Land Information Systems

Developments for planning the sustainable use of land resources

by
H.J. Heineke, W. Eckelmann, A.J. Thomasson, R.J.A. Jones, L. Montanarella, B. Buckley
(eds.)
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COVER MAPS: EXTRACTS FROM THE EUROPEAN SOIL DATABASE
With an increasingly affluent population demanding more from our environment to support everyday life, it is becoming more and more urgent to plan and introduce sustainable practices of land use. The expanded European Union now constitutes the third most populous political grouping in the world and, in economic terms, is comparable with the United States of America and Japan. This level of development has only been achieved through the high intensity of agricultural and industrial activity, which, in global terms, is taking place in a relatively small area. Many of the resulting environmental problems, traditionally confined to Europe, are now beginning to appear in less populated areas of the world, as similar activities there intensify. In this respect we can look upon Europe as a laboratory for seeking solutions to the problems of production, pollution, and protection of land resources.

This background together with the explosive developments in Information Technology during the past decade stimulated the newly-constituted European Soil Bureau – ESB – based at the Joint Research Centre, Ispra (I), to propose this international workshop on land information systems and the part these play in planning the sustainable use of land. It was held from 20-22nd November 1996, at the Bundesanstalt für Geowissenschaften und Rohstoffe – BGR – (Federal Institute for Geosciences and Natural Resources), Hannover, Lower Saxony (D).

The meeting was organised by a team drawn from the BGR, the Niedersächsisches Landesamt für Bodenforschung – NLfB (Geological Survey of Lower Saxony), and the Soil Survey and Land Research Centre – SSLRC – Cranfield University, Silsoe (UK). The ESB provided EU funds to support the running of the meeting.

The Proceedings are divided into 8 sections covering: The European Perspective on the compilation, management, distribution and application of soil- and land-related databases; Summary and Recommendations; The National Perspective in Europe, with contributions from all over the continent; Techniques and Technologies on the application of new methodologies; Environmental Applications using information systems for solving practical problems in the management of land; Land Evaluation on traditional uses of soil and land data for land suitability; Poster presentations; and a Database Dictionary for the Soil Geographical Database of Europe.

This volume – Research Report No.4 – constitutes the fourth in a series produced by the European Soil Bureau and its predecessor, the Soils Information Focal Point. It makes a significant contribution to the development of a Soil and Land Information System for Europe, which is urgently required for the protection of the continent’s environment and for the sustainable development of its land resources.

R.J.A. Jones
EDITORS’ NOTE

We would like to thank all the contributors for their ready responses to our queries and their tolerance of our idiosyncrasies. Their friendly co-operation has made an otherwise onerous task a pleasure.

We would also like to thank all those people in NLfB and BGR who contributed to making the meeting in Hannover so productive and fruitful.

Hans J. Heineke – Wolf Eckelmann – Arthur Thomasson – Bob Jones
Luca Montanarella – Barbara Buckley
Table of Contents

**Section 1: The European Perspective**  
1_0 3-68

The European Soil Bureau  
*J. Meyer-Roux, L. Montanarella*  
1_1 3-10

A proposed European soil information policy  
*D. King, J. Meyer-Roux, A.J. Thomasson, P. Vossen*  
1_2 11-18

European Soil Database: information access and data distribution procedures  
*R.J.A. Jones, B. Buckley, M.G. Jarvis*  
1_3 19-32

The European Soil Information System  
*C. le Bas, D. King, M. Jamagne, J. Daroussin*  
1_4 33-42

Towards a European Soil Profile Analytical Database  
*H.B. Madsen, R.J.A. Jones*  
1_5 43-50

Elaboration of a European forest soil database for monitoring atmospheric pollution  
*E. Van Ranst, L. Vanmechelen, R. Groenemans*  
1_6 51-68

**Section 2: Progress and Recommendations**  
2_0 69-74

Welcome speech from Dr. Fischer, Minister of Economics, Technology and Transport of Lower Saxony  
2_0 70-71

Summary of Progress and Recommendations  
*R.J.A Jones, A.J. Thomasson*  
2_0 72-74

**Section 3: The National Perspective**  
3_0 75-234

Development of the soil information system BORIS in Austria  
*N. Arzl, A. Dvorak, A. Riss, Ingrid Schreier, Sigrid Schwarz*  
3_1 77-90

From Soil Survey to quantitative land evaluation in Belgium  
*L. Hubrechts, K. Vander Poorten, M. Vancllooster*  
3_2 91-100

Capture, updating and evaluation of field and analytical data for Bulgarian soils  
*I. Kolchakov, B. Georgiev, D. Stoichev*  
3_3 101-106

Development of the Soil Information System for the Czech Republic  
*J. Kozak, J. Nimeeek, O. Vacek*  
3_4 107-114

