content (%)

**Hydraulic conductivity**

For the hydraulic conductivity curve examples of PTFs are:

Vereeeken (1989) developed PTFs for the parameters of Gardner model (Gardner, 1958)

\[ K_{sat} = \frac{1}{1 + (\theta_b)^{n}} \]

With b and n soil dependent parameters which have to be evaluated by data fitting and

\[ b = 1/\theta_b \]

\[ \log(K_{sat}) = (20.62 - 0.96 (\log C) - 0.66 (\log S) - 0.46 (\log OM) - 8.43 (Bd)) \]

\[ \log(b) = -0.73 - 0.1877^*S + 0.058^*C \]

\[ \log(n) = 1.186 - 0.194^*log(C) - 0.0489^*log(\text{Si}) \]

(C: clay content (%), S: sand content (>50μ) (%), Si: silt content, (2-50μ) (%), OM: organic matter content (%), Bd: bulk density (g.cm\(^{-3}\)))
Jabro (1992): log Ks = 9.56 - 0.81 (log Si) - 1.09 (log C) - 4.64 (BD)
(C: clay content (%), Si: silt content (%))

Cosby et al. (1984): Ks = 60.96 * 10^-0.6 + 0.0126 * (S) - 0.0064 * (C)
(C: clay content (%), S: sand content (%))

Saxton et al. (1986): Ks = 24 * e ^ (12,012 - 7.55 * 10^-(-2)*S)+(-3,895+3,671*10^-(-2)*S)-
0.1103*(C)+8,754*10^-(-4)*C^2)/0.332-7,251*10^-(-4)*S+0.1276*(log C)
(C: clay content (%), S: sand content (%))

Puckett et al. (1985): Ks = 4.36 * 10^-(-3) * e ^ (-0.1975 * C)
(C: clay content (%))

3.1.2.2 Bulk density (BD)

(Nilsen & Lundin 2006)
(OM: organic matter content (%), C: clay content (%), S: sand content (%), Si: silt content (%), OC: organic carbon content (%), wc: water content (%))

Eschner et al. (1957):
0-15cm
BD = 1.3546 – 0.0346*OM
BD = 1.816 – 0.7891*log(OM+2)  R^2 = 0.453
BD = 1.8014 – 0.8491*log(OM+2) + 0.0026*C  R^2 = 0.483
15-30cm
BD = 1.5246 – 0.0491*OM R2 = 0.433
BD = 1.2498 – 0.0487*(OM) + 0.0063*C + 0.0034*S  R^2 = 0.487

Curtis & Post (1964):
log(BD*100) = 2.09963 – 0.00064*(logOM) – 0.22302*(logOM)^2  n = 103  R^2 = 0.96

Saini (1966):
Humic-gley soils:
BD = 1.62 – 0.06*OM  n = 30  R^2 = 0.74
Imperfectly drained soils:
BD = 1.53 – 0.06*OM  n = 40  R^2 = 0.65
Well drained soils:
BD = 1.52 – 0.06*OM  n = 40  R^2 = 0.40

Jeffrey (1970):
BD = 1.482 – 0.6786*(logOM)  n = 80  R^2 = 0.818

Erviö (1970):
BD^0.5 = 1.306 – 0.106*OM^0.5  n = 98  R^2 = 0.933

Stewart et al. (1970):
BD = 100 / ((OM / K1) + (100 – OM / K2))
K1 = BD (bulk density) for organic material (0.25 g/cm^3), K2 = BD for mineral soil (1.40 g/cm^3)

Adams (1973):
BD = 100 / ((OM / K1) + (100 – OM / K2))
- K1 = BD for organic material (0.223 g/cm3), K2 = BD for mineral soil (1.27 g/cm^3)
- pF=3.0; K1 = BD for organic material (0.257 g/cm^3), K2 = BD for mineral soil (1.43 g/cm^3)
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- \( \text{pF}=3.3; \ K_1 = \text{BD for organic material (0.291 g/cm}^3\), \ K_2 = \text{BD for mineral soil (1.54 g/cm}^3\) \\

Drew (1973):

\[
\text{BD} = 1 / (0.6268 + 0.0361*\text{OM}) \quad n = 136 \quad R^2 = 0.709 \\
\text{BD} = 1.5697 - 0.0552*\text{OM} \quad n = 136 \quad R^2 = 0.683 \\
\text{BD} = 1.2776 + 0.1361/\text{OM} \quad n = 136 \quad R^2 = 0.346 \\
\text{BD} = 1.4964 - 0.1730*\log(\text{OM}) \quad n = 136 \quad R^2 = 0.676 \\
\text{BD} = 1.4918 - 0.0043*\text{OM}^2 \quad n = 136 \quad R^2 = 0.561 \\
\text{BD} = 1.5697 - 0.0552*\text{OM} \quad n = 136 \quad R^2 = 0.683 \\
1/\text{BD} = 0.8073 - 0.0788/\text{OM} \quad n = 136 \quad R^2 = 0.285 \\
1/\text{BD} = 0.6776 + 0.1061*\log(\text{OM}) \quad n = 136 \quad R^2 = 0.626 \\
1/\text{BD} = 0.6751 + 0.0029*\text{OM}^2 \quad n = 136 \quad R^2 = 0.634 \\
\log(\text{BD}) = 0.4568 - 0.0442*\text{OM} \quad n = 136 \quad R^2 = 0.704 \\
\log(\text{BD}) = 0.3966 - 0.1338*\log(\text{OM}) \quad n = 136 \quad R^2 = 0.659 \\
\log(\text{BD}) = 0.3962 - 0.0035*\text{OM}^2 \quad n = 136 \quad R^2 = 0.602 \\
\text{BD} = 2.4479 - 0.1431*\text{OM} \quad n = 136 \quad R^2 = 0.651 \\
\text{BD} = 2.2648 - 0.4573*\log(\text{OM}) \quad n = 136 \quad R^2 = 0.679 \\

Alexander (1980)

For upland soils

\[
\text{BD} = 1.66 - 0.308*\text{OC}^{0.5} \quad n = 386 \quad R^2 = 0.462 \\
\text{BD} = 1.57 - 0.287*\text{OC}^{0.5} +5.004*W15 - 41.866*W15^2 + 74.689*W15^3 \quad n = 386 \quad R^2 = 0.656 \\
\text{BD} = 2.92 - 0.230*\text{OC}^{0.5} +4.274*W15 - 36.901*W15^2 + 66.628*W15^3 - 1.44*(W15/C)^{0.1} \quad n = 386 \quad R^2 = 0.701 \\
\]

For alluvial soils

\[
\text{BD} = 1.72 - 0.294*\text{OC}^{0.5} \quad n = 335 \quad R^2 = 0.332 \\
\text{BD} = 4.99 - 0.257*\text{OC}^{0.5} - 3.537*(W15/C)^{0.1} \quad n = 335 \quad R^2 = 0.569 \\
\text{BD} = 4.92 - 0.250*\text{OC}^{0.5} - 3.723*(W15/C)^{0.1} - 0.360*\text{Si} + 1.381*S^2 - 1.462*S^3 \quad n = 335 \quad R^2 = 0.632 \\
\]

Harrison & Bocock (1981):

1: \( \text{BD} = 1.914 - 0.895*(\log(\text{OM})) \quad n = 145 \quad R^2 = 0.77 \\
2: \( \text{BD} = 1.429 - 0.677*(\log(\text{OM)}) \quad n = 190 \quad R^2 = 0.74 \\
3: \( \text{BD} = 2.089 - 1.156*(\log(\text{OM})) \quad n = 197 \quad R^2 = 0.96 \\
4: \( \text{BD} = 1.562 - 0.727*(\log(\text{OM})) \quad n = 80 \quad R^2 = 0.89 \\
5: \( \text{BD} = 1.531 - 0.735*(\log(\text{OM})) \quad n = 81 \quad R^2 = 0.88 \\
6: \( \text{BD} = 1.392 - 0.556*(\log(\text{OM})) \quad n = 50 \quad R^2 = 0.40 \\
7: \( \text{BD} = 1.362 - 0.669*(\log(\text{OM})) \quad n = 148 \quad R^2 = 0.83 \\
8: \( \text{BD} = 1.800 - 0.772*(\log(\text{OM})) \quad n = 186 \quad R^2 = 0.69 \\
(\text{OM: organic matter content (%)}

Van Lierop (1981):

\[
\text{BD} = 0.016 + 0.0495*\text{pH-CaCl}_2 \quad n = 30 \quad R^2 = 0.51 \\
\text{BD} = 14.707*\text{WPC}^{-0.731} \quad n = 30 \quad R^2 = 0.91 \\
\text{BD} = 0.152 + 0.0054*\text{ash} \quad n = 30 \quad R^2 = 0.72 \\
\]

Federer (1983):

\( \ln \text{BD} = -2.31 - 1.079 \ln \text{OM} - 0.113 (\ln \text{OM})^2 \)

Mbagwu et al. (1983):

\[
\text{BD} = 1.5056-0.1588*\text{OC} \quad R^2 = 0.18 \\
\]
D2.5  Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

Rawls (1983):
BD = 100 / ((OM / K₁) + (100 – OM / K₂))
K₁ = BD for organic material (0.224 g/cm³), K₂ = mineral BD from 1.0 up till 1.7 g/cm³

Gosselink et al. (1984):
BD = 100*(0.026/OC)  \( R^2 = 0.93 \)

Alexander (1989):
BD = 1.827\*e^{-0.1210C*-0.5}  \( n = 55 \)  \( R^2 = 0.809 \)
1/BD = 0.745 + 0.0105*OC  \( n = 55 \)  \( R^2 = 0.772 \)
BD = 1.27\*e^{-0.0074*OC}  \( n = 55 \)  \( R^2 = 0.723 \)
BD = 2.95\*OC^{-0.362}  \( n = 55 \)  \( R^2 = 0.779 \)
BD = 2.00 – 0.3094* ln(OC)  \( n = 55 \)  \( R^2 = 0.758 \)
BD = 1.586 – 0.100*OC^{-0.5}  \( n = 55 \)  \( R^2 = 0.734 \)

Griga et al. (1989):
BD = 0.073 + 2.369\*e^{-0.073*OM}  \( n = 812 \)  \( R^2 = 0.75 \)
BD = 0.669 + 0.941\*e^{-0.240*OM}  \( n = 800 \)  \( R^2 = 0.95 \)
BD = 0.075 + 1.301\*e^{-0.060*OM}  \( n = 1612 \)  \( R^2 = 0.93 \)
BD = 0.043*X + 4.258\*e^{-0.047*OM}  \( n = 232 \)  \( R^2 = 0.89 \)

Honeysett & Ratkowsky (1989):
(1-BD) = 0.564 + 0.0556 \*OM  \( R^2 = 0.975 \)
BD = 1.801 – 0.397*ln(OM)  \( R^2 = 0.95 \)

Huntington et al. (1989):
lnBD = -2.39 – 1.316*lnOM – 0.167*(lnOM)^2  \( R^2 = 0.75 \)
lnBD = -0.263 – 0.147*lnOC – 0.103*(lnOC)^2  \( R^2 = 0.72 \)

Manrique & Jones (1991):
BD = 1.510 – 0.113*OC  \( n = 19651 \)  \( R^2 = 0.36 \)
BD = 1.660 – 0.318*OC^{-0.5}  \( n = 19651 \)  \( R^2 = 0.41 \)
BD = 1.740 – 0.218*OC^{0.5} +0.005*C – 0.023*WC15  \( n = 19226 \)  \( R^2 = 0.58 \)

Federer et al. (1993):
BD = (K₁*K₂) / ((K₂*OM) + (1-OM)* K₁)
K₁ = BD for organic material (0.111 g/cm³), K₂ = BD for mineral soil (1.450 g/cm³)

Arrouays & Pelissier (1994):
lnBD = 0.317 – 0.092*lnOC  \( n = 70 \)  \( R^2 = 0.55 \)

Tamminen & Starr (1994):
BD2 = 1.565 - 0.2298*OM^{-0.5}  \( n = 158 \)  \( R^2 = 0.61 \)

Tomasella & Hodnett (1998):
BD = 1.578 – 0.054*OC – 0.006* Si – 0.004*C  \( R^2 = 0.599 \)

Bernoux et al. (1998):
BD = 1.352 – 0.0045*C  \( R^2 = 0.369 \)
BD = 1.398 – 0.0047*C – 0.042*OC  \( R^2 = 0.498 \)
BD = 1.606 – 0.0046*OC – 0.051*OC – 0.047*pH-H2O  \( R^2 = 0.542 \)
BD = 1.524 – 0.0038* C – 0.050*OC – 0.045*pH-H2O + 0.0010*S  \( R^2 = 0.558 \)

Salifu et al. (1999):
BD = 2.40 – 0.32*ln(OM) - 0.03*clay – 0.14*pH  \( R^2 = 0.62 \)
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

Leonavičiūtė (2000):
A-horizon: BD = 1.704 – 0.00313*Si + 0.00261*C – 0.1125*OC
\[ n = 140 \quad R^2 = 0.83 \]
E- horizon: BD = 0.999 – 0.00592*ln(Si) + 0.07712*ln(C) + 0.09370*ln(S) – 0.08415*ln(OC)
\[ n = 56 \quad R^2 = 0.47 \]
B- horizon: BD = 1.073 + 0.03273*ln(Si) + 0.03875*ln(C) + 0.07889*ln(S) – 0.05431*ln(OC)
\[ n = 296 \quad R^2 = 0.50 \]
BC-C- horizon: BD = 1.067 + 0.01074*ln(Si) + 0.08068*ln(C) + 0.08759*ln(S) – 0.05647*ln(OC)
\[ n = 455 \quad R^2 = 0.46 \]

Perruchoud et al. (2000):
BD = 1.11 – 0.15*OC^{0.5}
\[ R^2 = 0.44 \]
BD = 1.03 – 0.40*ln(OC)
\[ R^2 = 0.59 \]
ln(BD) = 0.04 – 0.11*ln(OC) – 0.05*(ln(OC))^2
BD = 0.44 + 0.65*exp^{-0.14*OC}

BD^{0.5} = 1.17 – 0.018*OC
\[ R^2 = 0.44 \]
BD = 1.29 – 0.50*ln(OC)
\[ R^2 = 0.59 \]
BD = 1/(0.622 + 0.098*OC)
\[ R^2 = 0.67 \]
BD = 1/((0.575 + 0.104*OC)*(1+0.0012*depth))
\[ R^2 = 0.69 \]

Soto et al. (2001):
BD = 1.2237 – 0.2027*lnOC
\[ n = 265 \quad R^2 = 0.662 \]

Treblay et al. (2002):
BD = (K1*K2) / ((K2*OM) + (1-OM)*K1)
K1 = BD for organic material (0.120 g/cm^3), K2 = BD for mineral soil (1.400 g/cm^3)
\[ n = 281 \quad R^2 = 0.56 \]

Kaur et al. (2002):
BD = 1.506 – 0.266*OC + 0.004517*C – 0.00352*Si
\[ R^2 = 0.50 \]
BD = 1.488 – 0.668*OC + 0.0002053*OC^{2} – 0.000309*C*S + 0.009816*C^{2} + 0.144*OC*C
\[ R^2 = 0.62 \]
BD = 1.386 – 0.404*OC + 0.00023505*OC^{3} – 0.00000587*C*S + 0.04956*C^{3}
\[ R^2 = 0.62 \]
BD = exp(0.313 – 0.191*OC + 0.02102*C – 0.000476*C^{2} – 0.00432*Si)
\[ R^2 = 0.62 \]

Callesen et al. (2003):
Entisol, Spodosol, Inceptisol
A-, B- and E-horizon:
BD = 1.590 – 0.1045*OC^{0.5}
\[ R^2 = 0.66 \]
C-horizon:
BD = 1.685 – 0.1045*OC^{0.5}
\[ R^2 = 0.66 \]
Alfisol och Mollisol
A-, E-, B- and C-horizon: BD = 1.83 – 0.131*OC^{0.5}
\[ R^2 = 0.58 \]

Hartshorn et al. (2003):
BD = 0.0016*z + 0.0359
\[ n = 31 \quad R^2 = 0.60 \]
(z: depth of first horizon (cm))

Prévoz (2004):
lnBD = -1.81 – 0.892*lnOM – 0.092*(lnOM)^2
\[ n = 414 \quad R^2 = 0.767 \]
D2.5  Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

\[
\ln(BD) = -0.98 - 1.104^{*}OM - 0.491^{*}\ln(OM) - 0.043^{*}(\ln(OM))^2 \quad n = 414 \quad R^2 = 0.774
\]

\[
BD = (K_1 * K_2) / ((K_2 * OM) + (1 - OM) * K_1) \quad n = 414 \quad R^2 = 0.637
\]

K_1 = BD for organic material (0.159 g/cm^3), K_2 = BD for mineral soil (1.561 g/cm^3)

**Heuser et al. (2005):**

\[
BD = 1.6134 - 0.074^{*}OC^{0.5} \quad n = 47028 \quad R^2 = 0.25
\]

\[
BD = 1.685 - 0.198^{*}OC^{0.5} - 0.0133^{*}wc + 0.0079^{*}C - 0.0007^{*}Si + 0.00014^{*}depth \quad n = 47015 \quad R^2 = 0.44
\]

**De Vos et al. (2005):**

\[
BD = 1.775 - 0.173^{*}OM^{0.5} \quad R^2 = 0.57
\]

\[
BD = 100 / ((OM / K_1) + (100 - OM / K_2))
\]

K_1 = BD for organic material (0.312 g/cm^3), K_2 = BD for mineral soil (1.66 g/cm^3)

\[
R^2 = 0.55
\]

**Jensen et al. (2005):**

\[
BD = -0.068^{*}OM - (0.002^{*}C) - (0.005^{*}fineSi) - (0.007^{*}coarseSi) - (0.005^{*}fineS) - (0.006^{*}coarseS) + 2.157 \quad n = 2431 \quad R^2 = 0.45
\]

3.1.2.3 Porosity

Percentage of total porosity (Lake, Akbarzahed & Mehrjardi, 2009)

**Page (1986):**

P (%) = (1 - BD) * 100
(BD: bulk density (g/cm^3))

Pedotransfer functions for isopturon sorption on soils and vadose zone materials (Julien Moeyes (2010))

**Julien Moeyes (2010):**

K_r = 0.2574 + 0.0989 OC

K_r = 3.279 + 0.08342 OC - 0.251 pH (OM = 1.72 OC)

(OC: organic carbon content (%))

Field capacity

FC = 39.8025 - 0.17796 * S (%) + 6.689 * log(OM)

(S: sand content (%), organic matter content (%))

3.1.2.4 Wilting point

WP = 6.72778 + 0.289494 * C (%) + 5.55396 * log(OM)

(C: clay content (%), organic matter content (%))

3.1.2.5 Soil organic carbon content

**Craft et al. (1991):**

OC = 0.4 * LOI + 0.0025 * LOI^2

(LOI: loss on ignition)

3.1.2.6 Total nitrogen

(Rashidi & Seilsepour, 2009)

**Rashidi (2009):**

TN = 0.026 + 0.067 OC

(OC: organic carbon content (%))

R^2 = 0.83
4 Soil data harmonization

4.1 Development of digital data bases

One of the most known and advanced European soil database systems is the European Soil Database (ESDB) of the European Joint Research Centre (Internet 3, 12.7.2011). ESDB is the common source of information from which the majority of other data information and services are derived. Basic components of ESDB are vector data:

- Soil Geographical Database of Eurasia at scale 1: 1,000,000 (SGDBE).
- Pedo Transfer Rules Database (PTRDB).
- Soil profile Analytical Database of Europe (SPARDB).
- Database of Hydraulic Properties of European Soils (HYPRES).

The ESDB also contains raster soil data for large number of soil related parameters:

- Raster library 1km x 1km - contains raster data files for the main soil attributes.
- Raster Version 1km x 1km - contains raster version of the vector based soil geometry.
- Raster library 10km x 10km - contains raster data files for the main soil attributes.

4.1.1 Soil Geographical Database of Eurasia at scale 1:1,000,000 (SGDBE) version 4 beta

The Soil Geographical Database of Eurasia at scale 1:1,000,000 is part of the European Soil Information System (EUSIS).

Database contains a list of Soil Typological Units (STUs) which are described by properties of the soils such as the texture, the water regime, the stoniness, etc. The STUs are grouped in soil mapping units (SMU). Each SMU corresponds to a part of the mapped territory and is as such represented by one or more polygons in a geometrical dataset. As a result, the SGDBE consists of geometrical dataset and a semantic dataset (set of attribute files) which links attribute values to the polygons of the geometrical dataset. How map polygons, SMU's and STU's are linked together is illustrated in the figure below (Internet 1, 9.7.2011).
4.1.2 The Pedotransfer Rules Database (PTRDB), version 2.0
Pedotransfer rules are mathematical operations used to estimate values for soil properties from available data. Within the Soil Database, the input attributes are selected among those in the SGDBE STU table (Internet 1, 9.7.2011).

4.1.3 Soil profile Analytical Database of Europe (SPADBE)
Soil Analytical database comprehends estimated profiles and measured soil profile datasets. Measured profile data are collected during the field sampling and analyzed according to national methodologies. Ideally these measured profiles should correspond to an STU from the SGDBE. Estimated profile data are representative for a specific STU and have been estimated by experts. The database includes the analytical results for the different soil horizons (Internet 1, 9.7.2011). The estimated profile data are:

- Texture (& particle size grades)
- Organic matter content (C, N)
- Structure
- Total nitrogen content
- pH
- ESP or SAR
- Calcium carbonate content
- Calcium sulphate content
- Electric conductivity
- CEC and exchangeable bases
- Soil water retention
- Bulk density
- Root depth
- Groundwater level
- Parent material
4.1.4 Database of Hydraulic Properties of European Soils (HYPRES), version 1.0

The HYPRES database contains information on a total of 5521 soil horizons. Each soil horizon was allocated to one of 11 possible soil textural/pedological classes derived from the 6 FAO texture classes (5 mineral and 1 organic) and the two pedological classes (topsoil and subsoil) recognised within the 1:1,000,000 scale Soil Geographical Database of Eurasia (Internet 1, 9.7.2011). Additionally class as well as continuous pedotransfer functions were developed. The class pedotransfer functions were used in combination with the 1:1,000,000 scale Soil Database of Europe to determine the spatial distribution of soil water availability (Internet 1, 9.7.2011).
5 Interoperability of soil data

5.1 Conceptual review: semantic and technical interoperability

The access, re-use and exploitation of digital environmental information have in the recent years become an important concern for public bodies and private enterprises. In the context of the climate change this issue became more and more important in Europe as well as worldwide.

While INSPIRE and its Implementing Rules (IR) offer a framework to establish the European spatial data infrastructure, vital obstacles in reference to harmonization and interoperability of data and services as well as the organisational structure still need to be addressed.

Data harmonization requires technically interoperable soil data, clear definitions of the parameters, type and/or coding of the parameter values and possibly a minimum dataset that comprises any auxiliary information needed for meaningful or valid harmonization procedures.

Based on the soil data and soil data types, data transfer structures have been developed which address technical interoperability by allowing the unambiguous exchange of soil data and their metadata.

Technically interoperable data with clear definitions can subsequently be semantically harmonized (harmonization procedures should be developed) that transform datasets into a common parameter and codification space (both at the user and data provider level).

This task considers the initial establishment of semantic interoperability in order to produce seamless geospatial information with improved data access for a wide community of different user groups. Semantic web service will aim to interchange of semantic data and to combine data from different sources and services without losing meaning.

5.2 Technical interoperability of data

5.2.1 Projections

Geodetic coordinate Reference Systems (CRS) define the constants and parameters needed for Geodetic Datums and are required for uniquely referencing spatial information in space as a set of coordinates (X, Y, Z) and/or latitude, longitude and height.

European soil spatial data require standard map projections to be defined to make the data delivery and exchange at the Pan-European level possible. The following projections are recommended by the INSPIRE:

- Lambert Azimuthal Equal Area (ETRS89-LAEA)
- Lambert Conformal Conic (ETRS89-LCC)
- Transverse Mercator (ETRS89-TMzn)

All of the listed projections are a part of European Terrestrial Reference System 1989 (ETRS 89). ETRS is a geodetic datum for pan-European spatial data collection, storage and analysis. It is based on the GRS80 geocentric ellipsoid. ETRS89 is the EU-recommended frame of reference for geodata for Europe. It is the only geodetic datum to be used for mapping and surveying purposes in Europe and it is also used as a standard for precise GPS surveying throughout Europe. It plays the same role for Europe as NAD-83 for North America.

The Lambert Azimuthal Equal Area (ETRS89-LAEA) is a single projected coordinate reference system for all of the pan-European area. It is an equal area projection, therefore it should be used when true area representation is required or for spatial analysis.
The Lambert Conformal Conic (ETRS89-LCC) is recommended for conformal pan-European mapping at scales smaller or equal 1:500,000. Since this is a conformal map projection system, angles between meridians and parallels are correct. Therefore there is no distortion of scale and directions only a distortion of areas.

Transverse Mercator (ETRS89-TMzn) is recommended for conformal pan-European mapping at scales larger than 1:500,000. Since this is also a conformal type of map projection, areas shown on map will not be distortion-free. ETRS89 Transverse Mercator Coordinate Reference System is identical to Universal Transverse Mercator grid system for the northern Hemisphere applied to ETRS89 geodetic datum and the GRS80 ellipsoid. ETRS-TMzn is a series of zones where "zn" in the identifier is the zone number. The width of each zone is 6°. Example: Zone 33 is centred on 15° east meridian and is used between 12° and 18° east meridian.

Projections are well defined and documented. It is estimated, that the technical problems expected are in general mainly related to the complexity of data projection procedures especially in case of large scale maps. In some countries where specific projection systems were or are still in use, more technical data projection problems can arise.

5.2.2 Data aggregation and scale complexity issues

5.2.2.1 Data aggregation concepts

Soil maps and databases are more or less structured in the same way. Usually information about soil and their properties are stored in soil mapping units (SMU). Soil attributes are proportional to the attributes and area of soil typological units (STU) in each SMU. Soil attributes (morphological, physical and chemical properties) for each STU are defined by soil experts. Since SMU's cover the whole survey area, region, country or even continent, these have to be represented on maps as georeferenced vector polygons. There are some basic topology rules how polygons should be matched together:

- No gaps between polygons. Each location on the earth's surface should fall into/belong to a polygon feature class. In other words we should be able to get the information from belonging SMU for every location.

- Each location on the earth's surface should correspond to only one polygon. SMU's therefore must not overlap. Silver polygons should be deleted.

These topological requirements have to be accomplished and any errors fixed already on the national level. When combining national soil maps together, however, the soil mapping units/polygon boundaries will usually not match (topologically as well as semantically). Spatial objects have to be that for matched especially where representing the same soil property along or across the national border. According to INSPIRE’s “Methodology for the development of data specifications” report, rules for so called edge-matching are less specific in case of area features and better for line and point features. The reason is mainly in the selection and generalisation criteria used to portray the area features (Methodology for the development of data specifications, 2007).

- All vector data must be of the same type - the same geometric features e.g. lines, polygons, cell value.

- Polygons must be geometrically and semantically alike:
  - For geometry, the condition may be given by threshold which will be function of the database accuracy. The use of distance threshold is convenient to enable some automation of the process. The geometry will have to be specified in detail. Threshold values related to geometric accuracy and precision have to be defined.
The identification of spatial objects must be harmonized. “Edge-matching can only be performed at a distance not exceeding the geometrical resolution accuracy of the data set and the minimum area size resolution.” (INSPIRE Drafting Team 'Data Specifications' 2007).

Figure 7: Example for edge-matching of polygon vector data (accuracy 125 m, scale range 1:250 000) (INSPIRE Generic Conceptual Model D2.5)

5.2.2.2 European national soil maps and soil mapping systems – scale complexity review/issues

The review was made on the basis of FAO and ESB (2000). There is not much written about scale complexity issues. Countries are using different scales for their national soil maps. Some scales are used in almost every country and some, especially detailed are very rare. Additionally there is an issue of the imperial system in the UK and the problems of harmonisation between the English Scottish and soil maps of Northern Ireland.

The list below demonstrates the great variety of soil maps and their scales in some European countries (source: GS Soil D2.3).

Austria:
- Most Austrian soil maps use the scale 1:25 000.
- 1:10 000 for the field maps.
- The Soil Taxation Survey uses the scale of the Austrian Cadastre, i.e. 1:2 000 or 1:2 880 (old cadastre).

Czech Republic:
- On the whole territory of the Czech Republic there exist soil maps in scale 1:10 000, and 1:50 000.
- Soil ecological maps of agriculturally used lands (1:5 000)
- Forest typological maps (1: 5 000)
- Maps of soil associations at scales 1:1 000 000, 1:500 000 and 1:200 000 were compiled by the generalization of the above mentioned large-scale materials.

Germany:
- For national need, maps at scale 1:2 000 000 and 1:1 000 000 are available (1:200 000 scale are in preparation).
- Smaller thematic maps available but with limited coverage (1:25 000 to 1:200 000).
- Soil surveys published soil maps at scales of 1:5 000 and 1:10 000 and soil maps of the entire state at scales of 1:300 000 to 1:500 000.
Although some state soil surveys could improve soil information, the availability of soil maps at identical scales and quality is still unsatisfactory with respect to national requirements.

**Hungary:**
- National soil map (1:500 000),
- regional soil maps (1:100 000),
- Small scale (farm scale) (1:10 000 – 1:25 000) and (field level) (1:5 000 – 1:10 000)

**Poland:**
- Soil quality class maps at scale 1:5 000 (agricultural area).
- Soil agricultural maps (soil suitability classes) 1:5 000, 1:25 000 and 1:100 000.
- Soil maps at a scale of 1:25 000 demonstrating spatial variability of soil types

**United Kingdom:**
- Maps at the 1:25 000, 1:50 000 or 1:63,360 scale most of the arable land (Scotland), is covered at the 1:63 360 scale.
- Northern Ireland has soil maps at the 1:50 000 scale.
- ‘National’ 1:250 000 scale soil mapping programmes have been completed in all four countries

**Slovenia:**
- National soil map (1:25,000) that includes data on soil mapping units and soil typological units.
- Data of soil profiles that include their location, described and measured profile and horizon related parameters (soil type classification, list of horizons in soil profiles, parent material, vegetation type, land use, horizon, standard pedological analysis data etc.)
- National soil quality map that is expressed in relative soil quality index points.
- Soil contamination data.
- Few more detailed soil maps (i.e. 10.000) on local scale level (municipality level)

The scale of 1:25,000 scale soil map is satisfactory to a certain extent only. Because of the great diversity of Slovenia’s landscape and especially because of the requirements in agricultural and ground water protection, there are serious needs for scale and content improvement of the 1:25,000 soil map in the future.

### 5.2 Semantic interoperability

Soil maps are elaborated using similar yet from several aspects different approaches. Different (national) soil classifications were used. Soil mapping process largely integrates integrate expert knowledge which is difficult to harmonize. Soil mapping procedures are not adequately documented in several countries. In many cases harmonizing procedures were neglected. Intensive preparation steps are required to harmonize the soil mapping process to a satisfactory extent. Generally speaking, soil maps are subjective interpretations of groups of soil surveyor's who posses expert knowledge. The matter in question is however the missing possibility to harmonize the approaches of all groups.

The main reasons why high semantic interoperability of existing soil maps can be expected are the diversity of soil mapping approaches, surveyor’s subjectivity and various scales used. Consequently soil mapping units such as basic graphic soil mapping elements are defined and mapped differently, depending on the national classifications, mapping rules and surveyors interpretations.
6 Soil classifications in use

The conceptual basis for modern soil classification is genesis (Schelling, 1970) most commonly being morphogenetic. Since the early works of Dokuchaev, there was a motion of the correlation between the soil properties and soil processes dependent on soil-forming factors. It is expressed as: factors of soil formation → internal soil system functioning specific pedogenic processes → soil properties and features → external soil functions (Targulian and Krasilnikov, 2007). The concept is practical and used in soil mapping. The limits of soil polygons are usually placed on the borders of areas with uniform soil-forming factors (the same relief, parent materials, hydrology, etc.) (Hudson, 1992). Because mapping has been the main area of application of soil classification, it seems logical that the soils with the same soil-forming factors, pedogenic processes, properties and external functions should be grouped into the same classes. However, the dependence of soil properties on soil-forming factors is not linear, and as most soils are polygenetic they vary in space reflecting also the soil-forming conditions of the past which may only partially be reconstructed (Phillips et al., 1996). Because the direction and intensity of similar processes vary in time and space it is useful to consider the concepts of ‘divergence’ and ‘convergence’ (Rozanov, 1977). Divergence means that soils formed under similar conditions in different places commonly exhibit variable properties (Johnson et al., 1990; Phillips, 1993; Ibáñez et al., 1994) due to local factors. Convergence means that different pedogenic processes under different environmental conditions might lead to similar soil properties and morphology. For example, such processes as podzolization, clay eluviation and surface gleying generally lead to the formation of a bleached, clay-depleted surface horizon. Thus one cannot expect a complete correspondence of soil-forming factors, pedogenic processes and soil properties. External functions are less suitable for classifying soils; however, they are important for most interpretive groupings. For example, the most important soil function, its productivity, depends mostly on the availability of nutrients and toxicants in the surface horizon, which is dynamic, spatially variable, and easily modified by human impact. Early soil classifications used mainly factor-based approaches. At that time it was believed that the factors → processes → properties relation was linear and simple. Empirical data were usually insufficient for establishing the ranges of properties for every soil group. This approach survived almost to the end of the 20th century; for example, it was used in the Classification and Diagnostics of Soils of the USSR (Egorov et al. 1977). In that classification, the emphasis on soil-forming factors resulted in certain contradictions with empirical data. Different soils were placed in the same taxa if they were found to be in the same climatic zone. For example, the soils without a bleached surface horizon in the ‘podzolic zone’ were called ‘cryptopodzolic’ or ‘weakly differentiated podzolic soils’. Though most specialists currently reject a strictly factor-oriented approach, some soil classifications now consider surrogates of the climate factor to be measurable internal properties of soils. The US Soil Taxonomy (Soil Survey Staff 1999) and Chinese Soil Taxonomic Classification (Gong Zitong, 1994) use internal water and temperature regimes as quantitative diagnostic properties at high levels of taxonomic hierarchies. Another conceptual approach was proposed by Kuliëna (1953), who based his classification on soil evolution. Chronosequences of soils were established on the basis of empirical data and theoretical concepts about the stages of soil development. This scheme is widely used in German and other classifications. Soils are grouped according to the kind and degree of development of their profiles, considering that more developed soils should have more complex profiles. The concept is not universally accepted as many deep steppe soils, for example, might be considered weakly developed because they have a simple A/C profile. It is important to note, that the evolutionary grouping of entities in soil science is distinct from that in biology (cladistics). Soils are grouped according to the stage of their development (horizontal grouping) and not on the basis of the same ‘evolutionary branch’ (vertical grouping). For example, shallow young soils on limestone, Rendzinas, are not grouped with ancient limestone-derived residual soils, Terra Rossa. The evolutionary approach does not modify significantly
basic soil grouping compared with other approaches and can be regarded as a convenient arrangement of soils, useful mainly for educational purposes to indicate possible pathways of soil development. Most existing soil classifications use soil morphology and properties as marks or evidence of definitions used for soil groupings. The soils are still grouped according to concepts of their genesis, and observable and measurable criteria are used to provide objective identification for the placement of the objects in the classification system. Quite often the term ‘genetic classification’ is misunderstood in soil science. Every classification based on grouping soil profiles as combinations of horizons can be considered genetic. The diagnostics may be done on the basis of surrogates of soil-forming factors or on the basis of the properties of the soil profile itself, but the concept is the same. The profile is the result of soil formation and evolution, and the sequence and properties of the horizons are explainable and interconnected. Summarizing the information on the theoretical bases of soil classification, we conclude that practically all the approaches of various scientific schools have the same foundation, and most soil groups have rather similar abstract central concepts. The differences in theoretical approaches result mainly in the methods of defining and measuring diagnostics. In further text we are presenting some of the good practice examples for European soil classification:

### 6.2 National soil classification systems

Many countries developed national soil classification systems; Argentina, Australia, Brazil, Canada, China, France, Germany, Russia, Scotland, South Africa, and the United States, from which many have a long history. National soil classifications have been developed under the auspices of individual countries. The need was originally derived from the agricultural needs and tax collection reasons. In general national soil classifications describe the specific characteristics of soil in individual country tailored to its specific natural features. Difficulty arises in comparing different national classifications. Differences arise from different concepts, diagnostic features and soil analysis procedures. The following presents some of the main European classification and Soil Taxonomy.

#### 6.2.2 Austrian soil classification

The new Austrian soil classification (Nestroy et al, 2000) was prepared to replace the older system (Fink, 1969), which had been used for many years for national soil survey and inventory. Though the list of soils did not change much in the new version of the classification, the diagnostics and conceptual bases of the taxonomy were updated according to the actual demands, including the need for integration of national soil databases with the European soil information system and correlation and harmonization with the World Reference Base for Soil Resources (WRB) (Nestroy, 2001). Geographically Austrian classification covers the national territory.

It is quite natural that the actual Austrian soil taxonomy has the classification of Walter Kübiëna (1953) as the source system. In Kübiëna’s classification the lower levels of the taxonomy were not developed because he proposed a conceptual scheme, not a tool for large-scale mapping. That is why the classifications rooted in Kübiëna’s system are often different. Though their basic ideas (like the evolutionary approach to soil grouping) and upper taxonomic levels are similar, at the lower levels of taxonomy the older and the new Austrian classifications differ. The same is true for the Austrian and German classifications. At first glance these two systems seem almost identical; however, they have a lot of minor differences which make difficult the transfer of cartographic data between the two countries. Apart from the basic pedogenetic and evolutionary ideas of Kübiëna, the new Austrian classification partly accepts the novel ideas of quantitative diagnostics and the use of formal criteria for soil grouping.
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

The upper collective level of the Austrian classification includes two main orders: terrestrial and hydromorphic soils. Compared with the German classification (Ad-hoc-AG Boden, 2005) which developed from the same roots, the division on the highest level is made more general (two orders at the highest level vs three branches of the German classification). As in many classifications, the upper collective level serves mainly for showing the priorities of the authors (compare sinlithogenic, postlithogenic and organic trunks in Russian classification and branches and orders according to hydromorphism level in the German and Austrian classifications. Within the orders there are collective classes that group soils according to the stage of their profile development and general geochemistry. Soil types form a generic level of taxonomy. Subtypes specify particular features of soils, such as humus form and the presence of secondary carbonates. The varieties give additional characteristics of soils, both qualitative and quantitative. The structure of this classification is a hierarchical taxonomy with formalized borders between classes.

The new Austrian soil classification includes a system of diagnostics based on quantitative evaluation of soil morphological and chemical parameters. The definitions of the horizons are less strict than in the WRB giving some flexibility to the soil surveyor. Only internal properties of soil profiles are recorded, no regime monitoring is required. The division of terrestrial and hydromorphic soils is made on the basis of soil morphology and observations about the position of the pedon in a landscape. The diagnostics, in general, are semi-quantitative chemical-morphological.

The first soil classification in Austria was proposed by Walter Kubiëna who had already in his famous book Micropedology (1938) schematically grouped European soils. Later he developed and finalized his classification (Kubiëna, 1953). As mentioned above, his classification was too general for soil inventory and large-scale mapping. The first Austrian working document that permitted soil survey in a uniform way was published in the late 1960s (Fink, 1969) about the same time as most countries published official classifications applicable for detailed soil mapping (USA, USSR, France, The Netherlands, etc.). This classification was successfully used in Austria for more than 30 years. The new soil classification (Nestroy et al, 2000) is not a revolutionary change of concepts; it is a continuation of the older version based on improved understanding of soils and soil cover.

6.2.3 French soil classification system

The French soil classification is one of the most developed in methodological. All the concepts used are defined in detail, and the whole process of classifying soils is described. The objects of soil investigation are always so-called soil mantles (couverture Pédologique), which are defined as real natural three-dimensional bodies. Soil section, solum, is a conceptual two-dimensional cut of soil mantle. Soil mantle is not homogeneous, and requires profound investigation, which includes digging several sections, as well as research work using drill, auger and remote-sensing methods. The characteristics of soil are given on the basis of these complex data; the same as in biology, where the object of classification is not a single organism, but a population (Zarenkov, 1993). Soil profile is understood as a gradient of one or several properties in a vertical section of soil, for example, texture profile, salinity profile and so forth. In the process of investigation a soil scientist divides the soil into horizons and, based on research in the field and laboratory, refers each real horizon to a reference one. The operation results in a transition from a real soil section to a conceptual solum having a sequence of reference horizons. The great achievement of the authors of the French classification is that they made clear the cognitive process of soil classification. In classifications based on a factor genetic approach a specialist makes decisions using ‘black box’ principles based mainly on his non-verbal knowledge (Hudson, 1992), while in formalized classifications the role of a specialist to a great extent is reduced to fulfilling an algorithm. In the French system the process of recognizing soil horizons and their reference to the conceptual
constructions is clearly described. A conceptual solum is then referred to a certain soil reference (reference Pédologique), which is a sequence of reference horizons. The idea of a soil reference is the basic one for the French classification, and serves as an archetype of a certain soil.

Though reference horizons have quantitative diagnostic criteria, there is a basic difference in interpretation of these horizons in the French system and in the majority of other soil classifications, for example, in the US Soil Taxonomy (Soil Survey Staff, 1999). If a horizon does not fit quantitative criteria in Soil Taxonomy, it cannot be called diagnostic, and a soil is referred to another taxa. If a diagnostic horizon does not fit the definition given in the French classification for some properties, but is generally close to the 'central image' of such a horizon, it is still called that diagnostic. In fact quantitative criteria are given only to describe the 'central image' better, but around this there is a 'buffer zone', where similar soils exist, and they are also referred to the same class. Also in the French classification it is allowed to give mixed names for soils if they show transitional properties between two or more reference groups.

Référentiel Pédologique is declared not to be a hierarchical taxonomy (AFES, 1998). Instead it proposes the use of qualifiers which allows naming soils in a more precise manner. To a great extent the structure of the French classification is very similar to that of the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2006). It is not surprising, because one of the main ideologists of the French classification, Alan Ruellan, led the WRB Working Group during the initial stage of its work (at that time IRB — International Reference Base). The qualifiers proposed can be purely descriptive ('at the bottom of a slope', 'on limestone', etc.), or can reflect a genetic interpretation of the observed properties ('podzolized', 'paleuvic', etc.). To a great extent the problems existing in soil classifications were not solved by Référentiel Pédologique, but just hidden by moving them to the qualifiers level. For example, some of these qualifiers reflect not the properties of the solum itself, but opinions about soil genesis and factors of soil formation. The use of such a system of qualifiers has both advantages and disadvantages. An advantage is that the problem of hierarchy of properties for classification does not exist: all the qualifiers are listed in a line. However, one of the most important functions of classification is lost: a function of curtailment of information. In fact Référentiel Pédologique makes a step back to a nominal system. The openness of the French classification can lead to uncontrolled growth of the quantity of qualifiers. The number of soil references also can grow significantly: the authors promised to increase them, mainly to account for tropical soils.

Though French soil classification is not hierarchical, it has at least two levels. At the first level there are 'references', which are determined as conceptual sequences of reference horizons. Currently 102 references exist; in the future the authors plan to increase the quantity up to 150. The second level, soil types, are references with specified qualifiers. Currently there are 235 qualifiers. Conceptually the number of types is almost unlimited: if one uses four to six qualifiers for a single type, then the number of combinations is up to 1014. Even if we take into account the restrictions for the use of qualifiers (they should not be repetitive or contradictory to the reference and other qualifiers), the number of theoretical soil types is very large.

References can be grouped into 'great groups of references' (grand ensemble de Réferences), though the authors stress that they do not have a taxonomic significance, and are used only for the convenience of presentation of material in a text.

Thus, Référentiel Pédologique is a classification in the form of a reference base with fuzzy borders between the taxa, having some features of a nominal system.

The diagnostics of soil references are composed of properties of horizons themselves, and also landscape criteria. The diagnostics of soil horizons are made according to quantitative
6.2.4 German soil classification

The German soil classification has a morpho-genetical approach. Its aim is to order soils into natural groups for a better understanding of soil genesis and geography, for education, and for soil mapping at various scales (Ad hoc-AG Boden 2005). The current German classification was developed since the 1950s and was strongly influenced by the classification of Kubiëna (1953). Kubiëna’s classification divided soils according to their water regime in a broad sense (terrestrial, hydromorphous and subaqueous soils); the terrestrial soils were arranged according to their stage of development. Traditionally, the German classification includes shallow underwater soils as equal objects. Anthropogenic soils deeply transformed by cultivation are included as separate taxa. Urban soils and technogenic or transported materials are not included in the classification itself; however, the German soil science school has a rich tradition of classifying urban and technogenic soils (e.g. Blume, 1989) which are used apart from the main official classification. Additionally, the German substrate classification offers a detailed classification of technogenic materials (Ad-hoc-AG Boden, 2005).

The main ideas of soil classification were outlined by Kubiëna (1953) in his seminal book Bestimmungsbuch und Systematik der Böden Europas. Even today German pedologists continue developing the theory of soil classification (e.g. Albrecht et al, 2005). Basically, the authors of the classification clearly understood the difference between an ideal natural grouping of entities (‘systematics’) and a provisional grouping of soils in a real world (‘classification’). The taxa are defined mostly by qualitative criteria: the German classification gives conceptual sequences of horizons rather than establishes strict quantitative limits between soil units. The archetypes remain almost the same as outlined by Kubiëna, which, in their turn, were derived from classical German studies at the beginning of the 20th century. The overall arrangement of the classification also follows the ‘evolutionary’ scheme of Kubiëna, from the simplest poorly developed soils to the most complex, polygenetic ones. Apart from a pure substantial characterization of soils, the classification partly includes a genetic interpretation of soils. Many deeply weathered soils are understood as paleogenetic, if their formation mainly occurred before the Holocene.

The German soil classification has six hierarchical levels. Soil branches (or orders) combine soils of certain levels of hydromorphism and of the nature of parent material (organic or mineral): terrestrial soils, semi-terrestrial soils, semi-subaqueous and subaqueous soils, and peat soils (fens and bogs). Soil classes (or suborders) are differentiated according to a similar stage of soil evolution and the dominant pedological processes. Soil types represent the basic unit of the classification. Each soil type is defined by a specific sequence of soil horizons. Subtypes are either modifications of the ‘central image’ or transitions between types (e.g. Braunerde-Podsol, Pseudogley-Fahlerde, etc.). Varieties and sub varieties reflect quantitative modifications of soil properties. Independent from the soil classification is the substrate classification. The combination of soil classification and substrate classification leads to soil forms (or series). According to its structure the classification is a hierarchical taxonomy with fuzzy borders between taxa.

The object of classification in the German classification is the soil itself. Climatic conditions and other factors of soil formation are not taken into account. On higher levels of taxonomy the diagnostics are based on soil morphology; on lower levels some properties should be determined in a laboratory. The authors try to use mainly qualitative criteria or properties...
easily measured in the field (e.g. horizon depth, gravel content). The diagnostics in the German classification can be called semi quantitative chemical-morphological.

A number of early soil classifications exist in Germany, even from the 19th century (e.g. Richthofen, 1886). In the 1920s and 1930s Hermann Stremme and his co-workers developed a system for soil mapping and published several soil maps of Germany (e.g. Stremme, 1936) and Europe. In the 1950s, the development of the current system started, which was done to some extent separately in West and East Germany. However, both systems were mainly based on the classification scheme of Kubiëna (1953). Eduard Mückenhausen elaborated the fundamental outline for the West German system (Mückenhausen 1962, 1977). Afterwards, three editions of the classification system were published (AG Bodenkunde 1965, 1971, 1982). The East German classification was issued by Ehwald et al. (1966). Immediately after unifying the country in 1990, a uniform soil classification was established (Ad hoc-AG Boden 1994). In the meantime, the fifth edition (counting the three West German and the two common editions) of the system is in use (Ad hoc-AG Boden 2005).

### 6.2.5 Hungarian soil classification

Hungary is one of the pedologically most studied countries in Europe. Though its territory is small, Hungary possesses a great variety of soils. A demand for soil classification was determined both by the needs of scientific soil research and practical soil mapping. The current official soil classification of Hungary is one of the last systems in Europe designed in the old style based mainly on the assumptions on soil genesis. It does not use diagnostic horizons and has practically no artificial terms. The lower taxa are developed in detail to be effective for soil survey at any scale. As there is no major soil survey activity going on, the current official system is applied mainly for land evaluation and soil conservation planning. Because of the need for harmonized soil information in the EU, education about the World Reference Base for Soil Resources (WRB) became necessary. The younger generation of soil scientists is familiar with both the national and WRB systems. The Hungarian soil classification was developed mostly for mapping soils of agricultural lands of the country, and does not include urban soils or technogenically disturbed substrates.

The Hungarian soil classification has two main roots. First, it borrowed a pedogenetic basis from the Russian soil classification and the highest taxa are determined mainly according to pedogenetic concepts as primary criteria. Second, the Hungarian classification was influenced by the German school, especially Kubiëna’s taxonomic system (1953). The ‘dynamitic soil classification developed by de Sigmond (1938) included diagnostic elements and influenced several modern classification systems and approaches (Jenny 1941) but only slightly influenced the development of the Hungarian system.

### 6.2.6 Polish soil classification

Poland has an old, developed school of soil science. Soil surveys started there in the early 1950s, and the country faced the need for a unified soil classification. The first classification (Anonymous, 1956), though based on a qualitative approach, was successfully used in Poland for mapping and classifying soils for more than 30 years. However, in the late 1980s it was decided that the classification should be updated according to new concepts in pedology, and that the diagnostics should be quantitative as in most classifications. The Polish classification is suited for soil mapping at any scale and for scientific soil research (Polish Society of Soil Science, 1989). This classification is designed for use only within the country. Like most recent soil classifications, the soils of urban and industrial areas, and soils deeply transformed by agriculture, are included in the classification at high taxonomic levels. Bare rock and underwater sediments are not regarded as soils.
 Polish soil classification is based on pedogenetic understanding of soil processes and soil bodies, on traditional archetypes, and on quantitative diagnostics for limiting these archetypes. The classification represents a compromise between traditional grouping of soils and formalized methods of grouping (Charzynski et al, 2005). Many recently reworked classifications, especially in Eastern Europe, have followed the same way.

There are six levels in the structure of the soil classification of Poland. The highest level of taxonomy is soil section, which collects soils according to the main group of factors affecting soil formation (lithogenesis, hydromorphism, salinization, anthropogenic effect, etc.). Within the sections there are soil orders, grouping soils of the same leading pedogenetic process or the most general features of the profile. Soil types serve as a basic level of taxonomy, and are determined as soils with similar profiles and close chemical and physical properties. Subtypes are distinguished by additional soil-forming processes that result in the presence of additional horizons or properties or modifications of properties. Genera are distinguished according to the origin of parent material and the content of carbonates in this material. Species are similar to soil series in other classifications; they are defined as soil individuals as adopted by the Polish Society of Soil Science. It is important to mention that the system of soil series is not traditional for Poland, and species is not regarded as a generic level of taxonomy. In the countries with traditional use of soil series each soil is described and mapped, and then referred to a soil series, or a new series is proposed. Then, if necessary, this soil series is classified in terms of soil taxonomy. Where a soil series system was not used in a country, a soil is first classified in terms of soil taxonomy, and then, if the profile has some particular features, it may be named a special series. Though the difference seems to be just in the sequence of operations, in fact they are two different mental processes of synthesis and analysis. The classification is a hierarchical taxonomy with partially formalized borders.

The object of diagnostics in Polish classification is the soil profile. The definitions of taxa are quantitative, based on a system of diagnostic horizons and properties. The diagnostics for the more important levels of the taxonomy (types and lower taxa) are based mainly on morphological and chemical criteria. The collective levels are more genesis-oriented, based mainly on the general morphological features of soils and their genetic interpretation. The diagnostics are mainly quantitative chemico-morphological ones.

6.2.7 Russian soil classification 2004

A new classification of the soils of the Russian Federation (Shishov et al, 2004) was made to replace the older taxonomic system used in the Soviet Union (Egorov et al, 1977). Initially planned as a tool for soil survey in the country, ironically, it was published when Russian Giprozem (State Project Institutes for Land Resources) practically stopped soil survey. These institutes were transformed into commercial enterprises mainly focused on the arranging of land ownership documentation, and the soil survey divisions were closed. Currently the new classification of Russian soils has a strange status: it is published, but not approved as an official one for Russia because there are no institutions that can approve it. Due to this undefined status of the classification, it is not included as obligatory material in university courses on soil science. It is included in some university courses by a decision of the departments, or particular professors. According to an on-line survey organized by the Faculty of Soil Science of Moscow State University, less than 20 per cent of university scientists and students use the new classification in their work. The classification is used in Russia at least by some members of the scientific community. It has many new ideas which have no analogies in other taxonomies, and is interesting from a theoretical point of view. The classification represents a major effort of a group of leading researchers, and reflects their views on soil genesis, classification and systematics. The geographical scope of the new Russian classification is narrower than that of the previous version (Egorov et al, 1977); it is limited to the borders of the Russian Federation. The authors of the classification decided to classify hu-
man-transported materials and substrates of urban and industrial areas apart from the main soil classification. Bare rock and underwater soils are also disregarded in the classification. Soils transformed by agricultural activities are widely represented in the Russian classification: in fact, this classification pays major attention especially to the degree and type of agricultural transformation of soils. The most transformed soils are classified at the level of soil section (collective level), the less transformed are at the level of soil types (generic level), and those with minor agricultural disturbance are classified at the level of subtypes (specific level).