Second-generation soil maps of Denmark – a case study from Western Zealand  
*Ege Lau Frandsen, H. Breuning-Madsen*  
3_5 115-124

Development of soil information systems in the Federal Republic of Germany - status report  
*H.J. Heineke, W. Eckelmann*  
3_6 125-132
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>The FISBo BGR Soil Information System: State of the Art</td>
<td>3_7</td>
<td>133-140</td>
</tr>
<tr>
<td>Land information systems in Greece: past, present and future</td>
<td>3_8</td>
<td>141-150</td>
</tr>
<tr>
<td>T. Lelentjis, J. Alatas, L. Toudios, S. Floras, G. Kapetanak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A database for sustainable agriculture and environmental protection in Hungary</td>
<td>3_9</td>
<td>151-164</td>
</tr>
<tr>
<td>G. Várallyay, J. Szabó, L. Pásztor, E. Michéli</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOSIS – Lombardy soil information system for sustainable land management</td>
<td>3_10</td>
<td>165-170</td>
</tr>
<tr>
<td>L. Andreoli, S. Brenna, M. Brigatti, D. Fasolini, R. Rasio, A.Rudini, U. Zecca</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Lithuanian Soil Database for sustainable Land Use: developments and planning</td>
<td>3_11</td>
<td>171-176</td>
</tr>
<tr>
<td>Vanda V. Buivydaite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using a soil information system to combat soil erosion from agricultural lands in Norway</td>
<td>3_12</td>
<td>177-180</td>
</tr>
<tr>
<td>Åge A. Nyborg, O. Klakegg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creating an FAO-compatible soil map of Poland</td>
<td>3_13</td>
<td>181-186</td>
</tr>
<tr>
<td>S. Bialousz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Romanian Soil &amp; Land Information System – an overview</td>
<td>3_14</td>
<td>187-196</td>
</tr>
<tr>
<td>C. Răujiă, V. Vlad, I. Munteanu, S. Cârstea, M. Dumitru, R. Lăcătus, C. Simota, Ruxandra Vintilă, D.M. Motelică</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROMSOTER-200: a Digital Soils and Terrain Database for Romania</td>
<td>3_15</td>
<td>197-214</td>
</tr>
<tr>
<td>I. Munteanu, C. Grigoras, Sorina Dumitru, C. Simota, Elena Dobrin, Victoria Mocanu, C. Iordachescu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Soil Information System of Slovakia and its utilization in land evaluation</td>
<td>3_16</td>
<td>215-218</td>
</tr>
<tr>
<td>J. Hraško, J. Kobza, V. Linkeš</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land information systems for sustainable development in the UK</td>
<td>3_17</td>
<td>219-234</td>
</tr>
<tr>
<td>M.E. Proctor, P.A. Siddons, R.J.A. Jones, P.H. Bellamy, C.A. Key</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Section 4: Techniques and Technologies**

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>An integrated agrometeorological forecasting system for Bulgaria</td>
<td>4_1</td>
<td>237-242</td>
</tr>
<tr>
<td>G. Georgiev</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-dimensional Soil Prediction: Fuzzy Rules and a GIS</td>
<td>4_2</td>
<td>243-250</td>
</tr>
<tr>
<td>M. Ameskamp, J. Lamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Architecture of the NIBIS Soil Information System of Lower Saxony, Germany</td>
<td>4_3</td>
<td>251-258</td>
</tr>
<tr>
<td>H.-U. Bartsch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multivariate distance methods for geomorphographic relief classification</td>
<td>4_4</td>
<td>259-266</td>
</tr>
<tr>
<td>K. Friedrich</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baden-Württemberg pedological information system – principal aspects of system conception</td>
<td>4_5</td>
<td>267-272</td>
</tr>
<tr>
<td>C. Fritz, F. Waldmann</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparation of MMK documentary Form A for practical applications</td>
<td>4_6</td>
<td>273-278</td>
</tr>
<tr>
<td>K.-J. Hartmann, G. Günther, D. Bothmer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Definition and Use of Functional Soil Horizons as Keys in Spatial Land Information Systems
J. Lamp, M. Ameskamp

Integrating GIS and process models for land resource planning
A.K. Bregt, J. Bulens

Linking digital soil maps and databases to simulation models: functional soil map aggregation in The Netherlands

Neural computing approach to soil monitoring systems in Poland
T. Stuczyński, J. Pauly, H. Terelak

The Romanian PROFISOL Database
A. Canarache, V. Vlad, I. Munteanu, N. Florea, Anisoara Rasnoveanu, Daniela Popa

Section 5: Environmental Applications

Vulnerability of main Bulgarian soils to acidification
D.A. Stoichev, I.H. Kolchakov

The potential risk of water and wind erosion on the soils of Czech Republic
M. Janecek

SOPIC: A soil information tool for research and environmental planning
K. Friedrich, P. Stock, Th. Vorderbrügge

Pedo-regional representativeness of site-specific data from small-scale soil maps
J. Utermann, G. Adler, O. Düwel, R. Hartwich, R. Hindel

A Land Information System for the application of sewage sludge in Greece
S.P. Theocaropoulos, A. Trikatsoula, D.A. Davidson, F. Tsouloucha, E. Vavoulidou

Esplan – software for engineering assessment of soils in Italy
D. Magaldi, G.L. Ricciardulli

Appraising levels of soil contamination and pollution with heavy metals
R. Lacatusu

Spatial Information Systems for Environmental Impact Assessment in the UK
M.J.D. Dufour, S.H. Hallett, R.J.A. Jones, J.W. Gibbons

Section 6: Land Evaluation

Root zone capacity maps for Denmark based on the EU soil profile analytical database
N.H. Jensen, Th. Balstrøm, H. Breuning-Madsen

A soil information system as a tool for conservation and sustainable land use
A. Hagemeister, P. Meier, TH. Vorderbrügge

Using soil data to predict potential native woodland distribution in Scotland
W. Towers, D. C. Macmillan, S. Macleay
### Section 7: Posters

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>A systematic calibration and validation procedure for a soil-crop model</td>
<td>7_1</td>
<td>461-468</td>
</tr>
<tr>
<td><em>S. Ducheyne, M. Vanclooster, J. Feyen</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A database of measured soil hydraulic properties for Europe (HYPRES)</td>
<td>7_2</td>
<td>469-470</td>
</tr>
<tr>
<td><em>A. Lilly, J.H.M. Wösten</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information on agricultural soils in Finland</td>
<td>7_3</td>
<td>471-472</td>
</tr>
<tr>
<td><em>J. Sippola</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MMK characterisation and classification of site conditions in the new federal states of Germany</td>
<td>7_4</td>
<td>473-478</td>
</tr>
<tr>
<td><em>D. Deumlich, J. Thiere, Monika Frielinghaus, L. Voelker</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geoscientific maps of Baden-Württemberg developed by GIS applications</td>
<td>7_5</td>
<td>479-480</td>
</tr>
<tr>
<td><em>C. Fritz, R. Schweizer, J. Schuff, G. Sokol</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A spatial information database for integrating soil, land use and relief</td>
<td>7_6</td>
<td>481-488</td>
</tr>
<tr>
<td><em>E.D. Spies, S. Broschinski, K. Friedrich, Th. Vorderbrügge</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedotransfer functions for Portuguese soils</td>
<td>7_7</td>
<td>489-492</td>
</tr>
<tr>
<td><em>M. da Conceição Gonçalves</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Characterizing vulnerability to acidification using the buffering capacity of soils</td>
<td>7_8</td>
<td>493-496</td>
</tr>
<tr>
<td><em>I. Gavriluta, Z. Borlan</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Section 8: Appendices

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute coding: Database Dictionary of the Soils Geographical Database of Europe at scale</td>
<td>8_0</td>
<td>497-552</td>
</tr>
<tr>
<td>1:1,000,000 - (Version: 3.21, 30/10/1996)</td>
<td>8_1</td>
<td>499-538</td>
</tr>
<tr>
<td>List of participants</td>
<td>8_2</td>
<td>539-546</td>
</tr>
</tbody>
</table>
The European Soil Bureau

Summary

Soil is one of the essential elements of the biosphere which necessitates a global policy for management, evaluation and conservation (Borlaug and Dowswell, 1994). To implement such a policy, it is necessary to have information harmonized both in space and time (Bouma and Bregt, 1989).

The European Commission is the originator of several programmes aimed at acquiring soil data (CEC-JRC, 1995). Associated with other sources of information (water, air, land management), these data are a valuable aid for decision support processes, in particular for the control of agricultural production (Vossen and Meyer-Roux, 1995), land management and environmental protection (Blum, 1990).

Introduction

The Monitoring Agriculture with Remote Sensing (MARS) programme enhanced and developed the geographical database for soil cover at a scale of 1:1,000,000 (Meyer-Roux, 1987). The MARS Soil and GIS Support Group brought together experts from different EU countries to propose a methodology that would constitute a scientific network for the acquisition and exchange of information on soil and related subjects (Burrill and King, 1993). Convening this Group resulted in contact with the abundant national and international studies, but also highlighted the absence of co-ordination not only between countries, but also between different Directorates-General of the European Commission.

The Soil Information Focal Point (SIFP) evolved from the MARS Soil and GIS Support Group and was formally set up at the Joint Research Centre (JRC), Ispra, Italy, in 1994. Following the work and initiatives stimulated by the European Environment Agency (EEA) Task Force, its mission was to manage information elaborated at the 1:1,000,000 scale and to organize thinking on the Commission's future needs for soil data.