Russian classification declares four principles as its theoretical basis: genetic approach, historical continuity, reproducibility and openness. These principles are common for many soil classification schemes. In practice these principles are not strictly followed but serve as guidelines. Completely new is the attempt to use a system of diagnostic horizons and properties. However, in the Russian classification these diagnostic genetic horizons have somewhat different meanings than in most Western schools. The latter ones are stricter, but often embrace broader concepts. Thus the same horizon in a real profile may fit the concepts of several diagnostic horizons, properties or materials: they are considered to be overlapping or coinciding in part. For example, in the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2006) a single horizon can fit the definitions of gyspic, calcic and argic horizons, and also a number of other properties – all of which may be taken into account for classifying soils. In the Russian classification the designated horizons are mutually exclusive which provides more order to the taxonomy; for example, this classification has a key for diagnostic horizons (Anonymous, 2008) that is impossible in other classifications. Any new combination of properties usually results in the introduction of a new horizon and, according to the logic of classification, results in a new soil type. The other important feature of the Russian classification is its special attention to the degree of agricultural transformation of soils. No other classification has such a large number of horizons and properties related to agricultural transformations. The basic concepts of the new Russian classification, including the system of naming agrogenic soil horizons and agricultural soils, are described in more detail in some journal articles (e.g. Lebedeva et al, 1996; Shishov et al, 2005).

In general the Russian soil classification follows the structure of the classification of soils of USSR (Egorov et al, 1977). The basis unit of this classification (generic level) is soil type, but its meaning has changed somewhat. Soil types have become much narrower; for example, in previous classifications textural differentiation in Chernozems was used only for distinguishing soils on the level of subtypes, whereas in the new classification this feature is used to separate Chernozems from clay-illuviated Chernozems. As a result the number of types has increased. Accordingly, the subtypes became narrower and mostly separate soils having slight gleying or minor agricultural transformations. The soils differing by the composition of rocks and groundwater are distinguished at the genus level. The concepts of classes, subclasses and sorts are the same as in the 1977 version. A new feature is the presence of two taxa on levels above type, namely trunks and sections. There are three trunks: postlithogenic, synlithogenic and organogenic soils. The first two are distinguished on the basis of the ratio between lithogenesis and soil formation, and the soils of the third trunk develop in peat. In the latter case the peculiarity of parent material determines all the soil properties. The structure of the classification is a hierarchical taxonomy with fuzzy borders between taxa.

The diagnostics of soil taxa in the new Russian classification are derived from the composition of a soil profile; the authors define this classification as ‘substantial-genetic’. A soil profile is defined as a sequence of diagnostic genetic horizons. The characteristics of horizons are determined using both field morphological criteria and laboratory analysis. However, the diagnostics of the genetic horizons are not very strict, and very few quantitative criteria are used. Thus, though at a first glance the diagnostics of Russian classification seem to be similar to other classifications, in fact its fuzziness occurs with the diagnostic horizons. The hori-
zonations are defined by the description of ‘central images’ rather than by clearly defined limits. The authors try to avoid formal quantitative criteria and appeal more to the genetic interpretation of properties than to their formal use. In practice the diagnostics are still subjective for the most part.

Climatic conditions of soil formation and the mineralogical composition of soils are classified independently of soil profiles. In general the diagnostics in this classification can be called qualitative chemical-morphological.

6.2.8 United Kingdom soil classification

Soil classification in the UK is based mainly on the ideas adopted from the North American pedological school. The British soil inventory is based on the use of a system of soil series that was introduced to pedology by the US Soil Survey (Simonson, 1989). The structure and terminology of the British classification are similar to those used in the older soil classification of the US (Baldwin et al, 1938). Soil classification of the UK also includes some elements from more recent concepts of the American school, such as the idea of diagnostic horizons (Soil Survey Staff, 1999). Soil archetypes were not revised in the British classification. They are closer to the traditional European soil archetypes, or to the older US system (Baldwin et al, 1938), than to the artificial taxa of Soil Taxonomy (Soil Survey Staff, 1999). The general scheme of the classification involves the concept of soil ‘evolution’: the stages of soil development are included in the highest level of taxonomy that is well illustrated by alluvial soils, which are not brought together in one major group, but scattered among major groups depending on the stage of soil profile development. Like the 1938 American classification the system of soil series was not always coincident with taxonomic classification. In practical soil mapping some series were divided into ‘variants’ that might belong to different taxonomic groups.

The British soil classification has four hierarchical levels. On the highest level there are ten major groups; each one includes several groups. The latter are divided into subgroups. The three highest levels are defined on the basis of the presence of certain horizons and properties at or within certain depths. Within subgroups there are series, defined as soil classes with identical sequences of horizons formed in similar conditions on the same parent material. The structure of the classification is defined as a hierarchical taxonomy with partially formalized borders between classes; on the level of series it reduces to a nominal system.

The object of diagnostics is the soil profile itself with no factors of soil formation. These factors may be taken into account at the series level, but they are not included directly as diagnostics. The definitions of horizons are less strict in British variants and fewer quantitative chemical criteria are used. In many cases a diagnostic is based only on the presence or absence of certain properties. The diagnostics could be called quantitative chemical-morphological.

The historical development of soil survey in Great Britain perhaps began in the 17th century when the Royal Society suggested collecting information on British soils (Clayden and Hollis, 1984). However, real soil mapping started in the UK in 1926, when the American method of soil series was introduced. The work on a taxonomic soil classification started in the late 1960s, after publication of the American and Dutch soil classifications. In a systematic form the classification was presented by B. V. Avery of Cranfield University (Avery, 1973). Minor corrections were introduced up to the 1980s, when the latest available version was published (Avery, 1980). Later on, the soil survey of the UK was closed, and there were no further updates of the system. The system is still widely used in the UK for education and scientific research (Avery, 1990).
6.2.9 The United States Soil Taxonomy

Several basic principles support the American soil classification. First, the object of classification is the profile or a small representative volume, not processes or factors of soil formation. Second, all the levels should be separated on the basis of quantitative diagnostic soil properties. Whittaker (1975) notes that in a hidden form Soil Taxonomy implies the idea of continuity of soil cover, which is artificially separated into classes by formal criteria. One of the main concerns of the authors of Soil Taxonomy about earlier classifications was that they paid too much attention to the factors of soil formation. It was stated that natural objects should be classified according to their internal properties. It is interesting to note, however, that Soil Taxonomy appears to be more ‘climatic’ than any other. It uses surrogate atmospheric climatic data to estimate and extend measurable internal temperature and moisture parameter trends in soils. Most suborders and two orders (Aridisols and Gisols) are distinguished by soil climatic conditions that limit current soil-forming processes. Traditionally Soil Taxonomy was erroneously contrasted with ‘genetic’ classifications, as it was considered to be more soil survey-oriented. The diagnostic horizons in Soil Taxonomy are distinguished not only on the basis of their practical significance for agriculture, but also because they are characteristic of many conditions affecting soil-forming processes. For some land management there is little difference if there is a spodic horizon in a soil or not. This horizon is thought to relate to the process of migration of aluminium, silica, humus and/or iron in a soil profile. The interpretation of the genetic nature of these diagnostic horizons is illustrated by the following change of methodology. For a long time a spodic horizon was recognized by the ratio of Al + 1/2 Fe, extracted by pyrophosphate, to the same elements extracted by dithionite-citrate-bicarbonate because it was considered that podzol formation was connected mainly with the migration of aluminium and iron-organic complexes which were believed to be extracted by pyrophosphate. Currently podzol formation is believed to be mainly the result of accumulation of X-ray amorphous aluminosilicates in the spodic horizon. These criteria were changed. An acid oxalate buffered solution is used for iron and aluminium extractions which are believed to dissolve amorphous allophanes and imogolite minerals.

In the US Soil Taxonomy there are the following levels: orders, suborders, great groups, subgroups, families and series. Soil type was dropped and considered to be a surface texture phase of a soil series. Phases are outside the formal classification system and commonly use defined properties or conditions that are relevant to the use and management of soils, such as stoniness, rockiness, slope degree and complexity, salty surface, protected from flooding, irrigated where not common and degree and kind of erosion. Phases may be designed for use with map units named at any categorical level, for example, Gently undulating Mollisols, or Steep, stony Udepts. Commonly they are carefully defined and controlled for use in soil survey activities. Because the system was designed to assist in making and interpreting soil surveys, the diagnostic properties and features selected to satisfy category definitions include both dynamic and static properties of soils. The margin of temporal and spatial attributes has often been misunderstood as inconsistency in applying diagnostics; however, the groupings of soils have permitted many pragmatic interpretations as well as identifying bodies of soils in the pedosphere and suggesting some aspects of their order in nature. Soil Taxonomy embraces six categories – from Orders to Series. The Order may be defined as soils having properties or conditions resulting from, or reflecting, major soil-forming processes that are sufficiently stable in a pedologic sense (Arnold and Eswaran, 2003). Insofar as highly organic natural accumulations, those of volcanic debris, those of highly weathered and resistant minerals, and those of high shrink–swell clays can be recognized and identified as soils, classes of Histosols, Andisols, Oxisols and Vertisols are separated as Order classes. Soils that have cold temperatures and reflect freezing and thawing, and other soils with relict features or current regimes of aridity are separated as Gisols and Aridisol Order classes, respectively. Thus diagnostic soil features are selected to specify the details for consistent recognition and placement of soil entities into the designated classes. The Subor-
order category may be defined as soils within an Order class having additional properties or conditions that are major controls, or reflect such controls, on the current set of soil-forming processes. At this level more dynamic features are selected as evidence of influences on pedogenesis. Some are relict properties such as fragipans, but many are dynamic temporal properties such as moisture regimes and/or temperature regimes if not previously used at a higher level in the system for that group of soils. Thus Alfisols may be separated into Aqalf, Cryalf, Udalf, Ustalf and Xeralf classes at the suborder level. In other Orders the major controls may be materials such as the sandy Arents, or the salty Salids. A quick examination of the Keys to Soil Taxonomy reveals the judgements about priorities for process controls in different environmental settings. The Great Groups are soils within a Suborder having additional properties that constitute subordinate or additional controls, or reflect such controls on the current set of soil-forming processes. Classes of Suborders consequently provide additional information useful for interpreting soil behaviour in various landscape settings. Priorities are given in the keys to guide consistent placement of soil entities. Because this approach subdivides the pedosphere into more homogeneous groups there is commonly one class that is the residual from the Suborder class being considered. It is designated as the Haplo-class and likely includes soils that may be separated in the future. The Subgroups are more complicated as they are soils within a Great Group having additional properties resulting from a blending or overlapping of sets of processes in space and time that cause one kind of soil to develop from, or towards, another kind of soil. These classes are intergrades with linkages to other Great Groups, Suborders, or Orders. Also included are other soils called extragrades, having sets of processes or conditions that had not been recognized as diagnostic for any class at a higher level, including non soil features. A bedrock contact (lithic) at a shallow depth would be such an extra grade. Families are soils within a Subgroup having properties that often are indicative of the potential for further pedogenic development. Such properties are often characteristic of chemical and physical capacity to change. Included are soil textures including coarse fragments at specified locations in a profile, additional soil temperature variations, mineralogy and activity of clays. Most diagnostics at the family level are relevant to use and management of soils. Details of soil series classification are not shown in the primary structure of Soil Taxonomy or its Keys as they pertain to many properties not applied in higher level classes, such as horizon thickness, colours, structural units, in-place biological features, and other information about the parent materials present in the family class. Most laboratory and other support data are provided in electronic data bases (NASIS) for designated soil series.

The placement into most taxa is made on the basis of the presence of certain diagnostic horizons, materials and properties in a soil profile. The diagnostic horizons, materials and properties are defined quantitatively. For most definitions special tests are needed; these tests require laboratory equipment, and only a few criteria are possible to determine in the field. In some cases not only simple chemical analyses are required, but also mineralogical composition and microstructure are investigated to confirm the presence of a certain horizon. These analytical requirements limit the possibilities for field soil diagnostics. However, the second edition of Soil Taxonomy has less diagnostic criteria requiring expensive and time-consuming laboratory analyses; more attention is given to field diagnostics. A peculiarity of the US Soil Taxonomy is that it requires measured or estimated information on water and temperature regimes of soils. It is theoretically impossible to classify any soil without climatic information; however, thousands of 30-year or more climate records exist around the world and current models permit estimations and extrapolations of such information. No other soil classification in the world is so climate-oriented. This was due, in large part, because the US contains various climatic conditions, from arctic to tropical ones. From a practical point of view it was important to indicate favourable and limiting conditions for agriculture, grazing and forestry. The use of quantitative criteria allows even a non-specialist to name a soil, if necessary in-
formation on the profile is available. The diagnostics in this classification can be characterized as quantitative climatic-chemical-morphological.

6.3 WRB soil classification

In the early 1980s, countries became increasingly interdependent for their supplies of food and agricultural products. Problems of land degradation, disparity of production potentials and of population-carrying capacities became international concerns that required harmonized soil information. Against this background, the Food and Agriculture Organization of the United Nations (FAO) felt that a framework should be created through which existing soil classification systems could be correlated and harmonized. Concurrently, it would serve as an international means of communication and for exchange of experience. The elaboration of such a framework required a more active involvement of the entire soils community.

The meeting decided to launch a programme to develop an International Reference Base for Soil Classification (IRB) with the aim to reach agreement on the major soil groupings to be recognized at a global scale, as well as on the criteria to define and separate them. It was expected that such an agreement would facilitate the exchange of information and experience, provide a common scientific language, strengthen the applications of soil science, and enhance communication with other disciplines.

In 1992, the IRB was renamed the World Reference Base for Soil Resources (WRB).

The first official text of the WRB was presented at the 16th World Congress of Soil Science in Montpellier in 1998. The WRB text was then adopted by the ISSS Council as the officially recommended terminology to name and classify soils. By general agreement, it was then decided that the text would remain unchanged for at least eight years, but that it would be tested extensively during this period and a revision proposed at the 18th World Congress of Soil Science in 2006.

In the period 1998–2006, WRB became the official reference soil nomenclature and soil classification for the European Commission and was adopted by the West and Central African Soil Science Association as the preferred tool to harmonize and exchange soil information in the region.

In the same period, the European Commission issued the Soil Atlas of Europe based on WRB (European Soil Bureau Network/European Commission, 2005). A major effort was undertaken to harmonize nomenclature with the Soil Taxonomy of the United States Department of Agriculture (USDA) and other major national soil classification systems. Some national classifications took up elements of WRB, e.g. the Czech soil classification (Němeček et al. 2001) and the Lithuanian soil classification (Būivydaitė et al. 2001).

The general principles on which WRB is based were laid down during the early Sofia meetings in 1980 and 1981, and further elaborated upon by the working groups entrusted with its development. These general principles can be summarized as follows:

- The classification of soils is based on soil properties defined in terms of diagnostic horizons, properties and materials, which to the greatest extent possible should be measurable and observable in the field.
- The selection of diagnostic characteristics takes into account their relationship with soil forming processes. It is recognized that an understanding of soil-forming processes contributes to a better characterization of soils but that they should not, as such, be used as differentiating criteria.
- To the extent possible at a high level of generalization, diagnostic features are selected that are of significance for soil management.
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I

- Climate parameters are not applied in the classification of soils. It is fully realized that they should be used for interpretation purposes, in dynamic combination with soil properties, but they should not form part of soil definitions.
- WRB is a comprehensive classification system that enables people to accommodate their national classification system. It comprises two tiers of categorical detail:
  - the Reference Base, limited to the first level only and having 32 RSGs;
  - the WRB Classification System, consisting of combinations of a set of prefix and suffix qualifiers that are uniquely defined and added to the name of the RSG, allowing very precise characterization and classification of individual soil profiles.
- Many RSGs in WRB are representative of major soil regions so as to provide a comprehensive overview of the world’s soil cover.
- The Reference Base is not meant to substitute for national soil classification systems but rather to serve as a common denominator for communication at an international level. This implies that lower-level categories, possibly a third category of the WRB, could accommodate local diversity at country level. Concurrently, the lower levels emphasize soil features that are important for land use and management.
- The Revised Legend of the FAO/UNESCO Soil Map of the World (FAO 1988) has been used as a basis for the development of WRB in order to take advantage of international soil correlation that has already been conducted through this project and elsewhere.
- Definitions and descriptions reflect variations in soil characteristics both vertically and laterally so as to account for spatial linkages within the landscape.
- The term Reference Base is connotative of the common denominator function that the WRB assumes. Its units have sufficient width to stimulate harmonization and correlation of existing national systems.
- In addition to serving as a link between existing classifications systems, the WRB also serves as a consistent communication tool for compiling global soil databases and for the inventory and monitoring of the world’s soil resources.
- The nomenclature used to distinguish soil groups retains terms that have been used traditionally or that can be introduced easily in current language. They are defined precisely in order to avoid the confusion that occurs where names are used with different connotations.
- Although the basic framework of the FAO Legend (with its two categorical levels and guidelines for developing classes at a third level) was adopted, it has been decided to merge the lower levels. Each RSG of the WRB is provided with a listing of possible prefix and suffix qualifiers in a priority sequence, from which the user can construct the second-level units. The broad principles that govern the WRB class differentiation are:
  - At the higher categorical level, classes are differentiated mainly according to the primary pedogenetic process that has produced the characteristic soil features, except where special soil parent materials are of overriding importance.
  - At the second level, soil units are differentiated according to any secondary soil-forming process that has affected the primary soil features significantly. In certain cases, soil characteristics that have a significant effect on use may be taken into account.

It is recognized that a number of RSGs may occur under different climate conditions. However, it was decided not to introduce separations on account of climate characteristics so that the classification of soils is not subordinated to the availability of climate data.

6.3.1 Architecture

Currently, WRB comprises two tiers of categorical detail:
1. **Tier 1: reference soil group (RSG):** \( N = 32 \)

2. **Tier 2: combination between RSG and qualifiers,** detailing the properties of the RSGs by adding a set of uniquely defined qualifiers.

In WRB, a distinction is made between typically associated qualifiers, intergrades and other qualifiers. **Typically associated** qualifiers are referred to in the key to the particular RSGs, e.g. Hydragric or Plaggic in the case of Anthrosols. **Intergrade** qualifiers are those that reflect important diagnostic criteria of another RSG. The WRB key dictates the choice of the RSG and the intergrade qualifier in that case provides the bridge to the other RSG. **Other qualifiers** are those not typically associated and that do not link to other RSGs. This group reflects characteristics such as colour, base status, and other chemical and physical properties provided that they are not used as a typically associated qualifier in that particular group.

### 6.3.2 Principles and use of the qualifiers in WRB

A two-tier system is used for the qualifier level, comprising:

**Prefix qualifiers:** typically associated qualifiers and intergrade qualifiers; the sequence of the intergrade qualifiers follows that of the RSGs in the WRB key, with the exception of Arenosols; this intergrade is ranked with the textural suffix qualifiers (see below). Haplic closes the prefix qualifier list indicating that neither typically associated nor intergrade qualifiers apply. Prefix qualifiers are always put before the RSG name.

**Suffix qualifiers:** other qualifiers, sequenced as follows:

(1) qualifiers related to diagnostic horizons, properties or materials;
(2) qualifiers related to chemical characteristics;
(3) qualifiers related to physical characteristics;
(4) qualifiers related to mineralogical characteristics;
(5) qualifiers related to surface characteristics;
(6) qualifiers related to textural characteristics, including coarse fragments;
(7) qualifiers related to colour; and
(8) remaining qualifiers.

Suffix qualifiers are always placed between brackets following the RSG name. Combinations of qualifiers that indicate a similar status or duplicate each other are not permitted.

### 6.3.3 The objects classified in the WRB

Like many common words, the term ‘soil’ receives several meanings. In its traditional meaning, soil is the natural medium for the growth of plants, whether or not it has discernible soil horizons (Soil Survey Staff, 1999). In WRB (1998), soil has been defined as:

“... a continuous natural body which has three spatial and one temporal dimension. The three main features governing soil are:

- It is formed by mineral and organic constituents and includes solid, liquid and gaseous phases.
- The constituents are organized in structures, specific for the pedological medium. These structures form the morphological aspect of the soil cover, equivalent to the anatomy of a living being. They result from the history of the soil cover and from its actual dynamics and properties. Study of the structures of the soil cover facilitates
6.4 Rationale about a common soil terminology

The geographical scope of most national soil classifications is limited to their national borders. Traditional soil classifications were designed mainly for agronomical purposes; however, currently society demands more environmental information.

Direct translation between soil terminologies is often not possible, due to differences in diagnostics and in archetypes. Quantitative diagnostics relate to methods of measurement as well as the soil features being considered. Depth, thickness, chemical limits, colours and so forth result in overlaps between taxa of one system relative to another. The difference in diagnostics of different national classifications may result in the following: a soil taxon is broader, a soil taxon is narrower. The difference in the limits of classes may be due to: (a) one classification uses fuzzy qualitative criteria, and the other uses quantitative criteria; (b) different qualitative criteria are used in two classifications; and (c) both classifications use quantitative criteria, but these criteria are different.

The most complicated situation is found if soil archetypes are different in different classifications; the situation occurs due to both historical reasons and the subjective opinion of classifiers. Sometimes old archetypes are broken apart in some classifications, and the borders between fragments differ in national classifications.

Difficulties exist with correlation of soils at different levels of a hierarchy, that is, if a soil group is recognized as an archetype in one classification (and appears on the generic level), and in the other it is not recognized as an archetype (and, thus, appears on the specific or varietal level). In the latter case the historically established archetypes are often divided between two or more archetypes.

Thus, correlation of soil names in different classifications cannot be regarded as a simple ‘translation’, and cannot be used, for example, for conversion of soil maps into another system of soil classification. In this case the primary field data should be used, and the profiles should be reclassified in the other classification.

6.5 Assessment of compatibility of selected national classifications with WRB

6.5.1 Austrian soil classification

Though certain harmonization was made with the WRB, the archetypes of the Austrian classification differ from those in the WRB. Special work was done on the correlation of steppe soils in the Austrian classification and the WRB (Nestroy 2001). The correspondence between the classes is in places very superficial, and may be misleading: for example, some Tschermer soils in Austria correlate with Kastanozems in the WRB and these soils form in completely different pedoenvironments. Some eroded steppe soils (Rump-Tschermosems) are formally classified as Calcisosols in the WRB system. We tried to avoid these analogies wherever possible. For the correlation, the soils are listed in the same sequence as in the text of the classification so as not to disturb the logical evolutionary sequence proposed by the authors. The correlation is provided down to the level of soil types.
6.5.2 French soil classification system

Many concepts and even qualitative characteristics of the French soil classification are close to those in WRB due to the same source of the two classifications. However, it is important to remember that WRB has strict limits for classes, whereas the limits in the French classification are fuzzy. Thus, even if the concept of soil groups appears to be identical in the two systems, in reality the extent of the group is larger in the Référentiel Pédologique. This report includes a correlation of references between the Référentiel Pédologique (AFES 1998) and WRB. The references are listed in alphabetical order, without noting great groups of the references.

6.5.3 German soil classification

In the following, a correlation will be given between the soil terms of the German classification down to the type level and the corresponding WRB terms. The soil names are listed in the same order as in the German classification. The translations of the terms of the German classification into English are derived from Wittmann (1997) with minor modifications. The German soil classification is difficult to correlate with WRB, since the two systems use different criteria for soil taxa designation. Some soil units seem to have similar definitions in the German classification and in WRB, but both their significance and the quantitative criteria are different. For example, for most shallow soils and for most surface horizons’ depths, the German system uses the limit of 30 cm, whereas WRB applies various, case-dependent criteria. The criteria for dystric and eutric subtypes in the German classification also differ from definitions of WRB. First, base saturation is a relatively insignificant criterion, used at the lowest levels of taxonomy, while in WRB it is one of the basic properties. Also, in Germany, base saturation is measured in the surface A horizon, while in WRB, the modifiers refer to base saturation at depths of more than 20 cm. The latest edition of the German classification (Ad-hoc-AG Boden 2005) contains a rough correlation with the first edition of WRB (FAO-ISRIC/ISSS, 1998). It is important to note that the correlations used in this book and in the text of the German classification are conceptually different: the text of the classification (Ad-hoc-AG Boden, 2005) tries to give all the intersections of the conceptual areas of the soil units in the two classifications. For example, the correlation of the type Ranker with WRB allows the following solutions:

- all Leptosols, except of Rendzic, Ardic, Gyspic and Calcaric Leptosols;
- if when Ah < 1 dm: Lithic Leptosols;
- in the presence of a mollic horizon: Mollic Leptosols;
- when having an umbric horizon: Umbric Leptosols;
- when having an ochric horizon with a base saturation < 50 per cent: Dystric Leptosols;
- with a base saturation > 50 per cent: Eutric Leptosols, also Gleyic, Hyperskeletic, Humic Leptosols;
- when Ah > 2.5 dm: Leptic Phaeozem, Leptic Umbrisol, Leptic Cambisol’.

In the present book we included only the correspondence of the ‘central images’ of the type to certain WRB units. For example, Rankers are mainly shallow soils with humus-enriched topsoils that correspond to Mollic or Umbric Leptosols. Though Rankers may be shallower, slightly deeper, or poorer in organic matter than Mollic or Umbric Leptosols, we list only these two units in the correlation.

6.5.4 Hungarian soil classification

The correlation between the Hungarian soil classification and WRB (IUSS Working Group WRB, 2006) is not very precise because the classes in the soil taxonomy of Hungary are mostly fuzzy (Michéli et al. 2006). The archetypes of soils are recognizable, and fit easily to certain WRB concepts, though their limits do not completely correspond. The correlation between soil names of the national soil classification and WRB is provided down to the type
level. The names of soil main types and types are listed in the same order as in their text of classification.