Three initiatives have been identified:

1. The creation of a co-ordination group from the Directorates-General of the European Commission (Inter DG Group) which includes the EEA.
2. Support for a second meeting of Heads of Soil Surveys and those responsible for the management of databases in the EU (Hodgson, 1991).
3. The creation of a scientific working group termed “Soil Information System Development” (SISD) bringing together experts in soil science and information systems.

The Inter-DG Group has produced a report identifying the demand for soil information from the Commission (CEC-JRC, 1995). The report highlights the large requirement for soil information, both within the Commission and in external institutes and organizations. This requirement is growing due to an increased focus on environmental issues and planning for sustainable land use. Currently, however, much of this need is not being met. The required information is either non-existent, exists only at an unsuitable resolution or is only available as incompatible or non-harmonized datasets from national or regional organizations.

The second meeting of the Heads of Soil Survey and those responsible for management of databases in the EU was held in Orléans in December 1994. The main recommendations of the meeting were (Le Bas and Jamagne, 1996):

1. Support for the ongoing process of updating the European geographical and analytical soil database corresponding to the 1:1,000,000 scale.
2. The establishment of the Soil Information System Development (SISD) working group.
3. The need for a more detailed database in Europe at scale 1:250,000.
4. The creation of a European Soil Bureau.

In 1996, the SISD working group produced an important policy paper entitled “European Soil Information Policy for Land Management and Soil Monitoring” (King and Thomasson, 1996) that sets guidelines for future European soil information policy. It recommends the creation of a European Soil Bureau.

The European Soil Bureau (ESB) was created in 1996 as a new body within the European Commission. It is located at the Joint Research Centre (JRC), Ispra, Italy, and is part of the Agriculture Information Systems Unit (AIS) of the Space Applications Institute (SAI). Its aim is to carry out scientific and technical duties in order to harmonize soil information relevant to Community policies, its relevant General Directorates (DGs), to the European Environment Agency (EEA) and to concerned institutions of the Member States. It reinforces the work which has been done by the Soil Information Focal Point (SIFP). It has been created following the recommendations of the European Heads of Soil Survey of the EU Member States and the Inter-DG Co-ordination Group on Soil Information of the European Commission. It is the result of a long development of the European soil science community that started in 1952 with the first attempts to create a harmonized soil map of Europe.

From 1952, studies were made of the different soil classification systems in Europe, with a view to eventual harmonization and production of a common system. The first result was the publication of the FAO soil Map of Europe at scale 1:2,500,000 (FAO, 1965). During the 1970s, work continued under the auspices of FAO on the Soil Map of Europe at scale 1:1,000,000. The legend was designed at the same time as that of the World Soil Map at scale 1:5,000,000, (FAO, 1975). Because of financial problems, the work was stopped by FAO and the map has never been published.

In 1978, the European Commission decided, with the agreement of the FAO, to revive the work for the countries of the European Communities. The Soil Map of the EC at scale 1:1,000,000 was published in 1985 (CEC, 1985). In 1986, the territories of Austria and Switzerland were added to the map at the initiative of UNESCO and the International Soil Science Society (CEC-ISSS, 1986).

The CORINE programme resulted in the computerization of the EC Soil Map in 1986 (Platou et al., 1989), constituting the first digital spatial soil database (version 1.0). The Soil and GIS Support Group was created within the MARS programme to improve the EC soil map and related database (Burrill and King, 1993). The development of the 1:1,000,000 scale European Geographical Soil Database was a good initiative to increase contacts between soil scientists, to exchange information across national borders and to create the first unified platform for decision makers. However this project also revealed the absence of co-ordination between member states, and between different Directorates-General of the Commission. In order to remedy this situation, the Joint Research Centre (JRC) created a Soil Information Focal Point (SIFP) in 1994 to organize thinking on the Commission’s future needs and to suggest initiatives for better harmonization of soil activities in Europe.

Two SIFP working groups were set up: a co-ordination group from the Directorates-General of the Commission (Inter DG Group) which includes the European Environment Agency (EEA), and a Soil Information System Development (SISD) working group. Official approval for the European Soil Bureau was given by Heads of Soil Survey at their second meeting (Le Bas and Jamagne, 1996). In June 1996, the ESB was officially launched with the approval of delegates from all the EU countries.

The Bureau is currently based at the Space Applications Institute within the Agriculture Information System Unit (AIS) of the Joint Research Centre (JRC) at Ispra, Italy. The activities of the ESB are of a horizontal nature, but are located within the environment and major natural hazards sector. The capabilities of the Bureau will be built up over several years with the intention of reaching full capacity by 1998. Participation of dispersed national experts within the ESB will be encouraged. By 1998 the Bureau should be a substantial centre of excellence capable of undertaking an extensive range of scientific and technical activities.

The major tasks assigned to the Bureau are:

- To serve as a point of contact for co-ordination of soil data needed for numerous purposes by the Commission or other external bodies.
- To respond to the needs of the Commission furnishing information necessary for the programmes of the DGs.
- To develop and implement a policy and guidelines for the production of harmonized, and therefore compatible, soil data.
- To develop and implement a policy for the distribution of information concerning soils, with the objective of favouring exchange of data without compromising the interests of the contributors.
• To develop and distribute the tools facilitating the exchange and use of soil data.

• To establish links with international bodies, such as FAO and UNEP, in order to assure a reciprocal flow of information.

The Bureau’s organizational structure is still evolving (Figure 1).

Organization of the European Soil Bureau (status end 1996)

<table>
<thead>
<tr>
<th>Secretariat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Research Centre (JRC)</td>
</tr>
<tr>
<td>Space Applications Institute (SAII) AIS-Unit</td>
</tr>
<tr>
<td>Secretary: L. Montanarella</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advisory Committee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representatives of EU Member States</td>
</tr>
<tr>
<td>Representatives of EFTA Member States</td>
</tr>
<tr>
<td>Observers from neighbouring countries and international organizations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inter-DG Coordination Group on Soil Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representatives of the various EC Directorates General</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scientific Committee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominated by the Secretariat</td>
</tr>
<tr>
<td>Operates through small working groups</td>
</tr>
<tr>
<td>Chairman: D. King</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Geographical Database of Europe 1:1 000 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Geographical Database of Europe 1:1 000 000 update, improvements and maintenance</td>
</tr>
<tr>
<td>Chairman: M. Jamagne</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information Access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working group for the definition of data distribution and licencing procedures</td>
</tr>
<tr>
<td>Chairman: R.J.A. Jones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Geographical Database of Europe 1:250 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific coordination of the Georeferenced Soil Database at Scale 1:250 000</td>
</tr>
<tr>
<td>Chairman: P. Finke</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Hydraulic Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil data to derive hydraulic parameters Pedotransfer functions</td>
</tr>
<tr>
<td>Chairman: J.H.M. Wosten</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Northern Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Territorial correlation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Western Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Territorial correlation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Eastern Europe</th>
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Figure 1: Organization of the European Soil Bureau.

At the end of 1996 the ESB comprised:

• A small Secretariat to co-ordinate and catalyze its activities and provide technical support as required.

• An Advisory Committee composed of national representatives from each EU and EFTA Member State, observers from neighbouring countries and international agencies to evaluate and advise on the Bureau’s activities.

• An Inter-DG Co-ordination Group on Soil Information representing the European Commission’s services concerned with soil information. This Group determines the needs of the Commission for soil information and conveys these to the Secretariat for subsequent action.

• A Scientific Committee nominated by the Commission according to its specific needs and the objectives specified by the Advisory Committee. This committee operates by small Working Groups.

The following Working Groups are currently active:

• Soil Geographical Database of Europe at scale 1:1,000,000 Working Group.
• Information Access Working Group.
• Soil Geographical Database of Europe at scale 1:250,000 Working Group.
• Soil Hydraulic Parameters Working Group.

This Advisory Committee is composed of one (Full Member) representative from each EU Member State carrying particular responsibilities for national soil surveys, soil databases and soil-related policy. EFTA countries are also represented. Representatives from EU neighbouring countries and international organizations are considered as observers. The Advisory Committee meets annually. The following objectives have been set for the Advisory Committee of the ESB:

1. Evaluate and monitor the activities of the ESB.
2. Advise the Secretariat on the objectives to be achieved.
3. Adjudicate formally on the guidelines or resolutions prepared by the Secretariat.
4. Advise on strategic issues such as the co-ordination and co-operation with national and international organizations.
5. Assure efficient communication between the CEC, ESB and the appropriate national political bodies.
6. Ensure the supply of information to the interested parties in the Member States.
The first meeting of the Advisory Committee was held on 13 June 1996 at JRC Ispra (I). The representatives of the EU member states, the EFTA member states and international organizations (e.g. FAO) reviewed the current activities of the newly established ESB. The policy documents (CEC-JRC, 1995; King and Thomasson, 1996) were approved.

The major recommendations of the Advisory Committee were:
1. Continuation of the ongoing work on updating the European soil geographical and the soil profile analytical databases at 1:1,000,000 scale.
2. Close collaboration with the newly-established European Topic Centre on Soil.
3. Finalization of the information access issues and a policy for data distribution.
4. The endorsement of the project to compile a future 1:250,000 soil geographical database for Europe.

The Inter-DG Co-ordination group on soil information establishes the specific needs for soil information within the Commission. The Commission is active in many fields involving soil information issues within and also outside the EU. The main EU policies that have an impact on soil information are the Environment Action Programme, the Common Agricultural Policy (CAP), the Framework Programme for research and technological development (RTD). The Soil Geographical Database for Europe Working Group has been operating for many years, well before the creation of the ESB. It has been the driving force of a joint effort of many soil scientists from different European countries. Chairman of the group is Dr. M. Jamagne (INRA-SESCP, France).