### 6.5.5 Polish soil classification

The correlation between the Polish soil classification and the World Reference Base for Soil Resources (WRB) is not too difficult because the main concepts of the two classifications are similar. Recent studies compared diagnostic criteria, horizons and properties of the two classifications (Charzyński et al. 2005; Charzyński 2006). The correlation of soil names is down to the type level. The names of soil groups and types are listed in the same order as in the text of the Polish classification (Polish Society of Soil Science, 1989). Polish words are used for the most part in the classification and in most cases a direct translation of soil names into English can be made, but some names borrowed mainly from folk terminology seemed to be stable terms (like Bielice – Polish soil name for Podzol). In that case no translation was made, or given in parentheses in italics. The mixture of languages in soil names may appear awkward (like acid brunatne soils or anthropogenic pararenzine); however, we favoured not to translate these terms. The same situation exists with some Russian soil names. For example, Chernozem would be translated as ‘black earth’, but this translation is not used because Chernozem is well-known. Some Polish terms are less known and difficult to pronounce for foreigners; they were omitted from the translation.

### 6.5.6 Russian soil classification 2004

Correlating soil classifications based on different basic principles is not an easy task; however, the central concepts of soil taxa are surprisingly close in the Russian classification and in the WRB. There is no correspondence for deeply ploughed soils. In the translation of the terms we followed the same rules as in the previous chapter. The word demnovy was translated as ‘humus’, not ‘sod’. The classification uses two synonyms for a relatively light-coloured surface humus-enriched horizon AY: demnovy and serogumusovy (‘grey-humus’), and both of them are used as formative elements for soil names. We used the term ‘greyhumus’ in all cases to avoid confusion. Only correlations of trunks, sections and types are provided. The classification has a complex hierarchical structure: thus, the types are presented in the order proposed by the authors of the classification. Post-lithogenic soils – a trunk of soils – bring together soils where soil formation processes occur on a previously formed parent material, and modern accumulation of matter on the surface is negligible (No identical units exist in WRB.) Texture differentiated soils – soil section ≈ Albeluvisols / Luvic Phaeozems / Planosols / Stagnosols / Luvisols.

### 6.5.7 United Kingdom soil classification

Correlation between the UK soil classification and WRB was relatively easy because its concepts and archetypes are clear and close to each other. However, the limits of classes differ, and one should be cautious with the correlation because certain overlapping between the groups occurs. Especially uncertain are the correlations of man-made soils; according to the British classification the concept is very general, while in WRB these groups are strictly defined. The correlation is given down to the level of the groups. Major groups and groups within major groups are listed alphabetically.

### 6.5.8 The United States Soil Taxonomy

Here we propose a correlation of the terminology used in the second edition of Soil Taxonomy (Soil Survey Staff, 1999) with the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2006). Unfortunately, the lack of space in this edition does not allow us to present correlation before the level of subgroups. We should stress that it is only correlation, an approximate correspondence: even in the cases when the WRB borrowed some diagnostic horizons or soil taxa from Soil Taxonomy, the quantitative criteria are in
most cases different. For example, Histosols are distinguished in Soil Taxonomy when the organic material depth is more than 40cm (>60cm if it is fibric material), and in the WRB this depth should be more than 50cm. Also the WRB is lacking the climatic criteria used for distinguishing suborders in most orders of Soil Taxonomy: that is why most of great groups in different suborders are correlated in the same WRB taxa.

6.5.9 Conclusions on review and analysis

Among all the existing classifications only three have worldwide coverage: the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2006), the USDA Soil Taxonomy (Soil Survey Staff, 1999) and the French soil classification (AFES, 1998). De facto, only the first two are used worldwide, and the French classification is only potentially suited for classifying world soils. The WRB was not designed as a full-fledged classification. Its declared objective was to serve as an ‘umbrella’ system for correlating national soil classifications. The European Union uses the WRB as an umbrella system for soil databases throughout Europe and assists in harmonization of new national soil classifications of the EU member states.

The geographical scope of most national soil classifications is limited to their national borders. Traditional soil classifications were designed mainly for agronomical purposes; however, currently society demands more environmental information. Thus, it is interesting to review what soils and soil-like superficial bodies are included in national classifications.

Only the WRB includes a full set of superficial objects, including technogenic substrates, bare rock and underwater sediments. Three soil classifications have almost complete coverage: the French, Austrian and Australian systems. The majority of classifications separate agricultural ‘man-made soils’ as a special group; some classifications, like the new Russian system, have a complex hierarchy for agricultural disturbance of soils. Technogenic substrates are recognized as soils in almost half of the national classifications and some countries (e.g. Germany and Russia) have separate classifications for technogenic substrates. In general, most recent classifications have a tendency to include substrates of urban and industrial areas in the scope of their systems. Shallow underwater sediments are regarded as soils only in Germany, Austria, Romania, Australia and Ghana. Even fewer countries, namely France, Austria and Ghana, classify consolidated rocks as soils, at least partly. As can be expected most countries are testing and evaluating various proposals to incorporate taxa strongly influenced by human activities, and consequently changes are likely to be forthcoming in many national classifications. Currently new research initiatives are underway to broaden the environmental scope of Earth sciences, thus pedology joins others to study the regolith and the vadose zone. Recently the European Union launched an initiative to study ‘whole soil-regolith pedology’ (Buol, 1994), now termed ‘Earth Critical Zone’ (ECZ), on a worldwide scale. The proponents desire a taxonomy that embraces soils, regolith and groundwater as an integrated natural body that supports life on Earth. Many parts of the ECZ are rapidly deteriorating due to increasing human impacts on nature, and for these reasons proponents of the ECZ want also to develop a new taxonomy of these combined natural resources.

The number of taxonomic levels in soil classifications, or the depth of classification (Holman, 1992) varies from two to eight. The least number of taxonomic levels is in classifications called reference bases, namely the WRB and the new French classification. Usually there are several unstated levels in reference bases. The French classification has an optional collective level. In the WRB, prefix and suffix qualifiers form two different hierarchical levels. The highest number of taxonomic levels is found in the classifications of Russia, Belorussia and the Czech Republic. The numbers of taxonomic levels and lower taxonomic units (individual soils) do not depend directly on the size of the country.
The number of taxa at a generic level generally corresponds to the size of the country and the state of the knowledge about its soils. The highest number is found in the US, a country with extensive and diverse territory and a high level of soil exploration. Russia, though bigger in territory, has fewer generic taxa because extensive northern territories of the country are still poorly studied. The low number of generic taxa in the WRB may seem strange because this system should cover the entire world. However, the paradox may be understood if one takes into account the historical reasons. The system was made initially as a map legend, and had to be simple. Thus it was artificially reduced, and many groups, in fact, represent collective units rather than different soils. The problem is that the generic level is difficult to find in a reference base system. All too often overlooked is the protocol to design a soil classification system. Of course it is assumed that the purpose of the scheme is known, as is the domain or population of interest, and the individuals that make up the diversity of the population. An assumed domain is all soils (however defined), so that is not numbered as a level in a hierarchy. Assuming further that three or four levels (categories) may be appropriate, the highest level is defined by an abstract statement about the population that will enable it to be divided into clusters whose properties are thought to be associated with the abstract definition. It has been accepted in modern soil science that environmental factor interactions influence processes in soils, resulting in rather specific morphological properties, thus sets of these features observed in soil profiles are evidence of major soil-forming processes, or of current dynamic processes influencing the morphology and/or behaviour of soil bodies. Each lower level then divides the taxa of the level above it into smaller more homogeneous groups, the definitions of which are less abstract (more specific) than the level above. This process continues to a level where the designers are satisfied that the soil information is sufficient to satisfy the purpose of the classification. For example, level 1 might be defined as soils with properties reflecting major soil-forming processes, and each class or taxa at that level would have soil properties thought to be associated with that definition. Level 2 might be defined as level 1 taxa soils with properties reflecting secondary processes of soil formation, and the selected properties for each taxa at this level would be associated with secondary features. Level 3 might be defined as level 2 taxa soils, the properties of which are thought to reveal overlapping or intergrading processes, and the properties for each taxa would be selected accordingly. Unfortunately the above rationale is seldom provided in soil classifications so we had to make assumptions about the definitions of the levels, then visualize the kinds of soil profiles that were being represented by each taxa, and on that basis try to make reasonable correlations with the taxa of the WRB as we understand them.

6.6 Adoption of the World Reference Base for Soil Resources (WRB)

6.6.1 Possibilities to adopt WRB for cross border harmonization of soil data

WRB was selected for correlating national classifications because it was initially constructed as a system for international correlation and is one of the most widely used classification systems for medium- and small-scale soil maps especially since the European Union accepted WRB as a basic system for soil mapping. WRB is now used throughout the world, theoretically including all the world soils, and the system is relatively simple, which is an advantage for correlation purposes.

Sometimes correlation is understood as a translation of the terms of different classifications, a kind of a dictionary, where every object in one classification has a direct analogy in the other. However, our previous experience with correlating soil classifications (Shoba, 2002) showed that direct analogies cannot be found. The main problems of soil correlations were summarized by Krasilnikov (2002); later Schad (2008) showed that not only different classifi-
cations, but even different versions of the same classification do not permit simple translation of soil names.

Direct soil terminology translation is often not possible, due to differences in diagnostics and in archetypes. Quantitative diagnostics relate to methods of measurement as well as the soil features being considered. Depth, thickness, chemical limits, colours and so forth result in overlaps between taxa of one system relative to another. The difference in diagnostics may result in the following: a soil taxon of a national classification is broader than a WRB group; a soil taxon of a national classification is narrower than a WRB group; or soil taxa of a national classification and the WRB classes only partially intersect. The difference in the limits of classes may be due to: (a) one classification uses fuzzy qualitative criteria, and the other uses quantitative criteria; (b) different qualitative criteria are used in two classifications; and (c) both classifications use quantitative criteria, but these criteria are different.

Different approaches to diagnostics of Podzols in WRB and in the Russian classification may illustrate the first case. The Russian ‘Podzol’ type seems to be broader, because only fuzzy morphological criteria (bleached horizon above iron and/or humus-enriched one) are used, whereas WRB requires certain depth and chemical requirements for a spodic horizon. However, some WRB Podzols are not within the Russian type ‘Podzol’, because in Russian classification, the soils with Fe, Al and humus illuviation, lacking a bleached superficial horizon, are included into other groups (Shishov et al, 2004). Thus, we have a partial intersection between WRB and the Russian ‘Podzol’ class. The other case is that different criteria are used for soil diagnostics. For example, Solonetzes soils both in WRB and in the older Russian classification (Egorov et al, 1977) were distinguished according to sodium content in the sodic (solonetzic) horizon. However, the new Russian classification (Shishov et al, 2004) uses the kinetics of soil swelling as the main criteria, because in southern Russia there are Solonetzes soils that do not meet the requirements for the sodium content; its physical properties are the same, but sodium has been washed out. In that case some of these Solonetzes soils correlate with the Solonetz group in WRB, but some should be correlated with Hyposodic Luvisols. The most striking example is the use of factors of soil formation as diagnostic criteria in some national classifications. Older Russian classification used terms such as ‘meadow’, ‘forest’ or ‘desert’ soil; these terms are difficult to correlate with WRB, which is based on profile properties only. The same is true for the US Soil Taxonomy, which uses temperature and water regime criteria at the highest level of hierarchy. It is impossible to reflect the difference between, for example, Usterts and Xererts, correlating them with WRB. The difference in quantitative criteria between classifications can be illustrated by an example of organic soils. Histosols in WRB, as well as peat soils in the new Russian classification, should have an organic horizon thicker than 50cm, whereas in the old Russian classification this limit was 30 cm, and in Soil Taxonomy 40 cm (60 cm for fibric material). Thus, the WRB Histosol group appears to be in some cases broader and in others narrower than Histosols according to US Soil Taxonomy. The problem is aggravated by the fact that some terms used in these classifications are similar, thus increasing misunderstanding.

The most complicated situation is found if soil archetypes are different in different classifications; the situation occurs due to both historical reasons and the subjective opinion of classifiers. Sometimes old archetypes are broken apart in some classifications, and the borders between fragments differ in national classifications. For example, ‘sod-podzolic soils’ in the Russian classification partially correspond to Albeluvisols in the WRB system, partially to Planosols, and partially to Albic Luvisols or even Alisols. It is not a problem of diagnostics: the classes in these classifications have different ‘central concepts’, and different definitions. Also, anthropogenic soils are difficult to correlate because human-transformed soils have not always been included in some classifications: the profiles of Technosols and Anthrosols (IUSS Working Group WRB, 2006), for example, can appear an Mollisols, Inceptisols or Enti-
sols in the US Soil Taxonomy (Soil Survey Staff, 1999). In some systems, urban soils, badlands and mine spoils are recognized as miscellaneous land types rather than as soil bodies.

Difficulties exist with the correlation of soils at different hierarchical levels, that is, if a soil group is recognized as an archetype in one classification (and appears on the generic level), and in the other it is not recognized as an archetype (and, thus, appears on the specific or varietal level). In the latter case, the historically established archetypes are often divided between two or more archetypes. For example, Terra Rossa soils in WRB (IUSS Working Group WRB, 2006) can be identified as Luvisols, Nitisols or Cambisols reference soil groups. Rendzinas are classified as Rendzic Leptosols and Rendzic Phaeozems, and Braunerde are particular cases of Cambisols or Umbrisols.

Thus, correlation of soil names in different classifications cannot be regarded as a simple ‘translation’, and cannot be used, for example, for conversion of soil maps into another system of soil classification. In this case the primary field data should be used, and the profiles should be re-classified in the other classification.

We consider that soil correlation has the main purpose of providing a general idea about the soils in unfamiliar classifications. For example, if we indicate that the central concept of Lou soils in China corresponds to Terric Anthrosols in WRB (instead of giving the whole definition used in the Chinese classification), it saves time and effort, and gives a reasonable idea of these soils although the diagnostic criteria are slightly different in the two classifications. We are trying to follow this main aim of soil correlation; consequently only one or two corresponding WRB names are suggested for taxa of national classifications, even though some intersect with other WRB classes. For example, the order Dermosols in the Australian soil classification (Isbell, 2002) includes various different soils, which may be correlated with up to seven WRB reference soil groups (Cambisols, Chernozems, Kastanozems, Phaeozems, Nitisols, Umbrisols and Durisols). However, we try to avoid such a broad correlation, which can mean that ‘everything correlates with everything’, and provide the major equivalents in the WRB.

6.6.2 Examples for the Polish soil classification

Lithogenic soils – soil section. ≈ Leptosols / Regosols / Arenosols
The section is divided into two orders:
Mineral weakly developed soils without carbonates ≈ Leptosols / Regosols / Arenosols

The following soil types are distinguished within the order:

- Undeveloped rock soils (litosol) ≈ Lithic Leptosols
- Undeveloped loose soils (regosole) ≈ Protic Arenosols / Regosols
- Undeveloped clay soils (pelosole) ≈ Regosols (Clayic)
- Soils originating from massive rocks without carbonates (rankery) ≈ Leptosols
- Weakly developed soils from loose rocks (arenosole) ≈ Arenosols

6.6.3 Examples for the Russian Soil Classification, 2004

Post-lithogenic soils – a trunk of soils – bringing together soils where soil formation processes occur on a previously formed parent material, and modern accumulation of matter on the surface is negligible. No identical units exist in WRB.
Texture differentiated soils – soil section ≈ Albeluvisols / Luvic Phaeozems / Planosols / Stagnosols / Luvisols

- podzolic soils – soil type. ≈ Albeluvisols
- gleyic podzolic soils – soil type. ≈ Gleyic Albeluvisols
- peat gleyic podzolic soils – soil type. ≈ Gleyic Histic Albeluvisols
- grey-humus podzolic soils – soil type. ≈ Umbric Albeluvisols
• grey-humus gleic podzolic soils – soil type. ≈ Gleyic Umbric Albeluvisols
• grey soils – soil type. ≈ Luvic Phaeozems (Albic)
• gleic grey soils – soil type. ≈ Luvic Gleyic Phaeozems (Albic)

6.6.4 Examples for the French Soil Classification System
Sols minéraux bruts – soil class, with three subclasses included.
Sols minéraux bruts non climatiques ≈ Arenosols / Fluvisols (Arenic) / Regosols (Skeletic, Arenic) / Technosols (Arenic)

There are six groups within the subclass:
• Sols minéraux bruts d’érosion ≈ Arenosols
• Sols minéraux bruts d’apport alluvial ≈ Fluvisols (Arenic)
• Sols minéraux bruts d’apport colluvial ≈ Regosols (Skeletic, Arenic)
• Sols minéraux bruts d’apport éolien ≈ Arenosols
• Sols minéraux bruts d’apport volcanique ≈ Arenosols (Tephric)
• Sols minéraux bruts anthropiques ≈ Technosols (Arenic)

6.6.5 Examples for the United States Soil Taxonomy
Alfisols – soil order ≈ Lixisols / Luvisols / Solonetz / Albeluvisols / Plianols / Stagnosols
Aqualfs – soil suborder ≈ Planosols / Stagnic Solonetz / Stagnosols / Luvisols / Albeluvisols

The following great groups are distinguished within the suborder:
• Albaqualfs ≈ Planosols (Albic)
• Cryaqualfs ≈ Gelic Planosols / Gelic Stagnosols
• Duraqualfs ≈ Planosols (Petrodric) / Stagnosols (Petrodric)
• Endoqaqualfs ≈ Gleyic Luvisols
• Epiaqualfs ≈ Haplic Stagnosols
• Fragaqualfs ≈ Planosols (Fragic) / Stagnosols (Fragic)
• Glossaqualfs ≈ Stagnic Albeluvisol
• Kandiaqualfs ≈ Planosols / Stagnosols / Stagnic Albeluvisols
• Natraqualfs ≈ Stagnic Solonetz
• Plintaqualfs ≈ Plinthic Planosols / Plinthic Stagnosols
• Vermaqualfs ≈ Planosols (Vermic) / Stagnosols (Vermic)

6.6.6 Examples for the German soil classification
Terrirische Böden (Terrestrial soils) – soil branch.
The branch is divided into the following classes:
O/C-Böden (O/C soils) – soil class. ≈ Folic Histosols / Leptosols

The following soil types are distinguished within the class:
• Fels humusboden (Rock-humus soil) ≈ Leptic Folic Histosol / Lithic Leptosol
• Skeletthumusboden (Skeletal humus soil) ≈ Hyperskeletic Folic Histosol / Hyperskeletic Leptosol

6.6.7 Examples for the Austrian soil classification system
Terrestrial Böden – soil order. (No equivalent in WRB at this level of generalization)
Terrestrial Rohböden – soil class. ≈ Arenosols / Regosols / Hyperskeletic Leptosols

The following soil types are distinguished within the class:
• Grobmaterial-Rohböden ≈ Arenosols / Hyperskeletic Leptosols
• Feinmaterial-Rohböden ≈ Regosols
6.6.8 Examples for the United Kingdom soil classification system

Brown soils – soil major group. = Cambisols / Luvisols / Arenosols
The following groups are distinguished within the major group:

- Argillic brown earths = Luvisols
- Brown alluvial soils = Fluvic Cambisols / Fluvisols
- Brown calcareous alluvial soils = Fluvic Cambisols (Calcaric)
- Brown calcareous earths = Cambisols (Calcaric)
- Brown calcareous sands = Brunic Arenosols (Calcaric)
- Brown earths (sensu stricto) = Cambisols
- Brown sands = Brunic Arenosols
- Paleo-argillic brown earths = Luvisols (Chromic)

6.6.9 Difficulties and issues jet to be solved

For further development of WRB classification it is reasonable to add some new prefixes and suffix qualifiers to explain the specific features of the national soil. Many of them were already added with new versions of WRB. The only correct way to use the WRB classification for further trans-national administration is classifying national soil under WRB classification.

In last time working group was formed under the auspices of the International Union of Soil Sciences to explore the development of a universal soil classification system (Golden et al., 2010). Therefore, with the efforts to adapt WRB classification to national classifications or adapting national classifications to WRB is better to wait to a new universal classification system.

6.6.10 Best practice guidelines for adaptation of national soil information to the WRB

The WRB was proven to be an effective means of international communication and correlation. In addition the WRB during the last decade has become a melting pot of soil classification ideas. A lot of interesting findings and concepts of national classification systems were absorbed by the WRB, and later, as feedback, were accepted by various national classification systems. Our experience in correlation was somewhat disappointing. The definitional, structural and diagnostic property differences for taxa in different classifications do not allow correlation of one taxon in a national classification with one taxon of the WRB. Many soil features considered to be important in national classifications are absent in the WRB. This can be easily improved by adding new modifiers to the WRB, but that does not solve the dilemma of correlating conceptually different classifications. For example, some classifications use landscape or moisture regime criteria which are not recognized by the WRB. We found this to be a deadlock as partial membership protocols and acceptance are not yet part of standard operating procedures. This attempt to correlate conceptually taxa from different systems may be considered an exercise in visualization that hopefully will open our eyes to the need for a rigorous universal basic system of soil classification.
7 Conclusions on review and analysis

There is a significant number of existing national soil maps available in Europe, from general, basic soil maps in various scales to thematic raster-based maps in different resolutions. D2.5 Part I reviews the existing data products reference material based on the compilation of meta information done under D2.3. Nevertheless, there is still a large proportion of insufficient documentation or limited accessibility. Therefore, it is very difficult to make a comprehensive review for all EU countries.

The methodologies used to elaborate soil maps are to a large extent country-specific. Soil data collection, mapping and processing is in general based on national methods, procedures and experience and practices. There are also a significant proportion of historic maps that still require digitization and inclusion into electronic national datasets. This report however describes several existing systems and practices in place such as EuDASM, as good practice standards in developing a common EU wide approach. Additionally big discrepancies in soil quality determination and awareness on what soil quality is/represents were detected. Based on good practice examples, the importance of defining a minimum soil quality indicator data was highlighted, presenting current systems in use with suggestion for a unified, additionally improved table of the most important soil quality data indicators. The differentiation according to the type of land use was also stressed as an important factor to be additionally considered. The soil quality information model was described using the GS Soil D4.2 (Generic Application Schema for Soil Information). The main approaches for data gaps and map applications were also reviewed; the main features and most used PTFs in Europe were described and their main weaknesses and strengths outlined.

With increasing demands for high resolution, comparable soil information, ready for interdisciplinary applications, the need for harmonised trans-border datasets is in rise. Significant efforts were already spent when establishing the European soil database. Another example for such a coordination effort is that of the FAO Guidelines for Soil Profile Description (4th Edition - 2006) which facilitates the comparable morphological description and documentation of a soil profile. In addition, a common reference terminology for soils already exists, the World Reference Base for Soil Resources (WRB), which also corresponds to the effort to achieve a common, harmonised soil classification. However, it is still questionable whether or how far historic data can be harmonized (e.g. existing soil profile descriptions using obsolete national vocabulary).

Based on the content reviewed, this Part I proposes further recommendations:

- to target a smaller, limited dataset of key soil profile parameters using the FAO guidelines; this set of core attributes will be sufficient in addressing most of the available methodologies for deriving knowledge from soil maps (pedotransfer functions),
- to apply the WRB classification. This process is well on its way however some countries are still well behind or haven’t even started the process yet,
- to jointly develop adequate PTFs, which are based on the specifications using FAO-coded profile parameters,
- to support the development of digital soil mapping methods as these enable derived and improved datasets.

These conclusions and recommendations will be taken up by Part II for formulating the Gs Soil Best Practice for the implementation of content-related rules.

The development of GIS technology, pedotransfer functions and other soil data processing algorithms enable advanced and more efficient soil data processing.
It offers better digital spatial information on major soil forming factors and helps to develop soil properties deriving techniques. Qualitative and quantitative spatial estimation of physical and chemical soil properties is becoming a promising technique to overcome missing data in the generally incompatible soil data sets in Europe. Since there is a great difference in the current practices for development of digital soil mapping between European countries, unification represents an important task for the future. Research activities and exchange of “know how” digital soil mapping techniques and data processing methods between countries (especially in EU) is extremely important and should be promoted.
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D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART I


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GS SOIL
Assessment and Strategic development of INSPIRE compliant Geodata-Services for European Soil Data

D2.5 Part II:
Best Practice Guidelines for Soil Data Interoperability
Summary of Part II

The analysis of existing reference documents and data sets in Europe (GS Soil D2.3 Soils Inventory and Theme Catalogue) has been analysed in Part I of this report, and was then further used to define a content framework for harmonized soil data in Europe. The main focus is on mid- to small-scale resolution soil typological maps, because this information is expected to mainly fall into the product categories to be provided under INSPIRE. The content framework is presented as best practice recommendations because following it allows the provision of harmonized soil information.

The analysis of soil data products and INSPIRE reference documents has demonstrated that full harmonization is very difficult, and that the requirements under INSPIRE towards semantic harmonization seem to be rather low (see also GS Soil D4.1, and also part I of this report). Therefore, the links between the INSPIRE interoperability components and harmonization was analysed first (Chapter 2), so that the minimum need for the definitions and best practice is identified first. In addition, the need for further recommendations about harmonization is derived from a very thorough analysis of existing reference literature (Chapter 3), and the heterogeneity of existing data sets and content definitions, such as soil classification (part I). it can be demonstrated that an extended level of content framework standards are already available for soil data, but the existing soil data deviate from this framework. Therefore, some new experiences with harmonization (e.g. applying WRB reference terminology to soil maps) is combined with an overview and synthesis of the existing content framework and harmonization methodologies in Europe (Chapter 4). This work is supplemented by applications of the best practice provided here, which are done in so-called test cases in work package 4.

On the basis of this report, the harmonization gaps between existing data sets and the content framework needed to develop a harmonized soil data base in Europe can be identified. The report therefore strongly supports activities of the European Soil Bureau Network in attempting the provision of harmonized soil data in Europe (see also Finke et al. 2001).
1. Introduction to GS Soil Best Practice

The analysis of INSPIRE documents for data specification development and the draft soil data specifications version 2.0 has shown that the understanding of interoperability and the technical and semantic harmonization requirements and transformation operations is still quite limited at the level of domain experts (e.g. soil mappers). At least some basic knowledge of informatics incl. web-GIS, OGC and data base development is needed in order to understand the INSPIRE process of data specifications development. However, in many domains, making theme-specific data available is a routine process only where information systems are being developed (Baritz et al. 20094). In some other cases, data are provided through central services (e.g. building a geodata infrastructure for all institutions’ data). In that case, the domain knowledge is not available at all in order to identify and implement transformations targeted to harmonize data sets.

While the technical framework of INSPIRE and ISO/OGC standards has been analysed it becomes important now to derive conclusions as to what kind of operations are needed to adapt data sets in its content. First, the question arises as to what kind of content-related issues are actually covered by INSPIRE. This would allow identifying a minimum level of harmonization needed to develop INSPIRE-conform data products. Secondly, the soil domain in Europe has already made some big process in developing harmonized soil information, and analysing and comparing the heterogeneity of existing data sets (especially high-resolution data sets). This has led to a common data product for Europe (the 1:1 Mio Geo-Referenced Soil Database of Europe), and a manual for developing a higher-resolution data set. This reference product and the reference manual for soil mapping provide key orientation for GS Soil, to further specify harmonization needs, and to provide best practice recommendations and methodologies for its implementation.