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Four working groups (see Figure 1) are currently active within the ESB:

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- The Information Access Working Group (IAWG) has turned out to be one of the most important within the ESB, as it is in charge of the development of a policy for access to European soil databases. The issue of data ownership is one of the most delicate, as it touches relevant interests of each contributing institute within each country. The overall aim of the group has been to develop guidelines that ensure the maximum protection of data ownership whilst at the same time minimising restrictions on use of the data by outside organizations. Chairman of the IAWG is Dr. R.J.A. Jones (SSLRC, UK).

- The Soil Geographical Database of Europe 1:250,000 Working Group represents the future of the ESB. It is concentrating on the design and construction of the new European soil geographical database at scale 1:250,000. It was established following a feasibility study by DG XI (Environment) (Dudal et al. 1993), that recommended the creation of such a database for future environmental applications within the EU. Chairman of the
The Soil Hydraulic Parameters Working Group has been established independently of the ESB, financed through the Human Capital and Mobility Network of the EU. During the second year of its existence it applied for inclusion in the activities of the ESB, as it is concerned with the compilation of a soil hydraulic parameters database linked to the 1:1,000,000 soil database of Europe. It is anticipated that the final version of the database will be distributed through the ESB according to the data access procedures formulated by the IA WG. Chairman of the group is Dr. H. Wosten (SC-DLO, Wageningen, NL).

The soil geographical database presently has four components:

1. the meta-database;
2. the so-called geographical database;
3. the soil profile analytical database;
4. the knowledge database.

The geographical extension (Figure 2) currently covers (Version 3.2) the EU Member States (excluding Sweden, Finland and Austria) and the Central and Eastern European countries (Poland, Czech Republic, Slovakia, Hungary, Romania and Bulgaria). It can be accessed (read-only) on the World Wide Web through a GIS-WWW gateway and is reachable via the following address:

http://taws08.jrc.it/gis-gateway/gateway_main.html

New EU countries and neighbouring countries are expected to be included during the next few years. A major challenge is to integrate the various databases (profile, pedotransfer rules, metadatabase, reference catalogue, etc.) into a single European Soil Information System (EUSIS). Such a system, covering the complete EU and the Central and Eastern European countries (CEEC) is expected to be completed by 1998.

The continuation of studies at the 1:1,000,000 scale for the Eastern European countries (NIS) and the Southern and Eastern Mediterranean countries (SEMC) is foreseen after 1998 in close collaboration with FAO.

The Information Access Working Group has developed guidelines (Jones R.J.A. and Buckley B., 1996) that are a major breakthrough in European data access policy. The key element is that data ownership and copyright remain with the Contributor. This means that the data supplied to the ESB by the Contributors for the creation of the European Soil Database are owned by the Contributors and not by the Commission. On the other hand, the principle of regulated access to the data by everybody is reinforced. The combination of these two statements produces a data access policy that maximizes database access and use and safeguards the intellectual property by the Contributors. Licensee of all the soil data is the European Commission through its European Soil Bureau that becomes the focal point for data licensing and distribution. Data are leased for a limited time and not sold. Charging is according to a price matrix. Data to be distributed are the Soil Geographical Database of Europe Version 3.2 and the Soil profile Database of Europe Version 1.0. The price matrix adopted differentiates the cost of lease of data according to the use. Minimum charge (cost of handling) is applied to Contributors and non-profit organizations for internal use. In the case of external use by these organizations, a charge is made. Maximum charging is applied to full commercial uses by private organizations.

The 1:250,000 Soil Geographical Database of Europe project started after a feasibility study by the Directorate General XI (Environment) prepared by R. Dudal, A. Bregt and P. Finke in 1993. This study was commissioned to meet the still growing demand for soil parameters in the environmental context – for which assessment on levels of regions or watersheds seems most appropriate. It was also initiated to support the databases already developed by CORINE, e.g. on land cover and biotopes at a 1:1,000,000 scale. Direct contact with national soil surveys and land research centres of the former 12 EU Member States demonstrated that the national coverage of soil mapping at scales appropriate for a more detailed soil map ranged from 10% to 100%.

However in all countries, some areas were found with coverage sufficient to be converted into a 1:250,000 soil map through generalization, complemented eventually with some additional fieldwork. Special attention was paid to soil and terrain attributes which need to be recorded in terms of environmental protection. Given the low availability of soil data suitable for preparing a more detailed soil map of Europe, it was determined that “a wall to wall soil map” or soil database could be accomplished only in the long term, but a recommendation was made to carry out studies in small pilot zones with a good coverage of data, with the aim of developing a methodology, a common legend and a common database useful for the final database at scale 1:250,000. This principle was also endorsed by the European Environment Agency (Scoping Study on Establishing a European Topic Centre for Soil, DGGU Service Report no. 47, 1995).
In order to start the project, a working group was created within the ESB. It is charged with the preparation of the Manual of Procedures, the delineation of the pilot areas and the overall scientific supervision of the project. From the operational point of view, the database will be created in selected pilot areas by regional co-ordinators for territorial correlation of each sub-project (Figure 3). Following the selection of the first pilot area, the work has already started with the delineation of an area covering the North Italian quaternary plains. Project leader for that area is R. Rasio (ERSAL-Lombardia).

The preparation of the draft Manual of Procedures (“Geo-referenced soil geographical database for Europe”) is completed. At the same time a draft soil map of Europe at scale 1:5,000,000 is being prepared. This map will be the basis for the delineation of the pilot areas of the project. A revised second version of the manual will then be submitted to the Scientific Committee of the ESB. The incorporation of the comments of the Scientific Committee will lead to the third draft edition to be submitted to the Advisory Committee. After approval by the Advisory Committee the Manual will be published as Version 1.0.

At this stage, regional co-ordinators will be nominated and the first pilot areas finally delineated. Experience gained during implementation of the Manual of Procedures will be incorporated in subsequent versions of the Manual.

Figure 2: Extension of the Soil Geographical Database of Europe at Scale 1:1,000,000, Version 3.2. Countries to be included by 1998 are shown in light grey.
The general concepts and the structure of the database are still under discussion. Preliminary proposals suggest a relational structure being composed of objects: soil bodies (themselves subdivided into horizon bodies), soilscape and soil regions. Soil bodies are defined by the FAO-UNESCO 1990 classification: the parent material, the depth to any obstacle to roots and the dominant texture. The soilscape should be a grouping of contiguous soil bodies in a watershed sub-basin. This means that a soilscape containing a characteristic grouping of soil bodies may be split on a map when the soilscape covers more than one bordering watershed sub-basin. Soil regions are delineated on a 1:5,000,000 map of Europe on the basis of parent material for the definition of major classes of soil regions, and subsequently a combination of texture, parent material and main relief to define and delineate soil regions.

The 1:250,000 project presents several aspects of great interest to national, regional and local administrations. The regional administration of one pilot area (the quaternary plains of Northern Italy) has already demonstrated some interest. Preliminary discussions revealed a desire for the creation of a consortium of North Italian Regions for such a project. This could be a demonstration case for similar activities in other parts of Europe.

In conclusion, the European Soil Bureau, established at the JRC in Ispra in 1996, can now be considered operational. It essentially collects soil information identified as needed by the Member States through its Advisory Committee and by the European Commission through the Inter-DG Co-ordination Group on Soil. It transfers these needs and requirements to its Scientific Committee then translates them into structured projects and establishes specific working groups charged with the scientific and technical tasks required. The resulting products (databases, guidelines, etc.) are then distributed to the European user community through appropriate information access procedures.
References


Summary

Within the framework of the EU programme Monitoring Agriculture with Remote Sensing (MARS), a geographical database for the soil cover of Europe at 1:1,000,000 scale (CEC, 1985) was developed for the EU Directorate-General (Agriculture) with support from the Joint Research Centre. This programme led to a clearer appreciation of the nature and precision of information necessary for sustainable land use.

The preparation of a report expressing the requirements of all the Directorates-General of the Commission has further clarified the situation. The present paper summarises an initial response to these requirements by defining the needs and proposing some aims and objectives.

Introduction

The European Commission’s MARS programme initiated the development of a geographical database for soil cover at an accuracy of 1:1,000,000 scale (King et al., 1994; Madsen and Jones, 1995). The Soil and GIS Support Group, which brought together experts from different EU countries, has proposed a methodology and constitutes a scientific network for the acquisition and exchange of information (Burrill and King, 1993). Group members were familiar with the abundance of national and international studies, and became aware of the lack of co-ordination between countries, and between different Directorates-General of the Commission. The latter was addressed by the creation of a co-ordination group from the Directorates-General of the Commission (Inter DG Group) which includes the European Environment Agency (EEA).

The Inter-DG Group produced a report identifying the demand for soil information from the Commission (CEC-JRC, 1995; Burrill, 1996). The policy in the domain of soils appeared to be scattered and compartmentalized according to the needs of each DG, without any evident co-ordination. The objectives were to analyse this demand, to specify the needs for soil information and to propose the directions for programmes to coordinate the collection and management of data (King and Thomasson, 1996).

Analysis of demand and definition of needs

Soil functions

The first functions of soil are those involved in the production of biomass, i.e. agricultural and forestry production. It involves principally physical support for plants and a reserve for the supply of water and mineral nutrients. With the emergence of environmental problems, these functions are endangered and other functions have emerged. For example, water managers emphasise the critical role of soil to filter out pollutants. It is equally an essential link for biodiversity at levels ranging from microbiology to landscapes. We should also recall the support function of soil, often neglected, in construction works.