This part of D2.5 extends those findings of Work package 2 and part I, which are relevant for defining a framework for harmonized soil data in Europe. It further elaborates on those definitions which are needed (a) to assess the degree of harmonization of existing data sets, and (b) provides an overview on all issues needed to be considered in order to generate harmonization among existing data sets for web-based representation. In principle, this report is not intended to provide a framework for mapping new data, although the presented content definitions may also apply for new data.

First, the scope of interoperability under INSPIRE with regard to the content of soil data is investigated. Where interoperability touches semantic, content-related issues, data providers will be required to implement these requirements. The analysis of the INSPIRE data specification provides an understanding about the minimum level of harmonization, which must be achieved under INSPIRE. With regard to full harmonization, for example to produce a new European high-resolution data base 1:250,000, further content-related definitions are needed, and also provided here. This will give an overview about the challenges and possible tasks involved with harmonization of soil data in Europe.

**Best practice** is given with regard to the following issues:
- to identify and fulfil INSPIRE harmonization requirements,
- to identify operational criteria for full harmonization,
- to be conform to, and to implement existing content definitions for a harmonized soil map in Europe.

The recommendations will mostly build on common term definitions related to the development of harmonized soil data bases.

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D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II

2. Best practice implementation of interoperability criteria

2.1 INSPIRE interoperability and content definitions

According to INSPIRE, interoperability means "the possibility to combine spatial data and services from different sources across the European Community in a consistent way". The general interoperability criteria were initially defined acc. to INSPIRE D2.5: Generic Conceptual Model. The theme-specific data specifications are now available for Soil (Version 2.0). It includes a very specific set of soil parameters from plot data (point locations), soil basic maps as well as soil thematic maps. On that basis, interoperability is achieved mostly by technical export and presentation of data (web-based data exchange), with some semantic aspects such as parameter selection. Content in INSPIRE this mainly refers to the selection of parameters in a so-called core model, and further extensions related to use cases. As far as feature types are concerned, term definitions are provided as well (see also D2.5 part I, Ch 2). With regard to the harmonization of data (see also D4.1 Ch. 5.4 Conceptual Harmonization), no further specification details are given except recommendation such as using the international nomenclature and FAO-defined parameters for soil profile description. These recommendations are crucial for assessing harmonized data, and are being investigated in the GS SOIL test cases.

INSPIRE proposes a technical framework for exchanging data about so-called real world soil phenomena, which, for the purposes of INSPIRE, are: soil profiles, soil sites, soil plots, soil samples, soil delineated areas (determination based on certain soil characteristics), soil characteristics that change over time (allowing soil monitoring), soil contamination. An object model for the exchange of such data is presented, so that structured interoperability is achieved. Real-world soil phenomena fit quite well with the object model, with a hierarchy such as:

1. ped face
2. ped
3. horizon (horizon descriptive information)
4. profile (profile descriptive information)
5. profile plot or site (site descriptive information)
6. sample (could belong to any of the above features)
7. sub-sample (part of a sample, either taken in the field or during sample preparation in the laboratory)
8. sample extract
9. analysed attribute (belongs to sample, sub-sample or sample extract)

Currently, the need for higher resolution harmonized soil map and property data is discussed in Europe (refer to ESBN plenary protocols). There are several approaches which could provide such a data bases, for example digital soil mapping, the upscaling of measured soil profiles, and also the use of existing map and profile data. In case the latter approach will be taken, the harmonization of existing data sets will be important. GS SOIL content definitions may help to develop the frame conditions to achieve harmonized soil map data across Europe.

The content of soil maps is highly complex because it can usually only be explored and understood by experts. That is why the characteristics of mapping units are very often additionally interpreted for map users by the experts (e.g. in explanatory notes). The complexity also comes from the fact, that even in very high resolution maps, individual soils (within mapping units) are very difficult to identify in the field because of the high spatial variability. The soil mapper thus needs to be familiar with the dominating and key morphogenetic soil processes in a given mapping project or area. This kind of local expert knowledge allows the simplification of the complex reality by the means of soil terminology. Without such a terminology, the spatial dimension of soil bodies cannot be described and understood. Harmonization and
2.2 Introduction to INSPIRE interoperability components

The INSPIRE interoperability criteria were already reviewed and analysed in an earlier document D4.1. Figure 8 again presents these criteria. It was demonstrated that many of these criteria refer to technical aspects of data representation rather than semantic ones. While the technical aspects are already described in the INSPIRE draft data specifications for the theme soil, semantic aspects are omitted. It is therefore not clear, for example, how property data can be harmonized although much experience exists at the member state level. Such experience will be demonstrated in later chapters as well as in D4.3 (GS Soil test cases for harmonization).

![INSPIRE interoperability components](image)

Figure 8: INSPIRE interoperability components (see also D4.1)

“Even if data are harmonized according to very well defined rules, they rarely fit exactly for various reasons” (INSPIRE D2.5). Consistency deals with this problem. The complexity of harmonization increases once data from several themes are to be combined. However, the “understanding of the cross-theme relationships” is still very limited, and further investigations are needed. INSPIRE D2.5 provides some recommendations, which are helpful in approaching to harmonization:

- “conformance to data specifications including the data capturing rules”
- The conformance to “be checked only within the same or close levels of detail”
- This raise the question to the soil domain: are there defined levels of detail in soil maps? How about soil profile descriptions?
- In D2.5, it is further stated that an “interlinked and agreed vocabulary is needed”, and
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II

- “harmonisation of data specifications is the best way to promote consistency” between data sets. “Specific studies related to the use of ontologies in data specifications should be encouraged”.
- These statements demonstrate that many domain-specific interoperability and harmonization aspects are still unresolved. This can be compared to the open issue of data quality in the meta data topic area.
- If the harmonisation of application schemas becomes rather simple, the harmonisation of data capturing rules between data producers would be very useful. The better the data capturing rules are defined and followed, the smaller the inconsistencies. This may be true for new data, but the harmonization of existing data seems impossible, when looking at available experiences for the soil domain at the European level.

With regard to the definition of a content framework, D2.5 gives valuable advice: the harmonisation of data capturing rules is considered a complex issue for the following reasons:
- the rules (if they exist) often refer to under-defined concepts (the hidden “ontology”),
- the rules are often not fully described,
- the rules are not formally described (because the technical knowledge is missing),
- the cost of transforming the data according to new data capturing rules is far more expensive than the cost of transforming the data to a new application schema. However, it must be stated here, that schema transformation is a technical procedure, which does not (yet) include harmonization operations.

Taking these questions as support to address the domain-specific challenges to harmonization, then the question arises whether additional conceptual descriptions of data sets would help harmonization operations5, either at the level of the data provider or interactive transformation operations. This is impossible to achieve if a multilingual vocabulary is still missing. Such a vocabulary exceeds the concept of a thesaurus (e.g. for harmonizing key words as meta data) because it defines and compares the meaning of semantic terms. INSPIRE D2.5 explicitly mentions that “spatial data in INSPIRE will be slightly different from the original data of the provider.” This is because data transformations may involve modifications or adaptations of the data content in order to achieve consistency between two different data sets, for example along a country border.

In the following, the semantic issues identified in the INSPIRE process will be addressed first, before the domain-specific status quo is summarized (in terms of harmonization). On that basis, and together with the findings in part I and D4.3 (test cases), a content framework for European soil data can be developed. Such a framework can immediately be used to identify the options and challenges to improve existing data and to develop new (e.g. higher resolution) soil data sets in the near future.

2.3 Harmonization required by INSPIRE interoperability

2.3.1 Spatial objects in the INSPIRE normative framework

When studying the INSPIRE interoperability components, some conceptual definitions have to be discussed before the given standards-based concepts ISO 19000 series) are applied to the soil domain. The “identification of user requirements and spatial object types” is one of the steps required to develop data specifications (see also GS Soil D4.1, Ch. 4.2.2). the

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5 Such descriptions would exceed the core meta data elements, and include data capturing rules. This is exercised in the GS Soil WP4 test cases. The results will be presented in D4.3 (Data Harmonization Best Practice Guidelines).
identification of spatial objects is very closely related to the use case, for which soil information is needed.

The INSPIRE data specifications on soil identify a set of core objects, which represent the key soil world phenomena: soil profiles, sites, plots and samples and delineated areas. Two other “objects” are mentioned which represent the state and condition of soil objects and are not objects per se: soil characteristics which change over time (soil monitoring), and soil contamination.

The identification of spatial objects in soil maps may conceptually resemble “other objects” (e.g. geometrical or topological primitives), and cannot be considered as objects such as buildings or dams. Having understood this, then certain interoperability components such as multiple representation may not apply directly to soil objects, unless the uniqueness of object definitions is based on a reference terminology. Such a terminology would require agreement and acceptance among data providers. For example, a Europe-wide framework legend for small scale soil maps would represent such a terminology (and classification of objects), or well-defined reference soil groups valid for all of Europe (WRB as an accepted reference soil classification system). If such definitions of soil objects would be agreed upon, they would need to be identified and integrated into a soil data application schema. This is currently not the case, and quite in contrast to the Geology domain. There, on the basis of the One-Geology Europe project, an agreed and tested terminology is being introduced to the INSPIRE data specification.

Mapping units and soil profiles may be considered spatial objects in a broad sense, which are described by spatial object types, such as soil types. On the basis of available data, soil types in mapping units are defined differently among data providers and scale. Therefore, not only the definitions are variable, but also its content is not identical, for example, Cambisols (even if it is well-described by qualifiers) take different characteristics, which do not follow clear rules - so that the same soil type in different maps takes the same meaning and vice versa. INSPIRE D2.5 distinguishes objects which have well-defined boundaries, and other which depend on human cognition (Smith and Varzi, 2000, cited from INSPIRE D2.5).

2.3.2 Specific requirements to harmonization as identified by the interoperability components

The interoperability criteria provide the framework for the development of data specifications. They are very closely related to user requirements as to what kind of data need to be available for a certain domain, and what to do in order to make this information spatially fit that of data from other domains. The data specification for each INSPIRE theme therefore provides details (“specifications”) about so-called interoperability components. In the following, the interoperability components thus the draft data specifications for the theme soil are analysed with regard to requirements about harmonization. Technical aspects such as map projections, meta data, registers, multi-linguality are not covered here.

Knowing about the harmonization requirements under INSPIRE provides the following information for the user of this best practice guideline:

- judgement about the necessary working steps to modify existing data, or to adapt the data capturing in the case of new products, in order to provide interoperable data according to INSPIRE, as compared to providing fully harmonized data in Europe

- understanding of the content definitions which need to be addressed when developing harmonized data sets
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⇒ The main objective of the INSPIRE data specifications is structural interoperability for selected objects and attributes describing their state (see also D2.8.III.3_v2.0). The following sub-sections will address harmonization for each of the interoperability criteria.

⇒ Interoperability components with purely technical requirements are not further discussed here: INSPIRE principles (a), reference model (c), spatial and temporal aspects (e), multi-lingual text (f), coordinate referencing and units model (g), object referencing modelling (h), portrayal\(^7\) (k), registers (l), maintenance (n), conformance\(^8\) (t). These rather technical aspects of interoperability are not further considered in the following analysis about harmonization requirements under INSPIRE.

[alphabetical letters are used to sort the interoperability components acc. to Figure 1]

(B) Terminology

The Generic Conceptual Model of INSPIRE recommends the building of a glossary which explain all relevant theme-specific terms and definitions. With regard to the Data specifications on soil, this information is to a large degree received by the narrative description of the application schema, and definitions provided for all feature types.

With regard to feature type SoilType, it is recommended to use WRB as a classification scheme in order to promote interoperability (INSPIRE data specifications for soil, 5.2 Application schema soil core model, narrative description). It is up to the data provider whether WRBSoilType can be provided or not.

The INSPIRE data specifications for soil stress the importance of “derived soil profiles” in the building of soil map databases. One or several derived soil profiles represent a soil typological unit, which is not physically delineated. Such derived soil profiles can be very simple, for example on consist of few topsoil characteristics including a soil name.

It was shown in the GS Soil test cases, and concluded from the WP2 analysis of existing data sets, that the building of soil map legends is very complex and greatly differs between soil maps. The only structure-giving elements in INSPIRE are the following:

- hierarchy of soil complexes depending on scale and resolution
- dominant and co-dominant (or associated) soils are presented as different soil typological units, each soil represented as a derived soil profile
- the feature type “soil region” must be mapped as a “soilcomplex”
- parent material as an important element of many soil map legends is not further specified except at the level of layers and horizons (e.g. layerRockType)

Other than these alternatives, complex soil legends can only be described using the soilComplexLabel attribute (no language requirement, i.e. national language can be used).

---


\(^{7}\) Rules for visualizing the boundaries and content (e.g. soilComplexLabel) of soil complexes

\(^{8}\) Conformance reports the consistence to data specifications through metadata. It includes, for example, information about the operations conducted to transform a data set from source to target specifications.
Box: SoilComplex (INSPIRE) vs. soil mapping unit

The term soil complex is a real-world concept in many soil mapping systems. It is a repeating pattern of soil types in a landscape, e.g. drumlin fields which have different hydrological characteristics that depend on topographic position or soils on terraced lava flow topography. The patterns are often a result of geologic processes at the landscape scale, rather than pedogenic processes alone. A soil mapping unit may contain more than one real-world soil complex, depending on scale. These patterns were termed „land systems“ in the 60’s and within the systems were „facets“ and „elements“. SoilComplex as used in INSPIRE replaces the term soil mapping unit although it may rather be a sub-type of soil mapping units.

(D) Rules for application schemas and feature catalogues

The development of an application schema for any domain is described in Application schemas define the structure of the data (feature types9, attributes etc.). The following table provides examples of generic semantic aspects involved with the development of an application schema:

<table>
<thead>
<tr>
<th>Semantic aspects</th>
<th>Example</th>
<th>Reference literature</th>
</tr>
</thead>
</table>
| referencing between map units and soil profiles | one soil profile ("DerivedSoilProfile") represents the dominant soil within a mapping unit | - Instructions guide soil map 1:1Mio (Lambert et al. 2003)  
- SOTER manual (FAO 1993) |
| stratification of soil maps             | soil regions are often used to stratify mapping units (to allow hierarchical aggregation of diverse mapping units throughout Europe) | Finke et al. (2001) to be mapped as “SoilComplex” |
| core feature types of soil profiles in soil map data bases | any soil profile can be described by layers ("topsoil", “subsoil”, “depthInterval”) or horizons | toposoil and subsoil characteristics can describe soil typological units (Lambert et al. 2003) or soil bodies (Finke et al. 2001), thus represent a simplified soil profile, even though morphological profile parameters may be missing (such as attribute data in the European soil data base) |

(I) Identifier for spatial objects/identifier management

The generic conceptual model includes the criteria for interoperability. The model is built on the idea that a spatial object is clearly identified, and that users are searching for the distribution and characteristics of spatial objects. According to INSPIRE D2.5, each spatial object carries a unique identifier (spatial objects = feature types). The following requirements for unique identifiers (2 elements: registered namespaces, and local identifiers) are stated:

<table>
<thead>
<tr>
<th>Uniqueness</th>
<th>only one identifier for a unique spatial object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistence</td>
<td>identifier shall not be changed during the life-time of an object</td>
</tr>
<tr>
<td>Traceability</td>
<td>a spatial object must be found based on its identifier</td>
</tr>
<tr>
<td>Feasibility</td>
<td>identifiers under existing national identifier systems can be mapped</td>
</tr>
</tbody>
</table>

9 “Feature type” is equivalent to “object type”
The definitions of identifiers and the management of identifier for harmonized data sets have not been addressed so far in any domain-specific document. At this point, no consequences for harmonization methodologies result from this interoperability component, unless the specifications of a harmonized data product become identified and agreed upon.

(J) Data transformation

Because INSPIRE focuses on data distributed via web services, this topic mainly focuses on technical operations transforming data between a local data storage system into an exchange “format” (structured XML; so-called schema transformation). However, this cannot be done without good knowledge of the source data. The definitions of the object types, its attributes and relationships need to be investigated and compared with that of the target schema (e.g. the INSPIRE soil schema, or the recently drafted ISO 28258 SoilML exchange format). While an agreed, technical data exchange format is the core element needed to exchange interoperable data, other elements (- interoperability criteria) are important as well: adaptations of the portrayal, meta data extensions, edge matching, provision of code lists. These elements – at least currently – cannot be conducted on-the-fly – but need to be addressed by the data owner/provider. Except for the transformation of data into the target coordinate referencing system, all other transformations require information and knowledge about the data.

(M) Metadata

The current metadata profile is not sufficient in order to allow the transformation of data to a harmonized level independent of the knowledge of the data provider (e.g. based on transformation services). Therefore, most of the INSPIRE interoperability components are being dealt with more at a technical rather than at the semantic level, and thus do not lead to fully harmonized data sets. In-depth semantic harmonization is currently fully addressed only at the level of the data provider - and is voluntary. The specifications of existing reference material (such as Finke et al. 2001, Manual of Procedures for mapping 1:250,000) were not sufficient in order to be widely applied.

GS Soil is addressing this deficit in the metadata profile and harmonization among existing data sets with the following activities/products:

- GS Soil WP3 Thesaurus
- GS Soil WP4 Reference terminology, WP4 test cases: testing common FAO terminology for soil profile description and classification
- GS Soil WP2 Good practice guidance (to be finalized on the basis of the results of the WP4 test cases)

Therefore, GS Soil extends the INSPIRE framework by looking at the requirements to fully harmonise soil data sets.

(O) Data quality

The criteria for data quality are defined in standards of the ISO 19100 series. This includes the items completeness and consistency. The examples provided in the draft INSPIRE soil data specification include:

- the number of observedSoilProfiles which characterize a derivedSoilProfile (Completeness – Commission)
- missing data with regard to SoilProfile, ProfileElement, Soilcomplex, e.g. area not represented by a derivedSoilProfile (Completeness – Omission).
- Overlapping geometries (Logical consistency - Topological consistency)
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- Count of items which do not add up to the representation as expected (Logical consistency - Domain consistency)

From a domain point-of-view, the approach to data quality requires further elaboration. This has not been done yet, and will certainly require (a) background information about the development procedures of data products (mapping methodology and data base), and (b) evaluation criteria (e.g. representativity with regard to a target resolution of a soil map, for example)

(Q) Data consistency

"Ensuring data consistency between themes and between levels of detail raises the problem of geometrical deformations: forcing data consistency lay on geometrical changes." This issue relates to the harmonization of geometries. Annex B of D2.6 (Methodology for the development of data specifications 2008) provides extensive advice on geometric adaptations. It refers to "connections between spatial objects at international boundaries (i.e. edgematch-ing)". In addition, approaches to deal with vector data differ somewhat from raster data. The vector-oriented procedure requires that the content of the geometries and the rules of its delineation are known, so that corrections can be addressed. This shows that consistency involves semantics, such as "spatial objects" which have the same code or same name. Data specifications about the theme soil, including a somewhat agreed terminology, must ensure that soil map units, e.g. the dominating soil types, the meaning of scale and soil association, are comparable between two countries (there are such issues between different national data sets, such as between regions). However, it is known, that the required data on semantics are (at least currently, and for existing digital products), unavailable. This is partly because existing soil map data are derived from (historic) printed maps, produced by an incredibly large number of soil mappers across Europe, e.g. 31 soil mappers operated in Scotland between 1934 and 2011.

(R) Multiple representation

Does this criterion only relate to maps (e.g. of different scale) which represent the same area? Or does it include the issue of neighbouring maps representing similar real-world soil types or soil complexes along their borders? Which information (or content definition) is required so that data users can judge whether the same real-word spatial object is represented by two maps meeting along a country border (e.g. both contain a soil mapping unit with the same soil type, representing similar physio-geographic conditions, but using different scales). Harmonization in both cases leads to agreed definitions of soil mapping units along borders. When adjoining maps are completed by different soil surveyors at different times and local soil mapping concepts have evolved in the interim period, the same real-world soils or repeating patterns of soils may be represented by different mapping units, giving artificial boundaries at or near to the edges of the adjoining maps.

(S) Data capturing

Data capturing rules are the main element to define the targeted level of detail in mapping (understood as a procedure to describe real world phenomena). Figure 9 below provides an idea about levels of detail. However, they are not defined clearly enough so that different data sets with the same nominal scale meet with its content and geometric resolution. At the European level, soil maps at scale about 1:1Mio are considered continental- and national-level, while scales of about 1:200,000 and 1:50,000 dominate the regional level, while 1:10000 and larger represents the local level (connects to the management unit level). It becomes obvious that the soil information exchanged under INSPIRE will be very different considering the wealth of products and data sources in Europe. Existing differences are mainly a result of different capturing rules / selection criteria for the different both levels of detail.
Currently, no data capturing recommendations are given or cited in the INSPIRE soil data specification version 2.0. This could be, for example, the definition of typical selection criteria (e.g. minimum area or functional characteristics such as a WRB reference soil group, applied to soil bodies\(^\text{10}\)).

### 2.4 Conclusion about harmonization in INSPIRE-soil

INSPIRE clearly states the technical requirements for interoperability. The core domain semantics are mainly focused on a specific set of common and typical feature types and its relationships, which is currently under testing. A second semantic requirement refers to the content of data: in front of selected use cases and European environmental policies, a limited set of soil attribute data was selected from the most common feature types. Beyond these two main pillars of the soil data specifications, no further precise harmonization requirements are provided. Only recommendations are given, e.g. regarding (classified) soil types. There are no definitions of scale, nor is there guidance for the building of legends (pre-requisite to agree on a specific content for GetFeatureInfo).

It has to be stated that such an approach to harmonization has been implemented in the Soil Geo referenced Database of Europe 1:1Mio. However, the methodologies to transform national soil maps according to the requirements of a Europe-wide data set are not documented, nor are the source maps and its quality clearly stated.

\(^{10}\) see also “Reference Terminology” (GS Soil D4.3)
3. Definitions, guidelines and standards

In relation to Part I, this chapter extracts and highlights those existing content definitions, which are important elements of the content framework for harmonized soil information in Europe. It will be demonstrated that the European soil domain can already build on well-elaborated terms and concepts. Existing national and regional systems generally operate in a basic content framework (soil mapping units representing soil associations, derived soil profiles). However, the resolution of the delineation, mapping purpose, amount of field work, stratification applied if any, as well as soil classification often substantially differ between countries. Therefore, existing data are usually not harmonized and lack comparability despite the existing content framework.

3.1 Harmonization history regarding map database building in Europe

There is an existing history in Europe regarding the building of a common European data soil base. For that purpose, the EC has created the European Soil Bureau Network (ESBN) in 1996. The ESBN is a network of national soil science institutions with the objective to collect and harmonise (and distribute) soil data which can be used to support European environmental policies. Two basic reference materials were produced which provide the framework for producing soil maps (this information is also provided in the INSPIRE D2.3 Definition of Annex Themes and Scope):

|---|---|

Since the beginning of the ESBN activities, the European soil geographical database (King et al. 1995) has been continuously developed. In addition, a soil profile analytical database has been compiled (Madsen, 1991, Madsen and Jones, 1995), and a pedotransfer rule database developed (King et al., 1994; van Ranst et al., 1995). Recently, this set of evaluation functions has been applied to the European soil map, and thematic maps were derived which present parameters not available as representative measured information. These thematic maps are made available as 1 km raster data sets.

The Soil Geographical Data Base of Europe at scale 1:1,000,000 is currently available as version 3.2.8.0 (SGDBE), and the Pedotransfer Rules Data Base as version 2.0 (PTRDB). At the moment, the Soil Geographical Database of Europe (SGDBE) is being extended to version 4.0 (Soil Geographical Database of Eurasia and the Mediterranean at scale 1:1Mio - which is not yet publically available). It now covers also Iceland and the New Independent States (NIS) of Belarus, Moldova, the Russian Federation and Ukraine and Turkey. In addition, the parent material list developed by ESB (1998) has been added, as well as WRB (Lambert et al. 2003).
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The Soil Profile Analytical Database is currently available as version 2.1.0.0. The database accompanies the SGDBE. Currently, one single representative soil profile is available for the dominant STU, compiled as the SPADE-1 database. The soil profile can be either described (or estimated from a range of profiles representing the dominating soil of a given soil landscape or soil association (soil mapping unit), or measured. In the case it is “measured”, the profile represents one single, typical sampled and analysed soil profile. For the compilation of this data, two formats were used: Proforma I for the estimated data, and Proforma II for the measured data (MADSEN and JONES 1995). SPADE-1 contains 447 estimated soil profiles, of which 240 are linked to STUs. Given the number of STUs for EU-15 (N = 3,164), only 8% of the STUs are represented with soil profiles. In order to improve the data situation of the SGDBE, an additional SPADE campaign was conducted (SPADE-2). It focused on primary soil attribute data, including particle size analyses, organic carbon, pH, bulk density. It was provided by 10 European countries only. However, a harmonization of the textural values was conducted using a spline interpolation method (Hollis et al. 2006). SPADE-2 contains 1,897 complete soil profiles, which are linked to 1,077 STUs (35% of EU-15) (see also HIEDERER et al. 2006).

A substantial effort has been invested into the European soil database, which has lasted more than 20 years, and which has provided representative geometries and core attribute data for topsoils and subsoils (so that basic applications can be applied to the European soils). However, referring to all of Europe, less than a quarter of the area is represented by typical and harmonized soil profiles (see also below under “Quality of existing European soil maps”).

With regard to the mapping scale 1:250,000, a separate manual for soil mapping has been developed by the European Soil Bureau Network. This manual builds on experiences with the SGDBE, and further refines the content framework for higher resolution soil mapping. It thus introduces soil bodies and soil scapes, which are both being used synonymously with soil mapping unit and soil typological unit, respectively. In addition, soil regions are used to aggregate complex legend, and to differentiate more clearly soils, which may have the same name, but have different properties and/or differently associated soil when being in different soil regions. Climate areas are part of that concept.

An EU-wide agreed definition of a hierarchy of geographical scales at which soil maps are (to be) produced (from large up to small scales) is desirable with consistent and comprehensible designators (names) for the geographically explicitly displayed objects (soil region, soilscape, soil association, etc.). This is not the case yet, although the nested system developed by the European Soil Bureau Network (ESBN) provides the framework for such an aggregation scheme. Scale-specific definitions of the hierarchical levels still need to be developed. Figure 1 presents the most common terms currently in use in soil mapping, and clearly assigns each term a clear and unambiguous position in a mapping concept. Such terms were not yet clearly defined for Europe, so that the GS Soil reference terminology (WP4) is expected to fill that gap, and thus providing sufficient understanding for further refining the content framework for Europe.
Example for content definitions

Soil mapping concept: aggregation of soil map (legend) units

Figure 9: Hierarchy of soil mapping concepts
See also http://eusols.jrc.ec.europa.eu/esbn/EUSIS.html

Figure 9 present the concept for building a soil information system based on a nested system of integrated maps. This concept was also realized in the design of the European Soil Information System (EUSIS). It distinguishes three different levels of precision: small study areas, 1:250,000 scale and 1:1,000,000 scale. Finke et al. (2001) also state that numerical scale-transfer functions will be developed for linking the different levels of detail in order to fully integrate the data bases.

3.2 Existing definitions and standards for soil mapping

3.2.1 Content definitions of the Soil Geographical Database of Europe 1:1Mio

The data base consists of two main elements, soil mapping units (SMU) and soil typological unit (STU). STU characterize distinct soil types which have been identified on the basis of national soil maps, Each STU is described by attributes which specify soil properties. The information is derived from soil profiles, but became aggregated to represent the topsoil and subsoil. There is no typical depth defined. STUs are not delineated. One to several STUs represent a soil mapping unit (SMU), which has defined borders.

A detailed revised instruction manual for the compilation of data for the Soil Geographical Database of Europe version 4.0 has been published by Lambert et al. (2003). It includes rules for mapping further developing the 1:1Mio. European soil database, and substantially extends the attributes currently defined in the SGDBE version 3.2.8.0. These changes have also led to updating the existing term dictionary (file DICTIONA.TXT, supplementing the published CD version). Table 12 presents the parameters as contained in the two latest version of the SGDBE.
Table 12: Attributes of STU 1:1Mio (SGDBE)

<table>
<thead>
<tr>
<th>Version 3.2.8.0</th>
<th>Attributes</th>
<th>Version 4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMU</td>
<td>Soil Mapping Unit identifier</td>
<td>SMU</td>
</tr>
<tr>
<td>STU</td>
<td>Soil Typological Unit identifier</td>
<td>STU</td>
</tr>
<tr>
<td>NB-POLYS</td>
<td>Number of polygons containing STU</td>
<td></td>
</tr>
<tr>
<td>NB-SMU</td>
<td>Number of SMUs containing STU as computed</td>
<td></td>
</tr>
<tr>
<td>AREA</td>
<td>Area of STU (in square kilometres) as computed</td>
<td>PCAREA</td>
</tr>
<tr>
<td>SOIL</td>
<td>Full 1974 (modified CEC 1985) FAO-Unesco legend soil name</td>
<td></td>
</tr>
<tr>
<td>SOIL90</td>
<td>Full 1990 FAO-UNESCO legend soil name</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil group of WRB</td>
<td>WRB-GRP</td>
</tr>
<tr>
<td></td>
<td>Soil adjective code of WRB</td>
<td>WRB-ADJ</td>
</tr>
<tr>
<td></td>
<td>Complementary code of WRB</td>
<td>WRB-SPR</td>
</tr>
<tr>
<td>TEXT1</td>
<td>Dominant surface textural class</td>
<td>TEXT-SRF-DOM</td>
</tr>
<tr>
<td>TEXT2</td>
<td>Secondary surface textural class</td>
<td>TEXT-SRF-SEC</td>
</tr>
<tr>
<td>SLOPE1</td>
<td>Dominant slope class</td>
<td>SLOPE-DOM</td>
</tr>
<tr>
<td>SLOPE2</td>
<td>Secondary slope class</td>
<td>SLOPE-SEC</td>
</tr>
<tr>
<td>AGLIM1</td>
<td>Dominant limitation to agricultural use</td>
<td>AGLIM1</td>
</tr>
<tr>
<td>AGLIM2</td>
<td>Secondary limitation to agricultural use</td>
<td>AGLIM2</td>
</tr>
<tr>
<td>MAT1</td>
<td>Dominant parent material code</td>
<td>PAR_MAT_DOM</td>
</tr>
<tr>
<td>MAT2</td>
<td>Secondary parent material code</td>
<td>PAR_MAT_SEC</td>
</tr>
<tr>
<td>ZMIN</td>
<td>Minimum above sea level altitude (in metres)</td>
<td>ZMIN</td>
</tr>
<tr>
<td>ZMAX</td>
<td>Maximum above sea level altitude (in metres)</td>
<td>ZMAX</td>
</tr>
<tr>
<td>USE1</td>
<td>Dominant land use</td>
<td>USE-DOM</td>
</tr>
<tr>
<td>USE2</td>
<td>Secondary land use</td>
<td>USE-SEC</td>
</tr>
<tr>
<td>DT</td>
<td>Depth class to textural change</td>
<td>TEXT-DEP-CHG</td>
</tr>
<tr>
<td>TD1</td>
<td>Dominant sub-surface textural class</td>
<td>TEXT-SUB-DOM</td>
</tr>
<tr>
<td>TD2</td>
<td>Secondary sub-surface textural class</td>
<td>TEXT-SUB-DOM</td>
</tr>
<tr>
<td>ROO</td>
<td>Depth class of an obstacle to roots</td>
<td>ROO</td>
</tr>
<tr>
<td>IL</td>
<td>Presence of an impermeable layer within the soil profile</td>
<td>IL</td>
</tr>
<tr>
<td>WR</td>
<td>Dominant annual average soil water regime class of the soil profile</td>
<td>WR</td>
</tr>
<tr>
<td>WM1</td>
<td>Normal presence of a water management system in agricultural land (on &gt; 50% STU)</td>
<td>WM1</td>
</tr>
<tr>
<td>WM2</td>
<td>Purpose of the water management system</td>
<td>WM2</td>
</tr>
<tr>
<td>WM3</td>
<td>Evident type of water management system</td>
<td></td>
</tr>
<tr>
<td>CFL</td>
<td>Global confidence level of the Soil Typological Unit attributes description</td>
<td>CFL</td>
</tr>
<tr>
<td>SOIL1</td>
<td>First level 1974 (modified CEC 1985) FAO legend soil name</td>
<td>Soil major group (1990 FAO-UNESCO soil revised legend)</td>
</tr>
<tr>
<td>SOIL2</td>
<td>Second level 1974 (modified CEC 1985) FAO legend soil name</td>
<td>Soil unit code (1990 FAO-UNESCO soil revised legend)</td>
</tr>
<tr>
<td>SOIL3</td>
<td>Third level 1974 (modified CEC 1985) FAO legend soil name</td>
<td>Soil sub-unit code (1990 FAO-UNESCO soil revised legend)</td>
</tr>
<tr>
<td>SN1</td>
<td>First character in item SOIL (meant for PTR)</td>
<td></td>
</tr>
<tr>
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<td>Second character in item SOIL (meant for PTR)</td>
<td></td>
</tr>
<tr>
<td>SN3</td>
<td>Third character in item SOIL (meant for PTR)</td>
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<td>SOIL901</td>
<td>First level 1990 FAO legend soil name</td>
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<td>SOIL902</td>
<td>Second level 1990 FAO legend soil name</td>
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<td>MAT11</td>
<td>First level dominant parent material code</td>
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</tr>
<tr>
<td>MAT12</td>
<td>Second level dominant parent material code</td>
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</tr>
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<td>First character in item MAT1 (meant for PTR)</td>
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</tr>
<tr>
<td>PM12</td>
<td>Second character in item MAT1 (meant for PTR)</td>
<td></td>
</tr>
<tr>
<td>PM13</td>
<td>Third character in item MAT1 (meant for PTR)</td>
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<tr>
<td>MAT21</td>
<td>First level secondary parent material code</td>
<td></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>MAT22</th>
<th>Second level secondary parent material code</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM21</td>
<td>First character in item MAT2 (meant for PTR)</td>
</tr>
<tr>
<td>PM22</td>
<td>Second character in item MAT2 (meant for PRT)</td>
</tr>
<tr>
<td>PM23</td>
<td>Third character in item MAT2 (meant for PTR)</td>
</tr>
</tbody>
</table>

All parameters of the data base are coded acc. to:

**ATTRIBUTE CODING FOR THE SOIL GEOGRAPHICAL DATA BASE OF EUROPE AT SCALE 1:1,000,000 VERSION 3.2.8.0, 19/07/1999**

(the document is attached to the digital version of the Soil Geographical Database of Europe)

In the following, those parameters are discussed which contain content definitions. It is then up to the data provider to develop methods which allow the correlation between national definitions and those defined in the European soil data base. In fact, this is also the reason why many European countries have experience with the transformation of data according to agreed rules. Unfortunately, the limited funding and strict IPR rules have prevented a higher degree of harmonization and data availability within the soil domain in Europe.

### 3.2.1.1 Limitation to agricultural use

**Table 13: Content definitions for the parameter “Limitation to agricultural use”**

<table>
<thead>
<tr>
<th>Gravelly</th>
<th>over 35% gravel diameter &lt; 7.5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stony</td>
<td>presence of stones diameter &gt; 7.5 cm, impracticable mechanisation</td>
</tr>
<tr>
<td>Lithic</td>
<td>coherent and hard rock within 50 cm</td>
</tr>
<tr>
<td>Concretionary</td>
<td>over 35% concretions diameter &lt; 7.5 cm near the surface</td>
</tr>
<tr>
<td>Petrocalcic</td>
<td>cemented or indurated calcic horizon within 100 cm</td>
</tr>
<tr>
<td>Saline</td>
<td>electric conductivity &gt; 4 mS.cm⁻¹ within 100 cm</td>
</tr>
<tr>
<td>Sodic</td>
<td>Na/T &gt; 6% within 100 cm</td>
</tr>
<tr>
<td>Glaciers and snow-caps</td>
<td>i.e. landfills, paved surfaces, nine spoils)¹</td>
</tr>
<tr>
<td>Soils disturbed by man</td>
<td>no further definition</td>
</tr>
<tr>
<td>Fragile</td>
<td>no further definition (now ‘Fragipan’²)</td>
</tr>
<tr>
<td>Drained</td>
<td>no further definition (now ‘Excessively drained’³)</td>
</tr>
<tr>
<td>Quasi permanently flooded</td>
<td>no further definition</td>
</tr>
<tr>
<td>Eroded phase, erosion</td>
<td>no further definition</td>
</tr>
<tr>
<td>Phreatic phase</td>
<td>shallow water table⁴</td>
</tr>
<tr>
<td>Duripan⁴</td>
<td>silica and iron cemented subsoil horizon⁴</td>
</tr>
<tr>
<td>Petroferric horizon⁴</td>
<td>no further definition</td>
</tr>
<tr>
<td>Permafrost⁴</td>
<td>no further definition</td>
</tr>
</tbody>
</table>

¹ Revised/introduced by Lambert et al. (2003)

⇒ Even though some definitions are not provided (in the case of lacking definitions, its meaning might be obvious), it seems that the content definitions provided allow easy application to national datasets. However, when looking at the 1:1Mio data set in depth, systematic errors, data lacks etc. can be observed along some country borders. It may be advisable to provide revised transparent and unambiguous definitions. More importantly, these definitions must be coordinated with WRB definitions, so that this parameter can be more easily derived from existing soil profile descriptions.
3.2.1.2 Parent material

The lithological units of the parent material list are not defined. A revision of the FAO parent material list has been recently developed, and a comparison has been made with regard to the parent material list of the European soil database (Schuler et al. 2011). This revision includes lithological definitions of the parent rock. Supposingly, it will substitute the existing parent material list of Finke et al. (2001). Because the terminology is coordinated with geologists, the data from geological maps can be clearly interpreted for application in soil mapping.

3.2.1.3 Slope

There are no specifications for slope at the level of the soil typological unit. It does not relate to the local slope at the position of a typical soil within the continuous soil landscape, it refers to the average meso-scale slope of the terrain of an assumed soil typological unit (which is not delineated during the development of the data base). In the case that national data provide classified parameters without the original values, a re-classification to the required slope classes may be difficult (see also GS Soil D4.3 for details).

Table 14: Content definitions for the parameter “Slope”

<table>
<thead>
<tr>
<th>Level</th>
<th>Dominant slope ranging from 0 to 8 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sloping</td>
<td>Dominant slope ranging from 8 to 15 %</td>
</tr>
<tr>
<td>Moderately steep</td>
<td>Dominant slope ranging from 15 to 25 %</td>
</tr>
<tr>
<td>Steep</td>
<td>Dominant slope over 25 %</td>
</tr>
</tbody>
</table>

3.2.1.4 Texture

Soil texture is one of the most important soil parameters required to further derive important soil quality parameters (see also this D2.5 Part I). Its harmonized assessment is rather complicated because the texture triangles differ quite widely throughout Europe. The requirements and experiences in applying the content definition for texture is covered in D4.3.

Table 15: Content definitions for the parameter “Texture”

<table>
<thead>
<tr>
<th>Coarse</th>
<th>Clay &lt; 18 % and sand &gt; 65 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>18% &lt; clay &lt; 35% and sand &gt; 15%, or clay &lt; 18% and 15% &lt; sand &lt; 65%</td>
</tr>
<tr>
<td>Medium fine</td>
<td>clay &lt; 35 % and sand &lt; 15 %</td>
</tr>
<tr>
<td>Fine</td>
<td>35 % &lt; clay &lt; 60 %</td>
</tr>
<tr>
<td>Very fine</td>
<td>clay &gt; 60 %</td>
</tr>
</tbody>
</table>

Sand: 50 – 2000 μm  
Silt: 2-50 μm  
Clay: < 2 μm

3.2.1.5 Soil name

The soil names were originally listed according to FAO 1974 and 1990. In its updated version, the World Reference Base (WRB) for Soil Resources (FAO, 1998) was applied to the existing data base using the available data. Three new fields were introduced. WRB-GRP refers to the Reference Soil Group, and WRB-ADJ includes 129 qualifiers. Both attributes are mandatory. The third one, WRB-SPE is optional: it can be either stand for a qualifier or specifier.
In the meantime, guidance for applying WRB to small-scale soil mapping data has been made available (Spaargaren et al. 201011). However, experience for applying it is still scarce. The existing soil names were repeatedly re-classified based on very limited information, so that a revision of the existing database should be conducted as soon as improved data sets become available (e.g. reference soil profiles from the BioSoil project, or additionally delivered national data as observed, measured or estimated, derived soil profiles).

All other topsoil and subsoil parameters do not need further definitions and can be derived directly from the selected typical soil profiles (from which typical topsoil and subsoil properties are derived).

3.2.2 Content definitions of the Soil Geographical Database of Europe 1:250,000

History of the mapping project 1:250,000

During meetings of the heads of soil surveys of the European Union (1989 and 1994) it was decided to develop a georeferenced soil database for Europe 1:250,000. This proposal was then taken up by the newly founded European Soil Bureau in 1996. A so-called Manual of Procedures was produced, which contains the methodology, concepts, and structure of the new soil database (ESB 1998; Finke et al. 2001). The new georeferenced database shall become “a fully computerized structure”, which is supposed “to allow for the storage of a maximum amount of soil information”. It was found that “the use of soil classification units only”, as applied in the SGDBE (1:1Mio), “is based on a restricted number of taxonomic criteria, limits the interpretation value of maps because certain parameters, needed for currently demanded applications, are not recorded (Vossen and Meyer-Roux, 199512).”

Content definitions

The key element of the georeferenced soil database is the soil body. Similar to the soil typological unit, it is defined by soil attributes. On the basis of the soil body, further structural components of the database are developed, the soil scape and the soil region. Both aggregation levels have the purpose to organize the spatial variability of soils in Europe, and to better manage data at the continental level. Each soil body is characterized by horizons with properties (in the sense of diagnostic horizons with regard to WRB). The diagnostics result from similar soil genesis. Each soil body is defined by the reference soil group with two qualifiers, parent material, soil texture (in five fractions with gravel content class), and depth to obstacle for roots. Guidance is provided to (empirically) decide which soils are allowed within a soil body, and at which level of dissimilarity a different soil body needs to be defined.

Because fine typological units can only be delineated at a high resolution, the method 1:250,000 allows for the combination of several soil bodies within a single mapping unit that could be delimited. Such a mapping unit is called soil scape. This is done while knowing about the uncertainties with grouping methods and lack of explanations for existing databases.

Current status of implementation

The development of 1:250,000 maps on the basis of the Manual of Procedures is tested in pilot areas (Figure 10). An overview of the existing data suitable for 1:250,000 mapping in Europe is presented in Table (this report). It can be seen that only the maps of France, Italy,

Finland, and Germany can be used as a basis for applying the Manual of Procedures. All other maps will probably face some serious aggregation/disaggregation procedures in order to become suitable for the new European soil map.

Figure 10: Pilot areas for testing the mapping 1:250,000 acc. to the Manual of Procedures

The terminology applied (soil body, soil scape) fully corresponds to the SMU/STU. It is unclear why new terms were introduced. Further, the data are described similar to the SGDBE 1:1Mio.

3.2.3 Content definitions in other soil maps

3.2.3.1 Hierarchical concepts of scale – nested system

An example for content definitions which include the complete range of scales for soil maps is provided by Caldwell and Brown (1990)\textsuperscript{13}. A similar example, but less precise, is found in the German soil mapping guide (Ad-hoc-AG Boden 1995\textsuperscript{14}; see also Figure 9).

\footnotesize

Table 16: Five orders (levels) of soil surveys with the field procedures used to create maps in varying degrees of detail (acc. to Caldwell and Brown 1990)

<table>
<thead>
<tr>
<th>Order of survey</th>
<th>Kinds of map units</th>
<th>Kinds of components</th>
<th>Field procedures</th>
<th>Appropriate map scales</th>
<th>Min-size delineation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Order</td>
<td>Mainly consociations and some complexes</td>
<td>Phases of soil series</td>
<td>The soils in each delineation are identified by transecting and traversing. Soil boundaries are observed throughout their length. Air photo is used to aid boundary delineation.</td>
<td>&lt;1:12,000</td>
<td>&lt;1.5 acres</td>
</tr>
<tr>
<td>2nd Order</td>
<td>Consociations, associations, and complexes</td>
<td>Phases of soil series</td>
<td>The soils in each delineation are identified by transecting and traversing. Soil boundaries are plotted by observation and interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals. Most modern county surveys are 2nd order.</td>
<td>1:24,000 to 1:31,680</td>
<td>1.5 acres to 10 acres</td>
</tr>
<tr>
<td>3rd Order</td>
<td>Associations and some consociations and complexes</td>
<td>Phases of soil series and soil families</td>
<td>The soils in each delineation are identified by transecting, traversing, and some observations. Boundaries are plotted by observation and interpretation by remotely sensed data and verified with some observations.</td>
<td>1:24,000 to 1:250,000</td>
<td>6 acres to 640 acres</td>
</tr>
<tr>
<td>4th Order</td>
<td>Associations with some consociations</td>
<td>Phases of solid families and sub-groups</td>
<td>The soils of delineations representative of each map unit are identified and their patterns and composition determined by transecting. Subsequent delineations are mapped by some traversing, by some observation, and by interpretation of remotely sensed data verified by occasional observations. Boundaries are plotted by air photo interpretations.</td>
<td>1:100,000 to 1:300,000</td>
<td>100 acres to 1,000 acres</td>
</tr>
<tr>
<td>5th Order</td>
<td>Associations</td>
<td>Phases of subgroups, great groups, suborders, and orders</td>
<td>The soils, its patterns positions for each map unit are identified through mapping selected areas (15 to 25 sq. miles) with 1st or 2nd order surveys, or alternately, by transecting. Subsequently, mapping is by widely spaced observations, or by interpretation of remotely sensed data with occasional verification by observation or traversing.</td>
<td>1:250,000 to 1:1,000,000</td>
<td>640 acres to 10,000 acres</td>
</tr>
</tbody>
</table>

3.2.3.2 Building of map legends in medium to small-scale soil maps

Figure 11 shows the construction of a map legend of the German soil associations map 1:200,000. The graph demonstrates the legend components. At the same time, this structure is also valid for the building of the map data bases (with identifiers and representative derived profiles). The legend contains the proportions of the main soil type-parent material combinations in connection with the dominating land use. The map data base contains typical derived soil profiles for the most frequent soils of each mapping unit. Because soils within the same soil landscape have similar properties, even though they are associated with different soils, the derived profile may be then the same for “neighboring” or similar mapping units. This demonstrates the importance to pre-stratify the mapped landscape into soil regions and soil landscapes. In WP 4 (test cases, D4.3), a check list for the content-based analysis of soil maps has been developed. It will help the understanding of the capturing and structuring of soil information in different soil maps.

15 Consociation: friendly or cooperative association, as between groups or organizations. In Ecology: a subdivision of an association having one dominant species of plant.
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Figure 11: Composition of a soil map legend (here: German soil associations map 1:200,000) (codes: “BB-SS: p-s/g-l” = “German soil type : parent material unit”)

Figure 12: Components of the German soil map legend 1:200,000
(The German soil map 1:200,000 consists of N=55 map sheets; each map sheet contains 50 – 99 soil mapping units, each unit contains up to 6 soil typological units. Additional rules for representation are also provided; see also Feinhals and Krug 2004 16).

⇒ The clear definitions of the content and structure of soil map data bases is the prerequisit to compare and harmonize the content of soil maps.

3.3 Quality of the existing European-wide maps and data bases

The documentation of the European Soil Data Base contains a rationale about the reliability of the data base. It is stated there that "it is not possible to express the accuracy or precision of the data in the various data sets according to any quantified standard procedure". Any future improvement of the data base shall consider this lack of information. On the basis of the scarce information provided along with the national contributions, consistency and reliability checks were almost impossible. For example, the range of resolutions throughout Europe is substantial, ranging from 1:1Mio in France to roughly around 1:5 Mio in Sweden.

The soil polygons (soil map units) on the printed European Soil Map (v 3.2.8.0) were digitised in the late 1980s. Very obvious problems along borders were directly bilaterally solved, but "no systematic checks on the content and integrity of the polygons were applied". For example, it has never been systematically investigated how re-classification of existing national data into FAO (or, as nowadays, WRB), requires background knowledge and guidance. Expert knowledge was first applied to transform national data into the original FAO system (ca. 1972-1978), then from there to the revised FAO legend (1990) (some data sets were provided later, meaning directly as FAO 1990 data sets), then to FAO (1998), WRB and soon into FAO (2006, update 2007; revised WRB, see also Lambert et al. 2003) – all re-classification/re-interpretation steps on the basis of expert knowledge and very limited data sets.

Recent applications of the data have revealed that there are also substantial systematic errors between some property data contained as STU-attributes. It has been reported that the attribute data were not checked for consistency, and that “the accuracy and integrity of these data has remained the responsibility of the national experts who supplied the data”.

It can be concluded from the findings here that substantial quality checks can only be applied on the basis of a much improved data bases. Only a small fraction of SMUs/STUs is represented by a representative measured profile. Without such data, harmonization is almost impossible. And without such data, the reliability and validity of applications (pedo-transfer rules and functions) with the European soil data base cannot be guaranteed.

3.4 Map scale and geometric complexity

Combining existing heterogeneous map products require the definition of a common aggregation level. Usually this level is more general than the original data sources. That means that the requirements for resolution and content may be differently defined for Europe as a whole compared to national soil maps – even if the same nominal scale is applied (such as 1:250,000). When in 1957 soil scientists\(^{17}\) discussed the harmonization of soil data in Europe, it was felt that because of the heterogeneity of existing maps, uneven density of data, and the lack of information in some parts of Europe, harmonization can only be achieved as a relatively small-scale map 1:2.5 Mio.

\[\text{Scale reduces the available area in a map for the presentation of a domain-specific natural phenomena – e.g. soil types. The definitions of the target scale and, correspondingly, geometric indexes, is the pre-requisite to select and compare soil map data sets along borders.}\]

Setting up a content framework for a specific target scale requires content definitions on the one hand (soil mapping unit, soil typological unit, stratification of the soil landscape, core

\(^{17}\) Working Party on Soil Classification and Survey (founded by FAO and the European Commission on Agriculture in 1955). Later, the Correlation Committee started to work on a harmonized soil map at the Soil Survey Centre in Ghent.
properties), and rules for the generalization of geometry on the other hand (thus minimum size of the represented area, e.g. 1:300.000 and 100 m² resolution) and aggregation of content (e.g. soil type). Thirdly, portrayal rules make sure that similar content is recognized as such by users of soil maps. Unfortunately, for many existing soil maps, such rules are not accessible and were in some cases maybe never formulated – especially for maps derived from other existing data bases, such as high resolution maps.

3.4.1 Essential characteristics of soil maps

The difficulty for discussing here some scale-dependent rules for map representation comes from the fact that soil information in soil maps can be recognized and represented in many different ways based on interpretation and rules setting in the field. Despite the existing of mapping guides, a large amount of knowledge about the development of the landscape to be mapped and interpretations in relation to soil genesis. The application of a given mapping methodology still requires the "individual" application of thresholds in the field (or at the desk if aggregation rules need to be constructed rather than rules for the delimitation of soils as polygons).

The intrinsic difficulty for minimizing the room for interpretation by the soil mapper is coming from the following three principles: The basic principle of soil (typological) maps is that they represent the spatial distribution of (classified) soil formation types (thematic applications including soil property maps are not considered at this point). The second principle of soil maps is that the variability of soil is emphasized. Both principles clearly separate soil maps from other maps, e.g. geology. While the first principle requires a classification system to be unambiguous, and at the same time correctly applied, the second principle makes the delimitation of soil features very difficult. The third principle is the vertical and lateral structure: the soil type represents the vertical structure of the pedosphere; at the same time, soils are a continuum; its (lateral) delimitation seems very subjective; the development and application of objective criteria is very difficult.(comment) experienced soil mappers are often specialized on a certain landscape or soil pattern; the delimitation of soils is based on observation of classified soil morphological features.

(comment) The classification difficulty starts at a level below the soil profile with the delineation of soil horizons. These have a classification requirement based on thresholds of morphological properties. At a level below the horizon are peds, which are not part of soil classification; peds are observed and described for the horizon unit. To model the spatial variability in soil attributes, a bulk sample is taken at a scale above the ped, which effectively removes the ped variability. Variability is thus projected to the level of soil horizons. Some horizons are more 'obvious' than others. For a derived soil profile, horizons are aggregated and attributes averaged within the aggregated horizons.

In the following some additional characteristics of soil maps need to be addressed, which are very individually and differently solved by the soil mappers.

- Inhomogeneous map units; inclusions of soils which belong to other map units, but which are too small to be delimited
- Hierarchy of dominating, co-dominating and associated soils in a map legend
- Over-emphasizing important azonal (e.g. peat, riverplain soils) or extrazonal soils (e.g. shallow soils along ridges)

3.4.2 Introduction: generalisation of maps

Generalization refers to the process of transferring a digital spatial data set to a smaller scale by reducing the accuracy of the geometry, e.g. by removing vertices from arcs (see also GS Soil D4.1, Ch. 5.1.1, sub-chapter on multiple representation).

According to Fuchs et al. (2002), generalisation can be separated into four steps (see also Table 17):
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II

- aggregation of its content
- aggregation of area
- generalisation of content
- geometric generalisation

Most of the existing medium to small-scale maps were produced by inferring delineations on the basis of existing large-scale maps and auxiliary data. Existing large-scale soil maps are very often only available for parts of the area, so that inference methods were often applied (see also reconnaissance mapping\(^{18}\)). Usually, the methodical approaches applied to generalisation are not documented, so that the data capturing is unknown. Figure 7 shows that GIS-based and statistical methods exist, but most of them require technical knowledge which most conventional soil mappers do not have or were not in a position to apply at the time maps were generalised. In the past, and probably still nowadays, expert knowledge about the mapping area coupled with information extracted from printed maps (such as geology, topography) are very often the main sources of information and method to freshly delineate medium to small-scale maps on the desk. That way, systematic integration between scales and data sets is prevented.

An additional factor preventing systematic aggregation between scales in a GIS is that the large-scale maps were aggregated to small-scale maps before widespread availability of GIS technology and many of the large-scale maps were not digitised at the time. A further barrier to systematic aggregation is the protection of IPR in large-scale maps, which prevents cross-border analysis of detailed data. Large amounts of legacy data are recorded on field sheets and in notebooks and would require major investment for capture and widespread relaxation of IPR to be made available.

Table 17: Methods to support the geometrical-conceptual generalisation of maps (acc. to Fuchs et al. 2002)

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\(^{18}\) **Reconnaissance mapping** [- scouting]: term originating from military operations to explore inaccessible area (e.g. area occupied by enemy forces); **terrain-oriented reconnaissance** is a survey of the terrain (its features, weather, and other natural observations). Using modern GIS and geostatistical models, soil inference modelling seems to apply to this term as well.

Land-system mapping was the term in use in the 60’s for terrain-based soil interpretation.
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Table 17 also contains semantic elements. For example, content-based aggregation pro-
duces new groups of ranked parameter complexes using multivariate statistics. These
groups must be then qualitatively interpreted – using expert knowledge. Therefore, these
procedures cannot be fully automated. The results then allow conclusions about changes in
the complexity/heterogeneity of the aggregation steps. Edge length indexes for example help
to consider scale-dependent (and/or product-dependent) geometric thresholds. Iterations of
such quantitative steps are necessary because the quality of the aggregation improves iter-
atively.

Especially content-based aggregation and conceptual generalisation require in-depth expert
knowledge. The following list provides some examples:
- define criteria of importance: this probably requires some preliminary analysis of avail-
able data, or field visit (e.g. leads to omitting “unimportant” info
- displace/enlarge/evaluate individual features (e.g. less dominant features per area may
be important to represent)
- simplify (e.g. smoothing borderlines by reducing its detail)
- merge (e.g. by defining rules of a specific distance or size of objects)
- classify (e.g. soil associations)

According to oral communication of GS Soil project members, mapping manuals and train-
ings are provided in the case of several large mapping campaigns (e.g. in Germany such as
Feinhal and Krug 2004), so that orientation is given for the most important methodological
steps during map production and database building (including generalization/aggregation).
However, this was not the case, for example in soil mapping in Scotland from 1950 to 1984.
Only towards the end of the mapping, a systematic attempt was undertaken to harmonise the
typological units used (during the 1:250 000 scale mapping).

3.4.3 Rules for constructing map geometries

Based on prior spatial/semantic analysis of available data as well as field visits, basic rules
for geometric generalisation and semantic aggregation can be set up:
- similarity in soil mapping unit composition: composition of soil types, similarities
at the level of soil properties (e.g. dominating texture class), associated soil-parent
material combinations, similarity. This information serves as the basis for using statisti-
tical distance measures to support the aggregation of soil map information.
- geometric similarity: e.g. average polygon size, average polygon length, distances
of similar soils, geometric complexity of the lining. It is the basis for geometrically
comparing and generalizing soil mapping units between neighbouring soil mapping
areas.
- thresholds: merging of similar mapping units related to the target scale; rules for
omission such as minimum represented area (see Table 18). Minimum representation
measures for polygon sizes and distances have to be taken into account, which also
depend on whether information is represented in colour/non-colour.

These general rules must be specified depending on the scale, physio-geographic setting,
and purpose of soil mapping and sampling.
Table 18: Thresholds for the aggregation and generalisation of soil mapping units

<table>
<thead>
<tr>
<th>Area</th>
<th>Minimum Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>3 mm (shortest side or diameter)</td>
</tr>
<tr>
<td>Area – line shaped</td>
<td>1 mm (Width)</td>
</tr>
<tr>
<td>Target scale</td>
<td>1:50,000, 1:1 Mio, 1:250,000</td>
</tr>
</tbody>
</table>

According to the measures given above, every polygon with a diameter less than the specified threshold is either eliminated or merged with a polygon close by. How close that neighbouring polygon can be needs to be defined as well. Which neighbouring polygon is chosen is also dependent on what that neighbouring polygon represents.

3.4.4 Selection of auxiliary maps to support the aggregation of information from existing soil maps

Soil map polygons often follow hard physical boundaries (delimitation of existing dominating site factors such as river plains), which can be identified from digital elevation models (DEM). These data thus can be used to adapt the soil map polygons to landscape features which are represented in the spatial layers of the following themes: relief, geology, hydrography, topography.

However, it must be noted that soil types change more gradually than described above, in relation to topography and climate. The gradual change is different to uncertainty in boundary position.

Figure 13 gives examples of activities necessary to adapt soil polygons to hydrographic basic maps. This requires first the elimination of all digital hydrographic elements in the „raw data set“, and later the implementation of corrections for the hydrographic line attributes. The delineation of riverplain soils could follow a combination of river lines and, more importantly, the lowlands received from a digital elevation model (e.g. baseline).

Figure 13: Adjustment of soil polygons according to hydrography

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Adaptation of polygons along borders requires that the content of soil maps is first correctly embedded into common basic topographic and hydrographic layers. Geology and geomorphography help to pre-stratify the soil landscape.

3.5 The role of World Reference Base (WRB) to harmonize soil map legends

WRB has been introduced to the European soil data base on the basis of a decision by the Scientific Committee of the ESBN. With this decision, the ESBN follows the recommendations by the International Union of Soil Sciences (IUSS). The application of an agreed soil terminology such as WRB translates the soil type in national soil maps into a harmonized form. On that basis, the content becomes comparable and can be understood by users across boundaries. The IUSS Working Group on WRB (2006) gives a recommendation about how WRB should be applied to soils maps (see Table 19).

Table 19: Recommendations to use WRB in small-scale soil maps

<table>
<thead>
<tr>
<th>scale levels</th>
<th>use of WRB</th>
<th>scale range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reference Soil Group (RSG) only</td>
<td>1 : 5 Mio and smaller</td>
</tr>
<tr>
<td>2</td>
<td>RSG with 1 main map unit qualifier</td>
<td>1 : 5 Mio</td>
</tr>
<tr>
<td>3</td>
<td>RSG with 2 main map unit qualifiers</td>
<td>1 : 1 Mio to 1 : 5 Mio</td>
</tr>
<tr>
<td>4</td>
<td>RSG with 3 main map unit qualifiers</td>
<td>1 : 250.000 to 1 : 1 Mio</td>
</tr>
</tbody>
</table>

Additional suffix qualifiers maybe used for larger scale maps. However, a revision of this recommendation has been recently issued (Spaargaren et al. 2010). It is stated there, that the above-mentioned initial approach may lead to important information losses: certain soil characteristics which are needed to describe a soil for its use, even in smaller scale maps, may not be revealed. The authors have also intended to improve the ability of WRB to become a true umbrella or reference system for national classifications (e.g. by giving weight to properties which can be derived with less analytics, as typically found in map data bases). Therefore, this new recommendation is presented in more depth in the GS Soil content framework.

Testing the application of WRB to the maps of existing soil maps (1:200,000, 1:250,000) have demonstrated that the information contained in the original legend could become aggregated depending on the applied classification level of WRB (e.g. the application of the reference soil group only leads to the highest possible aggregation thus a largely reduced soil map legend). This must be considered before geometries become aggregated and generalized.

For more details, see also Chapter 6, Part I.
4 Best practice implementation of content-related requirements for producing harmonized soil maps in Europe

The main objective of this chapter is to develop guidance for the development of harmonized soil maps. For soil profile data, international norms exist. Therefore, this best practice document will mainly focus on soil typological maps.

This report builds on and uses information provided in Part I and Chapter 3 of Part II. This guidance shall be applied to existing maps, particularly to processing existing soil maps (under INSPIRE) to a format which is comparable across Europe. This best practice involves the following topics:

- spatial objects: definition of map units
- soil map stratification
- (minimum) parameters (via derived profiles) needed in the map database,
- soil classification,
- portrayal, geo-referencing, projection

This guidance does not replace well-established and elaborated reference material for the building of harmonized soil map databases in Europe (e.g. Finke et al. 2010). Rather, an overview is presented which has evaluated, and which integrates, existing reference material. New experiences and results from national projects are provided as well. The key to harmonization is the documentation of the data provided. It has been demonstrated in GS Soil, that the existing meta data profiles are not sufficient to allow the interpretation of soil maps provided through different sources. Therefore, most of the following recommendations refer to the documentation of the existing data.

Best Practice

⇒ It is good practice to document content-related information about existing soil maps using explanatory notes. This can be done on the basis of terminology and methodical descriptions using few tables. In the following, guidance for content definitions and for documenting this information is presented.

⇒ The given recommendations also hold for higher resolution soil maps (European countries smaller by area may provide high-resolution soil maps under INSPIRE) and databases using U.S. Soil Taxonomy. Best practice methodologies will be developed in GS Soil WP4.

4.1 Definition of mapping units: SMU/STU

In large scale maps, the individual soil (pedotopes) of the soil cover is identified and delineated as a polygon; all polygons which represent the same pedotope are combined to a mapping unit, presented in the legend of the map. Soil mappers define the limits of the polygon of a mapping unit in a way that the main soil properties (mainly the morphological appearance of a soil) do not change. This will certainly be the area of a “soil type” (classified according to diagnostics) combined with a certain parent material, but since the soil properties can vary inside specific diagnostics, the pedotope is the area of a soil type which has a specific appearance in terms of main soil properties. The core set of the used and described properties usually relates to those properties which can be described visually (and includes more properties than needed for diagnostics/classification); it can also include some routine laboratory analysis. In addition to those properties which help to determine the type of soil (classification), also properties may be additionally used are important for deriving management options and for identifying hazards related to that soil.
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In small scale maps, it is cartographically not possible to represent individually mapped pedotopes. Rather they have to be grouped together following specific rules for aggregation. Such rules depend on the quality and resolution of the map content which can be represented in a readable way in maps. Table 18 provides such information.

Depending on the resolution of the map, but also on the natural landscape-specific soil developmental conditions, the representation/delineation of soils (soil associations) in maps differs, and different ancillary data help to improve the delineation (e.g. relief). On that basis, it is also possible to adjust the delineation of data sets from different data providers to common rules (e.g. national soil mapping institutions). Examples are presented below. As soon as soil maps cover large landscapes (smaller scale, less resolution, larger area extend of the map), associations of soils are being mapped rather than the individual soils. Soil mapping units then represent a composition of typical soils (dominating and co-dominating soils), which are only known as area proportions (soil typological units) rather than being delineated. This concept is now widely accepted in soil mapping. However, in many cases, only the dominating soil typological unit is known.

[For the Georeferenced Soil Database for Europe 1:250,000, it is defined how soil bodies are to be grouped to form soil scapes. The mapping concept (Finke et al. 2001) presents the concept of “soil body” and “soil scape”; both terms are described synonymously with “soil mapping unit” and “soil typological unit”. Therefore, these terms may be changed in the near future; the findings of the GS Soil project may be relevant for this process.]

Spaargaren et al. (2010) give some indication for the description of soil associations:

| dominant soils: | > 50 % of the soil cover |
| co-dominant soils: | 25 – 50 % of the soil cover |
| associated soils: | 5 – 25 % of the soil cover |

Best Practice

⇒ It is good practice to document the delineation criteria for soil mapping units, its definitions, input data used, and the elements and parameters used to describe the SMUs/STUs. These criteria depend on the target scale and the dominating site factors as far as identified at the conceptual stage of the map development. GS Soil work package 4 has developed a template for the documentation of the key meta information necessary to compare and harmonize existing soil maps (Table 20). Due to the variability of soils in Europe, and different histories, frame conditions and objectives if existing soil maps, a generic, more precise content framework cannot be develop (see Finke et al. 2001). It is recommended to apply this check list and to provide its content to expert users as part of explanatory notes.

Table 20: General check list for the documentation of maps (GS Soil WP4)

<table>
<thead>
<tr>
<th>Name of the map product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data capturing method</td>
</tr>
<tr>
<td>- soil mapping manual for documenting profiles/sampling (“field work manual”): Summary in English if possible</td>
</tr>
<tr>
<td>- laboratory/analytical methods used (if sampling and analysis is involved)</td>
</tr>
<tr>
<td>- any auxiliary data sources used, if at all (e.g. aerial photography)</td>
</tr>
<tr>
<td>- density of sampling and/or profiles (grid size)</td>
</tr>
<tr>
<td>- sampling schema</td>
</tr>
<tr>
<td>Soil systematic units</td>
</tr>
<tr>
<td>- version used</td>
</tr>
<tr>
<td>- description of units/categories/hierarchy (in English)</td>
</tr>
<tr>
<td>Soil mapping units</td>
</tr>
<tr>
<td>- version used</td>
</tr>
<tr>
<td>- description of units/aggregation rules (in English)</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Aggregation</th>
<th>content aggregation applied to geometric generalisation (e.g. soil type of a polygon of a certain size is merged with another polygon where its soil type meets certain criteria)</th>
</tr>
</thead>
</table>
| Coherence with topographic layers | - provide information on base map (Currency, Scale, Content: eg. only hydrography)  
- cartographic mapping practice: e.g. theme adjusted to topography (e.g. gleyic soils of river plains)  
- digitization: were adjustments to the topography/hydrography applied; if yes: how? |
| Pedotransfer rules/functions | (for thematic maps) |
| Scale | |
| Currency | Date of last revision  
Duration of production of map series/database (How many years) |
| Revision | frequency of updating (e.g. every 5 years)  
methods of updating (see 'Data Capturing Method') |
| Coverage | (in percent) of terrain or only parts of it |
| Accuracy | - positional  
- thematic (if possible, more detailed description required of what is meant) |
| Terminology | Describe/define terms used (see Reference Terminology) |

### 4.2 Definition of stratification

#### 4.2.1 Soil regions

Soil regions are the agreed stratification for European-wide high-resolution data sets. They stratify the continent according to macro-climate, large relief-structures and geology. Figure 14 presents the existing soil regions map version 2.0 (BGR 2005, Hartwich et al. 2005).

In order to achieve a consistently structured and useably representation of soils across an area as large as a whole continent, but also at national level, and in order to allow comparability between soil mapping units, a frame legend for Europe is needed. Soil can thus be clearly assigned to the stratum ‘soil region’, but possible also soil macro-scapes or soilscape, depending on national needs and definitions. The aggregation level ‘soil region’ has been defined by the European Soil Bureau Network (Finke et al. 2001, Hartwich et al. 2005). The objective is to be able to combine similar soils (soil mapping units) according to clear, consistent rules of soil development, association, abundance (and main properties and soil use). The present frame legend of the soil regions map is mainly based on lithogenetic criteria because the parent material is the dominating site factor at this broad resolution (1:5 Mio).

A rational about how to use soil regions to stratify the European soil map 1:250.000 is provided by Finke et al. (2001).

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Hartwich, R., S. Thiele, R. Baritz, M. Fuchs and D. Krug (2006). Erläuterungen zur Bodenregionenkarte der Europäischen Union und ihrer Nachbarstaaten im Maßstab 1:5.000.000. (Version 2.0) [The report additionally contains the Map of Climate Areas in Europe 1:10,000,000, and the Parent Material Associations Map 1:5,000,000. These products were developed for Finke et al. (1998) which is currently under revision]. BGR, Hannover, 2006. www.bgr.bund.de
Figure 14: Soil Regions map of Europe to stratify high-resolution continental-level soil map data in Europe (designed to support 1:250,000).

Figure 15 gives an example of how soil regions can be applied to existing map data, and which refinements are needed to incorporate the European soil regions 1:5Mio into 1:250,000 data sets. Its application may lead to alterations of the borders of the 1:5 Mio soil regions. It may be advisable to use a digital elevation model such as the cost-free SRTM dataset for support 21.

Figure 15: Application/versioning of soil regions to stratify the soil map 1:250,000 example: sheet Chemnitz)

21 SRTM: Shuttle Radar Topography Mission (SRTM) with ~90 m resolution)
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The introduction of soil regions into existing maps, for which this concept was not applied yet, is problematic. It requires good knowledge of the original soil mapping units, because the regions may separate individual polygons of soil mapping units. It must be decided by the soil mapper, which adjustment of the soil regions becomes locally necessary. The assignment of a soil mapping unit to a particular soil region can then be done on the basis of area proportions. This process may isolate smaller parts of mapping units, especially if polygons or a mapping unit are scattered across large parts of the soil map.

Best Practice

⇒ It is good practice to apply and document the use of the soil regions map of Europe. The map automatically offers the basis and orientation for developing a framework soil map legend for Europe.

4.2.2 Parent material as in soil map legends

While it is common to describe the soil mapping unit at landscape level (medium to smaller scales) using the classified soil types, very often, also the parent material is described. While parent material can be treated as an attribute of the soil typological unit, it can also be used to describe the soil mapping units as an association of soil types together with its (dominating) parent material. Thus, in addition to the stratification of the map legends, the parent material helps to further refine the differentiation of Europe-wide map legend, and indicates additional typical properties at the level of the soil mapping unit. Physio-geographic setting (incl. climate), soil association as well as parent material are the main factors influencing the properties of the soil typological unit.

Best Practice

⇒ It is good practice to apply the revised FAO parent material list, as it is introduced into the revised SOTER manual (www.esoter.org).

4.2.3 Land cover class

When building data bases of typical soil profiles for soil typological units, also the land use is important. Again, as with parent material, this can be seen as an attribute of the soil typological unit, but also as a stratification of a soil map database: Within a soil mapping unit, certain soils often typically occupy a certain terrain, such as more shallow soils at steeper, nutrient-poorer and/or drier or wetter parts of a mapping unit which is otherwise dominated by more deeply developed, cultivated soils. It may be helpful to use land cover as an additional criteria to identify soil typological units. At least, the main land cover classes ‘forest’, ‘cropland’ and ‘grassland’ should be considered. While land cover is usually not mentioned in soil map legends, the selection and storage of typical soil profiles in a map database should consider these land cover classes. In that respect, land cover can be seen as a stratifier, but also as an attribute to describe the soil typological units.

Best Practice

⇒ It is good practice to stratify soil typological units according to dominant land use.
4.3 Definition of mandatory attribute data and soil properties (minimum set needed for important PTF)

The INSPIRE data specifications provide a core set of attribute data, which are required to fill the data needs of use cases which were selected as representative for European soil-related environmental policies (see Table 21).

**Table 21: Attributes required by INSPIRE (soil data specifications version 2.0)**

<table>
<thead>
<tr>
<th>soil profiles</th>
<th>potential root depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>soil chemical parameters: base saturation, carbonate content, cation exchange capacity, organic carbon content, contaminants</td>
</tr>
<tr>
<td></td>
<td>physical parameters (particle size fraction)</td>
</tr>
<tr>
<td></td>
<td>upper and lower depth of the profile element (layer or horizon)</td>
</tr>
<tr>
<td></td>
<td>soil horizon name (if available: FAO 2006 classification system)</td>
</tr>
<tr>
<td></td>
<td>WRB soil type (if available)</td>
</tr>
<tr>
<td></td>
<td>local soil type (nationally defined)</td>
</tr>
<tr>
<td></td>
<td>available water capacity</td>
</tr>
<tr>
<td></td>
<td>genesis and rock type of soil layers</td>
</tr>
<tr>
<td></td>
<td>soil plot location</td>
</tr>
<tr>
<td></td>
<td>sample depth range</td>
</tr>
<tr>
<td>soil mapping units</td>
<td>soil complex (set of derived soil profiles)</td>
</tr>
<tr>
<td>soil thematic map</td>
<td>soil thematic property</td>
</tr>
</tbody>
</table>

Table 22 presents the list of current core attributes as contained in the European soil database (see also INSPIRE D2.3).

**Table 22: Attributes contained in the European soil database 1:1 Mio**

<table>
<thead>
<tr>
<th>Soil Geographical Data Base for Europe 1:1,000,000</th>
<th>- dominant soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>soil mapping unit (SMU) and soil typological unit (STU)</td>
<td>- co-dominant soil</td>
</tr>
<tr>
<td></td>
<td>- limitation to agricultural use</td>
</tr>
<tr>
<td></td>
<td>- soil code</td>
</tr>
<tr>
<td></td>
<td>- presence of an impermeable layer</td>
</tr>
<tr>
<td></td>
<td>- dominant parent material</td>
</tr>
<tr>
<td></td>
<td>- obstacle to roots</td>
</tr>
<tr>
<td></td>
<td>- slope class</td>
</tr>
<tr>
<td></td>
<td>- textural change</td>
</tr>
<tr>
<td></td>
<td>- textural class</td>
</tr>
<tr>
<td></td>
<td>- land use</td>
</tr>
<tr>
<td></td>
<td>- presence, type of an existing water management system</td>
</tr>
<tr>
<td></td>
<td>- soil water regime class</td>
</tr>
<tr>
<td></td>
<td>- elevation above sea level, etc.</td>
</tr>
</tbody>
</table>

The structure of the database as proposed for 1:250,000 (Finke et al. 2001) is similar to those of the 1:1,000,000-database (Lambert et al. 2003) and SOTER (currently under revision within the FP7 eSOTER project).

Table 23 presents the parameters proposed for 1:250,000 soil maps. This list still needs to be investigated in front of the data requirements for (a) WRB, and (b) the pedotransfer rules database of the European soil information system. The application of pedotransfer rules and functions depends on the data background of the map databases. Finke et al. (2001) distinguish derived (estimated) and observed (measured) soil profiles.
Table 23: Attributes proposed by Finke et al. (2001) for building the European 1:250,000 soil map database

<table>
<thead>
<tr>
<th>soil region</th>
<th>soil scape</th>
<th>soil body</th>
<th>soil horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>climate area</td>
<td>dominant soil</td>
<td>X-Y-coordinates of representative profiles (east. l. latitude, longitude)</td>
<td>starting/ending depth horizon (cm)</td>
</tr>
<tr>
<td>dominant land use</td>
<td>major landform</td>
<td>surface altitude (meter a.s.l.)</td>
<td>Munsell colour</td>
</tr>
<tr>
<td>parent material</td>
<td>regional slope</td>
<td>local slope (%)</td>
<td>clay, silt, sand content (%)</td>
</tr>
<tr>
<td>mean annual precipitation</td>
<td>hypsometry</td>
<td>drainage class</td>
<td>bulk density (g cm⁻³)</td>
</tr>
<tr>
<td>mean annual temperature</td>
<td>degree of dissection</td>
<td>infiltration rate class</td>
<td>organic matter content (%)</td>
</tr>
<tr>
<td>months with drought</td>
<td>permanent water surface (%)</td>
<td>summer potential for capillary rise</td>
<td>stone/gravel abundance and size</td>
</tr>
<tr>
<td>months with temp. below 0°C</td>
<td>min/max altitude</td>
<td>water holding capacity of the rootable depth</td>
<td>grade, size and type of structure</td>
</tr>
<tr>
<td>min/max altitude</td>
<td>relief intensity</td>
<td>surface rockiness</td>
<td>moisture content at field capacity</td>
</tr>
<tr>
<td>major landform</td>
<td>slope length</td>
<td>surface stoniness</td>
<td>moisture content at wilting point</td>
</tr>
<tr>
<td>wetness index</td>
<td>type of erosion/deposition</td>
<td>saturated hydraulic conductivity</td>
<td></td>
</tr>
<tr>
<td>domin. land use</td>
<td>degree of erosion</td>
<td>carbonates (g kg⁻¹)</td>
<td></td>
</tr>
<tr>
<td>parent material</td>
<td>sensitivity to capping</td>
<td>gypsum (g kg⁻¹)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>width of cracks (cm)</td>
<td>pH-H₂O</td>
<td></td>
</tr>
<tr>
<td></td>
<td>distance between cracks (cm)</td>
<td>sodium adsorption ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>depth to obstacle for roots (cm)</td>
<td>electric conductivity of saturated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>impermeable layer (cm)</td>
<td>exchangeable sodium percentage (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>depth to bedrock (m)</td>
<td>exch. Ca⁺⁺, Mg⁺⁺, K⁺, Al⁺⁺⁺, exch. acidity, CEC (cmol+ kg⁻¹)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>water regime</td>
<td>C/N ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>average depth to water table (dm)</td>
<td>oxalate extractable Fe (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>minimal depth to water table (dm)</td>
<td>oxalate extractable Al (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maximal depth to water table</td>
<td>lab and year of analysis for each parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>type of functioning water management</td>
<td>quality estimate of analysis for each parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>purpose water management</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 24 presents the minimum set of soil parameters which are required to apply the method list of the German soil mapping services (Ad hoc-AG Boden 2003).

Table 24: Core attributes of the German national soil database

| soil wetness |
| soil use |
| horizon symbol |
| horizon upper/lower depth |
| soil textural class (fine earth, coarse material, peat type) |
| stratigraphie |
| substrate genesis |
| parent material |
| substrate type |
| humus content |
| carbonate content |
| pH |
| effective soil density |

Based on the results of GS Soil WP4 test cases, a final proposal for core attributes can be made. In the European soil data bases, the concept of estimated and measures soil profiles, or derived and observed profiles, as stressed in the INSPIRE soil data specifications, has been specified. An analysis of the existing concepts and data bases can be found in Baritz et
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al. 2009 and Hiedderer22). Data availability seems more difficult with regard to observed profiles (N=496 from 17 countries including data gaps for various parameters, (e.g. 4.2 to 100 %; e.g. coordinates: 82%), while derived (polygon-georeferenced) profiles are available for all soil typological units (N=5,306).

Best Practice
⇒ It is good practice to provide derived soil profiles for all soil typological units. If available, the soil profile information should be based on observed profiles, with exact georeferencing available. However, existing national soil map data bases are usually covered with estimated soil profiles. A list of core soil parameters has been compiled which covers most of the reporting requirements identified for European environmental policies (including those data required for the delineation of priority areas for soil protection in Europe; Eckelmann et al. 200623). The core parameters are listed in Table 25.

Table 25: Core soil parameters for harmonized database building and data sharing

| soil horizon (derived soil profile) | - soil horizon  
| | - upper and lower depth of the soil horizon  
| | - soil horizon designation  
| | - texture class (FAO)  
| | - carbonate content (FAO)  
| | - humus content (FAO)  
| | - stone content (FAO)  
| soil horizon (observed soil profile) | as above, plus:  
| | - soil structure  
| | - pH (KCl) or pH (Ca₂CO₃)  
| | - particle size fractions  
| | - available water capacity  
| | - base saturation  
| | - carbonate content  
| | - cation exchange capacity  
| | - organic carbon content  
| | - electric conductivity  
| | - salt content  
| | - potential root depth  
| | - bulk density  
| soil typological unit | - area proportions of soil types, dominance, co-dominance  
| | - land cover type and land use (crop type and current crop rotation, grassland intensity, tree species composition)  
| | - erosion features  
| | - local land form  
| | - parent material  
| | - humus type  
| | - groundwater/stagnic water levels  
| | - major landform  
| | - regional slope  
| | - relief intensity  
| | - wetness index  

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4.4 WRB as a common classification system in Europe

Although WRB (IUSS WG WRB 2006\textsuperscript{24}) has not been developed to serve mapping purposes, a very recent effort has been made to improve the application of WRB in soil maps (Spaargaren et al. 2010\textsuperscript{25}). This new guideline contains information to construct map units (or soil typological units) and map legends for scales of 1:250,000 and smaller. The main principle is the selection and ranking of the main qualifiers for each RSG. It is recommended to follow the given order. Additional optional map unit qualifiers are also presented in an alphabetical order; its application can be adjusted to the individual user needs (Table 26).

Table 26: Recommendations for applying WRB to small-scale soil maps (acc. to Spaargaren et al. 2010)

<table>
<thead>
<tr>
<th>levels</th>
<th>use of WRB</th>
<th>scale range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>only the RSG, or RSG + 1 qualifier of the main list\textsuperscript{1)}</td>
<td>1 : 5 Mio and smaller</td>
</tr>
<tr>
<td>2</td>
<td>RSG + the first two applying qualifiers of the main list\textsuperscript{2)}</td>
<td>1 : 1 Mio to 1 : 5 Mio</td>
</tr>
<tr>
<td>3</td>
<td>RSG + first three applying qualifiers of the main list\textsuperscript{3)}</td>
<td>1 : 250,000 to 1 : 1 Mio</td>
</tr>
</tbody>
</table>

\textsuperscript{1)} The qualifiers are placed before the RSG name.
\textsuperscript{2)} As with \textsuperscript{1)}, and the first applying qualifier stands closest to the RSG name
\textsuperscript{3)} As with \textsuperscript{2)}, and the second applying qualifier stands in the middle

In addition, optional qualifiers may be used. Syntax rules for its application are provided by Spaargaren et al. (2010). It must be noted that it is possible to use less than the recommended qualifiers depending on the soil type and the data available to sufficiently describe the soil based on the existing data and interpretation needs. Table 27 gives an example for the RSG Podzol.

Table 27: Selection of WRB qualifiers in soil maps (Example: Podzol)

(acc. to Spaargaren et al. 2010)

<table>
<thead>
<tr>
<th>Main map unit qualifiers (Podzol)</th>
<th>Optional map unit qualifiers (Podzol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbic/Rustic</td>
<td>Anthric</td>
</tr>
<tr>
<td>Albic/Entic</td>
<td>Densic</td>
</tr>
<tr>
<td>Gleyic</td>
<td>Drainic</td>
</tr>
<tr>
<td>Stagnic</td>
<td>Fragic</td>
</tr>
<tr>
<td>Folic/Histic/Umbric</td>
<td>Gelic</td>
</tr>
<tr>
<td>Hyperskeletal/Leptic</td>
<td>Hortic</td>
</tr>
<tr>
<td>Vitric/Silanic/Aluandic</td>
<td>Lamellic</td>
</tr>
<tr>
<td>Haplic</td>
<td>Novic</td>
</tr>
<tr>
<td></td>
<td>Ornithic</td>
</tr>
</tbody>
</table>

http://www.zwz.tum.de/bk/pdfs/uebungen/WRB_update07.pdf

\textsuperscript{25} Spaargaren, O., P. Schad and E. Michéli (2010). Guidelines for constructing small-scale map legends using the World Reference Base for Soil Resources. Addendum to the World Reference Base for Soil Resources.
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In the following, examples are provided from an application of this WRB mapping guideline. There, the German 1:200,000 soil map was used as a 1:250,000 test sheet (sheet Flensburg, which borders Denmark; only the German database was used for this test; see also Schad et al. 2010). The example does not contain the stratification according to soil regions, as it was recommended by Finke et al. (2001). More information about experiences and approaches to apply WRB will be given in GS Soil D4.3.

Figure 16: Application of the WRB mapping guideline to the scale 1:250,000 (sheet Flensburg) (acc. to Schad et al. 201026)

Best Practice

- It is good practice to apply WRB as recommended by Spaargaren et al. (2010). At least the Reference Soil Group (RSG) of the dominating soil type (dominating soil typological unit) should be included together with the national soil type.

- It is good practice to describe the terminology of the national classification system according to guidance developed for harmonizing datasets in GS Soil D4.3.

4.5 Definition of soil map output design: portrayal, legends, GetFeatureInfo

4.5.1 Cartography – Editorial Guideline

In the following a guideline is given to be followed by partners in order to obtain a European wide representation of small scale soil maps that were semantically harmonised using WRB.

1. For printed maps
2. For online presentation as WMS/WFS

Optimum Scale

The development of a harmonised map across Europe requires the definition of a common scale. For example, in the existing European soil information system, this was 1:1Mio; for the next higher resolution map, the target scale is 1:250,000 (see also http://eusoils.jrc.ec.europa.eu/esbn/EUSIS.html). The optimum scale is a metric index which gives an estimate of the “real” scale and thus helps aggregation and generalization of existing data to read and map into the target scale. This index helps to describe and compare existing maps; there is no absolute truth. It must be noted that different geographic conditions of soil landscapes determine different natural variabilities and soil association complexities, so that “natural variability” has to be taken into account as well. For example, applying this index to the German soil map 1:200,000 has indicated that the resolution of that map resembles the real scale 1:150,000 (Gehrt et al. 2010).
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II

An extensive content framework to develop a harmonized European 1:250,000 soil map is provided by Finke et al. (2010).

Best Practice
⇒ It is good practice to provide the optimal scale for comparability reasons. If possible, this information may be provided in a stratified form (e.g. separately for lowlands, mountainous areas, Alps). This information can also be derived upon data availability through a central data centre or GIS-user.

4.5.2 Basic topography and hydrography

If possible “EuroRegionalMap” is to be used (www.eurogeographics.org). “EuroRegionalMap is a multi-functional topographic reference dataset at a scale of 1:250 000, covering Europe. It features seamless and harmonised data created and maintained by the National Mapping and Cadastral Agencies official national databases”. Since this product is not free of charge, it must be investigated whether the vector map level 0 (DIGITAL CHART OF THE WORLD) METADATA LONG FORM can be used (source: Originator: National Imagery and Mapping Agency):

- Publication Date: 2009
- Title: Vector Map Level 0 (Digital Chart of the World)
- Edition: 5
- Geospatial Data Presentation Form: model
- Publication Information:
  - Publication Place: Bethesda, MD
  - Publisher: National Imagery and Mapping Agency
  - Other Citation Details: NIMA Reference Numbers VMAP0EURNASIA, VMAP0NOAMER, VMAP0SASUS, VMAP0SOAMAFR)

The topographic map contains the following data: country borders, major cities, hydrography. In addition, the EuroRegionalMap contains some relief information.

This information can also be derived upon data availability through a central data centre or GIS-user.

Best Practice
⇒ It is good practice to use the EuroRegionalMap. This may require adjustments of the delineations. On that basis, gaps may be filled, and adjustments implemented (e.g. following river lines). As for existing databases, it can be hardly expected, that such corrections are applied. In case such steps can be conducted, and are being done by a central data centre, the personnel must be trained beforehand according to agreed principles with the data providers. Such principles must still be derived, and depend on the target scale.

⇒ In case the above-mentioned recommendation cannot be fulfilled, it is good practice to document the used topography, and the GIS-operations implemented during digitization (⇒ Explanatory notes).
4.5.3 Petrography rules

**Area Colours**

There exists already a colour schema which can be used for the presentation of maps published by FAO (Table 28). It is suggested to use those colours to portray reference soil groups (e.g. Histosol). For the representation of WRB-Suffixes and Prefixes as point symbols, an additional combination of abbreviations is suggested.

**Table 28: Available colour schema for reference soil groups (FAO; European)**

<table>
<thead>
<tr>
<th>Legend Item</th>
<th>Colour (RGB)</th>
<th>Transparency</th>
<th>Outline Colour</th>
<th>Outline Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrisol</td>
<td>247 152</td>
<td>50%</td>
<td>NONE</td>
<td>N/A</td>
</tr>
<tr>
<td>Albeluvisol</td>
<td>254 194</td>
<td>194</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andosol</td>
<td>254 0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthrosol</td>
<td>88 87</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arenosol</td>
<td>245 212</td>
<td>216</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcisol</td>
<td>254 254</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cambisol</td>
<td>254 190</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chernozem</td>
<td>145 77</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryosol</td>
<td>75 61</td>
<td>172</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluvisol</td>
<td>0 254</td>
<td>254</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gleysol</td>
<td>128 131</td>
<td>217</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsisol</td>
<td>254 245</td>
<td>165</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Histosol</td>
<td>112 107</td>
<td>102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kastanozem</td>
<td>202 147</td>
<td>127</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leptosol</td>
<td>209 209</td>
<td>209</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lixisol</td>
<td>247 43</td>
<td>153</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luvisol</td>
<td>250 132</td>
<td>132</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phaeozem</td>
<td>189 100</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planosol</td>
<td>247 125</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Podzol</td>
<td>12 217</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regosol</td>
<td>254 227</td>
<td>164</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solonchak</td>
<td>254 0</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solonet</td>
<td>249 194</td>
<td>254</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stagnosol</td>
<td>142 120</td>
<td>255</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Umbrisol</td>
<td>115 142</td>
<td>127</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertisol</td>
<td>145 0</td>
<td>157</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glacier</td>
<td>245 245</td>
<td>255</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake</td>
<td>184 219</td>
<td>242</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Marsh**

| Foreground   | 64 101 253     | 64 101 253     | 0.4 pts       |
| Background   | 151 219 242    | 151 219 242    |               |
| Scale x and y | 1 = 1          | 1 = 1          |               |

**Rockoutcrop**

0 0 0

**(Auxiliary) point symbols**

<table>
<thead>
<tr>
<th>Legend Item</th>
<th>Colour (RGB)</th>
<th>Size</th>
<th>Type (letter, geometric figure...)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text for suffixes-und prefixes</td>
<td>0 0 0</td>
<td>7 pts</td>
<td>To be completed see Annex 2 of the World Reference Base for Soil Resources 2006: Recommended codes for RSG, Qualifiers and Specifiers. Arial</td>
</tr>
</tbody>
</table>
D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II

**Topography**

- Borders

<table>
<thead>
<tr>
<th>Legend Item</th>
<th>Colour (RGB)</th>
<th>Width</th>
<th>Type (letter, geometric figure…)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Border - outline</td>
<td>0 0 0</td>
<td>1 pts</td>
<td>Line (cartographic pattern: 10 pts, 5 pts, 1pt, 5 pts, 1 pt, 5 pts)</td>
</tr>
</tbody>
</table>

- Cities

<table>
<thead>
<tr>
<th>Legend Item</th>
<th>Colour (RGB)</th>
<th>Size</th>
<th>Type (letter, geometric figure…)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cities - position</td>
<td>87 87 87</td>
<td>2 mm</td>
<td>square</td>
</tr>
<tr>
<td>- name</td>
<td>0 0 0</td>
<td>12 pts</td>
<td>Text, bold, Calibri</td>
</tr>
</tbody>
</table>

**Hydrography**

<table>
<thead>
<tr>
<th>Legend Item</th>
<th>Colour (RGB)</th>
<th>Size</th>
<th>Type (letter, geometric figure…)</th>
</tr>
</thead>
<tbody>
<tr>
<td>River/Channel</td>
<td>0 95 230</td>
<td>2 pts</td>
<td>line</td>
</tr>
<tr>
<td>Areal Water</td>
<td>0 95 230</td>
<td>0,1 pts</td>
<td>polygon</td>
</tr>
<tr>
<td>Bodies - outline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- area</td>
<td>150 220 240</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Relief**

<table>
<thead>
<tr>
<th>Legend Item</th>
<th>Colour (RGB)</th>
<th>Size</th>
<th>Type (letter, geometric figure…)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey scale</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 17: Examples for applying the proposed symbology

**Projection**

The following information is taken from the document “INSPIRE Specifications on Coordinate reference systems”. The requirements and recommendations for map projections are based on the results from the “Map Projections for Europe” workshop14. These are:

- Lambert Azimuthal Equal Area (ETRS89-LAEA) for pan-European spatial analysis and reporting, where true area representation is required;
- Lambert Conformal Conic (ETRS89-LCC) for conformal pan-European mapping at scales smaller than or equal to 1:500,000;
- Transverse Mercator (ETRS89-TMzn) for conformal pan-European mapping at scales larger than 1:500,000.

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D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II

Therefore, we will recommend ETRS89-TMzn for integrating existing data into a Europe-wide harmonized 1:250,000 soil map. “Zn” is the zone number (see also Table 29).

**Table 29:** Zones of the ETRS89 Transverse Mercator Coordinate Reference System
(source: Table 11, pg 114, Map projections for Europe, Institute for Environment and Sustainability 2001, EUR 20120 EN)

<table>
<thead>
<tr>
<th>Zone number (zn)</th>
<th>Longitude of Origin (degrees)</th>
<th>West Limit (degrees)</th>
<th>East Limit (degrees)</th>
<th>South Limit (degrees)</th>
<th>North Limit (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>27° West</td>
<td>30° West</td>
<td>24° West</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>27</td>
<td>21° West</td>
<td>24° West</td>
<td>18° West</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>28</td>
<td>15° West</td>
<td>18° West</td>
<td>12° West</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>29</td>
<td>9° West</td>
<td>12° West</td>
<td>6° West</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>30</td>
<td>3° West</td>
<td>6° East</td>
<td>0° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>31</td>
<td>3° East</td>
<td>0° East</td>
<td>0° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>32</td>
<td>9° East</td>
<td>6° East</td>
<td>12° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>33</td>
<td>15° East</td>
<td>12° East</td>
<td>18° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>34</td>
<td>21° East</td>
<td>18° East</td>
<td>24° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>35</td>
<td>27° East</td>
<td>24° East</td>
<td>30° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>36</td>
<td>33° East</td>
<td>30° East</td>
<td>36° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>37</td>
<td>39° East</td>
<td>36° East</td>
<td>42° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>38</td>
<td>45° East</td>
<td>42° East</td>
<td>48° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
<tr>
<td>39</td>
<td>51° East</td>
<td>48° East</td>
<td>54° East</td>
<td>0° North</td>
<td>84° North</td>
</tr>
</tbody>
</table>

**Best Practice**

⇒ It is good practice to follow the recommendations for harmonized portrayal.

⇒ It is recommended that at the soil map legends are stratified (soil regions), and that the soil mapping units are presented according to the Reference Soil Group of the dominating soil typological unit.

⇒ It is recommended that *GetFeatureInfo* is extended so that more complex information about soil mapping units becomes available to users of WMS. A structured procedure must still be elaborated.
4.6 Relevance of the content framework for soil map harmonization in Europe

Table 30 provides an overview of the possible national data bases involved with INSPIRE. The left column presents those map products which are expected to be used for building a new harmonized soil map of Europe, possibly in the scale 1:250,000. The right column presents the existing supplementary soil maps, which are likely to be used for supporting the aggregation/disaggregation steps necessary to adapt the data sets of the left column towards 1:250,000 specifications. Such higher-resolution data sets are also needed as to derive area proportions of soil typological units of the (new) 1:250,000 mapping units, and also to derive typical soil profiles and properties.

It can be concluded from Table 30 that most of the maps require some sort of aggregation (if the existing data are at a higher resolution compared to the target scale 1:250,000) or disaggregation (if the existing data are coarser than the target resolution). Despite the availability of European reference material (Finke et al. 2001), very few conform map products exist. It can be assumed that the content specifications are not sufficiently “individual” as to facilitate harmonized map products. According to the GS Soil review and analysis, the successful mapping of existing content into common terminology and data structures will require the following extension of the existing reference material:

(a) clear definitions and the documentation of a common terminology as a common denominator, derived on the basis of practical tests (e.g. applying FAO codes and definitions)

(b) exemplary methodologies for applying data specifications and content definitions

ad a)

The GS Soil best practice content framework together with the results from the Work Package 4 test cases will fulfil these requirements (D2.5 part II, and D4.3). This will also allow for a realistic estimate of the possible effort to fully harmonize existing soil (map) data.

ad b)

Aggregation/disaggregation procedures need to be tested and applied. This was expected to be achieved in the 1:250,000 pilot areas (see also Figure 10). However, clear objectives and an active communication and coordination process around these pilot areas was missing, so that clear conclusions and recommendations were not derived. In the meantime, digital soil mapping may serve as a support in developing aggregation procedures. This is currently being tested in the EU project eSOTER (www.eSOTER.com). There, high-resolution data sets are analysed and aggregated in order to validate predicted soil mapping units as derived from GIS-models. Where available, existing data sets are being utilized; in the case of data gaps, digital soil mapping is used.
Table 30: Overview of existing map data for high-resolution soil mapping in Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Existing data sets in the range of the target scale 1:250,000</th>
<th>Existing data sets to support the “European mapping”¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>soil map of Austria: 1:750,000</td>
<td>1:10,000 (published 1:25,000); 63% of agricultural land published, for 10% more, scripts exist</td>
</tr>
<tr>
<td>B</td>
<td>1) 1:160,000 (1853)</td>
<td>1:10,000, published at 1:20,000 (1 sheet=8,000 ha); 375 out of 457 map sheets published (rest black and white) (100%)</td>
</tr>
<tr>
<td></td>
<td>2) 1:500,000 (1972, synthesis map of 2.)</td>
<td></td>
</tr>
<tr>
<td>CZ</td>
<td>1:500,000 and 1:200,000 (modus 1:250,000; also translated into SOTER)</td>
<td>Agriculture: 1:10,000 (field sheets); 1:50,000 for administrative districts (completed for half of CZ); forest: 1:5,000</td>
</tr>
<tr>
<td>D</td>
<td>1:200,000 (ca. 80%, ongoing)</td>
<td>project ongoing: derivation of the 1:250,000 using the 1:200,000 soil map of Germany</td>
</tr>
<tr>
<td>DK</td>
<td>Surface geology (see left column) published as 1:100,000 (50% of DK published)</td>
<td>Surface geology (also yields sandy and clayey soil for the whole country); 90% of DK mapped 1:20,000 (1888 until present)</td>
</tr>
<tr>
<td>EE</td>
<td>1:400,000 (1946); later generalized and published: 1:200,000: 1:500,000</td>
<td>1:10,000; launched in 1949; basis for all smaller scale maps; digitizing finished in 2001</td>
</tr>
<tr>
<td>FI</td>
<td>1:250,000 (2002 - 2009)</td>
<td>1:100,000 and 1:400,000 (geology: Quaternary deposits, incl. soil type down to 1m; plough layer in agro-geo. Maps)</td>
</tr>
<tr>
<td>F</td>
<td>1:250,000 ‘Regional Soil Survey’ (R.R.P.) (since 1990)</td>
<td>pedological map at 1:100,000 with irregular coverage (partly based on the departmental map of agricultural land at 1:50,000</td>
</tr>
<tr>
<td>GR</td>
<td>several mapping campaigns (1:50,000 to 1:300,000) (regional coverage: ca. 31 %)</td>
<td>(a) 1:5,000 to 1:15,000 (published 1:5,000 to 1:20,000) (39% of agricultural area, 6% of Greece); (b) Land Resource Survey (1:50,000 (100% of the hilly and mountainous forested areas, 75% of total Greece (1980-1998)</td>
</tr>
<tr>
<td>HU</td>
<td>1:75,000 (agricultural lands of hilly regions); 1:100,000 (100%); 1:500,000 (100%)</td>
<td>genetic soils maps (1:10,000) (70% of the agri area) 1960-1975, per farming units</td>
</tr>
<tr>
<td>IR</td>
<td>generalized soil map (1:575,000) (1979, 100%)</td>
<td>1:10,560 (published as 1:126,720) (44% mapped), since 1959</td>
</tr>
<tr>
<td>IT</td>
<td>1:250,000 (only 4 regions had a map until 1994; EU project: 1999-2003) (100%)</td>
<td>Mapping status (1999): 1:25,000 or larger (10%); 1:30,000-1:100,000 (32%); 1:150,000-1:250,000 (30%)</td>
</tr>
<tr>
<td>LV</td>
<td>1:400,000 (100%, 1945 and 1958); 1:100,000 (agri. land and forests) (11 out of 26 regions)</td>
<td>soil mapping pre war: 1:200,000, 1:75,000, 1:5,000 (ca. 50 %) soil mapping post war: 1:10,000 (all agri soils)</td>
</tr>
<tr>
<td>LT</td>
<td>1:300,000 (100%)</td>
<td>1:10,000 (for each farm, ended 1991) (100 % agri); forest site mapping; 1:50,000 (100% for each region)</td>
</tr>
<tr>
<td>MT</td>
<td></td>
<td>1:31,680: 10 % mapped based on field observations, the rest from aerial photos and occasional ground-truth observations</td>
</tr>
<tr>
<td>NL</td>
<td>(a) 1:200,000 (1952-1954, published 1965) (emphasis on ‘physiographic' properties)</td>
<td>1:50,000 (1964-1995); all maps: digital maps at ca. 20 % (250,000 ha)</td>
</tr>
<tr>
<td></td>
<td>(b) 1:250,000 (derived from 1:500,000, when ca. 70% were mapped (1985, 100%)</td>
<td></td>
</tr>
<tr>
<td>PL</td>
<td>1:300,000 (1949-1961); 1:500,000 (1972, 100%, digital); 1:250,000 (Odra river basin)</td>
<td>1:5,000 (1955-1968); soil agricultural maps 1:25,000 (based on 1:5,000) (100 % agri land = 60% of Poland; soil agricultural maps 1:100,000 derived from 1:25,000; partly digital)</td>
</tr>
<tr>
<td>PO</td>
<td>1:250,000 according to mapping progress of 1:25,000</td>
<td>1:250,000 (published at 1:50,000) since 1958 (completed in southern P. in 1965; 55% of P.)</td>
</tr>
<tr>
<td>SV</td>
<td>1:500,000 (1973); revised into 1:400,000 (1993)</td>
<td>1:5,000 (10,000 sheets) since 1973 (100%: agric 1:5,000, forest: 1:10,000</td>
</tr>
<tr>
<td>SL</td>
<td>1:400,000 derived from digital soil map 1:25,000 (DSM25)</td>
<td>(a) 1:25,000 (since 1963; after 1981, initial 1:50,000 maps were refined to 1:25,000) 50% coverage by end of 1986 (b) digital soil map of Slovenia 1:25,000 (1987-1999) (100%)</td>
</tr>
<tr>
<td>ES</td>
<td>most maps in the 60s and 70s: 1:200,000 or smaller</td>
<td>1:50,000, partly 1:25,000</td>
</tr>
<tr>
<td>SE</td>
<td>1:250,000 (0.15 % of Sweden)</td>
<td>(a) Quaternary and lithological maps incl. mineralogy, texture down to 50cm; 1:50,000 for 20 % of Sweden; 1:100,000-1:400,000 for all of Sweden; (b) Geochem. maps of the parent material 1:250,000-1:1,000,000</td>
</tr>
<tr>
<td>UK</td>
<td>(a) 1:250,000 (1979-1984; based on larger scale maps where available) (100% for UK); (b) soil scapes of England and Wales</td>
<td>England and Wales 1:25,000-1:63,360 (1939-1987) (24 %), similar for Scotland</td>
</tr>
</tbody>
</table>

¹) list of maps and databases which are likely to be used to derive 1:250,000:
(a) aggregate/disaggregate existing small-scale data (left column) towards the target resolution 1:250,000
(b) data sources to identify soil typological units (selection of typical soil profiles and properties) and to derive area proportions
5 Conclusions

The INSPIRE requirements for harmonization as well as the requirements for full harmonization were studied. It was observed that many interoperability criteria are not clear enough to be understood by soil experts. Therefore, more detailed conclusions about semantic aspects are required in order to allow applications as to provide harmonized soil data sets. Now, with the soil data specifications being drafted, and the lack of terminology requirements, and the technical language which is performed under INSPIRE (which is difficult even for soil informatics experts guidance), the data sets provided under INSPIRE will not be comparable in its content. Therefore, the GS Soil best practice recommendations aim for full harmonization.

For the GS Soil Best Practice, the existing reference material has been further aggregated to very common harmonization requirements. Most of them were already discussed many times before, and even tested in many EU member states during the process of the development of the Georeferenced Soil Database of Europe 1:1Mio. Examples will be provided in GS Soil 4.3 (Data Harmonization Best Practice Guidelines), based on experiences from test cases. Because the best practice recommendation provided here are conform to this discussion, and also to the existing reference material, they are expected to represent the current level of understanding among soil data providers in Europe.

The Best Practice recommendations would be meaningless, if its successful application were not demonstrated somewhere. This is done in the GS Soil test cases. On that basis, a realistic estimate of the effort can additionally be made as to develop a new, high-resolution soil map data bases for Europe.
Annex 1: Existing ISO norms for sampling and analysis

ISO 10381 series, Soil quality – Sampling
ISO 11074, Soil quality – Vocabulary
ISO 15903, Soil quality – Format for recording soil and site information
ISO 25177, Soil quality – Field soil description

The following list of standards and norms has been compiled from FSEP and FSCC (2003, 2006). Laboratory ring test under the ICP Forests programme have shown that national deviations and modifications of analytical procedures are quite common, and that the quality of analytical data is high because the respective laboratory have gathered a large amount of routine with certain methods. It is therefore difficult to prescribe a single analytical method to produce harmonized results. This issue has been discussed extensively in various reports on soil monitoring.


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D2.5 Best practice guidelines for developing a content framework for interoperable soil data in Europe – PART II