An interdisciplinary approach to these phenomena indicates that these functions are not dissociated. The soil emerges as a multi-purpose reactor taking a leading role in the major bio-geochemical cycles. We can mention research on the role of
the soil in the production of greenhouse gases. All productive use of the soil (biomass, water, construction materials) entails a modification of these cycles. The soil should be considered as a nonrenewable resource in the short-term; misuse can cause an irreversible disequilibrium (e.g. the accumulation of heavy metals caused by disposal of urban wastes).

There is a requirement to respect a certain equilibrium between the different soil functions. The economic context may dictate short-term decisions, but the protection of other soil functions must be respected for the long term. These other functions are not necessarily included in an economic appraisal (e.g. quality of water draining to groundwater supplies; maintenance of landscape diversity). However, in certain situations it can be established that disequilibrium leads directly to a reduction in productive potential (due to soil compaction, slaking, erosion). The term ‘sustainable agriculture’ is used to underline this relationship between short- and medium-term soil functions.

Finally, human activities other than agriculture can have dire consequences for soils, for example, the production by industry of atmospheric pollutants causing acidification of soils; construction works or drainage channels initiating erosion; the disposal of urban waste resulting in contamination, etc. Guarding the soil heritage is not limited only to the agricultural context, but has a global dimension if the quality of terrestrial ecosystems is to be maintained.

**Role of the Commission and its partners**

The role of the European Commission is to participate in the orientation of land use policy and to support agricultural production in the countries of the EU, while recognising the interests of neighbouring countries or principal economic partners. Equally, it is to define quality criteria for the environment as a function of the risks incurred.

Taking account of the different soil functions already stated, it is necessary to keep a watch on their good management under the economic and environmental constraints to which they are subject. Both spatial and temporal monitoring projects can be envisaged: for spatial aspects, a good balance between the functions asked from the soils of an area, and their genuine capability to assure those functions, should be verified. A concrete case may be the choice of cropping system to promote or support in a region; another case is the scientific definition of less favoured areas. For temporal aspects, good equilibrium of functions including a sustainable land use system should be verified. This requires a monitoring network in order to measure trends and changes in soil properties (e.g. organic matter, structure, leachate quality).

Member states and regions already have many well-designed programmes on soil mapping and monitoring. The role of the Commission is to watch over the compatibility of these programmes, to promote exchange of data and compare the potentials between regions (or their level of degradation). It must also ensure that it has its own information system, in order both to handle the information that is transmitted to it and to have an overall picture of these phenomena at the EU scale. Environmental problems and economic strategies for agricultural production are transnational. It is therefore a priority to extend the information system to states bordering the EU and secondly to global level.

Exchange of information remains one of the most important issues. It concerns firstly the internal relations between different DGs and their requests from other European bodies having a close or more distant connection with soils (e.g. EEA, learned societies). The Commission must then ensure a flow of information with its national and regional partners and in the same way encourage exchanges between regions. Finally it must participate actively in global programmes involving knowledge and monitoring of soils, in collaboration with international organisations active in the agricultural or environmental domains (FAO, UNEP, ISRIC, etc).

**Nature and quality of information**

Soils show a strong variability of characteristics in space and sometimes a rapid change of properties with the passage of time. This paper attempts to specify the nature of pedological data as viewed from these two angles, to determine the precision and resolution of information appropriate to the level of decision required.

**Spatial nature of soil data**

In many cases, it is important to have a complete picture of soil properties in space and time. The classical method to achieve this is soil mapping, widely used by the different EU countries. The strong spatial variability of soils leads to emphasis on “simple” parameters, those easily measurable during programmes of field survey (e.g. texture, colour, etc). A large number of observations, often purely qualitative, allow reliable maps to be produced.
Conversely, these maps can be criticized as not revealing information on "complex" soil parameters. The development of Geographical Information Systems (GIS) has not necessarily resolved this problem, since it is often limited to the simple digitization of conventional maps. The parameters termed "complex" are so-called to the extent that their acquisition necessitates complex or expensive apparatus or procedures (e.g. hydraulic conductivity, chemical sorption processes, etc). Complementary to mapping processes, research work has made much progress in identifying statistical and deterministic linkages between complex soil parameters and more easily mappable properties. Many such linkages, termed pedotransfer functions have been elaborated or are being developed (Bouma and Van Lanen, 1987; Lilly, 1995).

The definition of useful parameters should not therefore be limited by the constraints of cartographic surveys. It is first necessary to define the parameters needed to describe the soil functions identified in preceding paragraphs. The number of models to simulate complex processes involving soil parameters is being continuously enlarged. For example an agrometeorological model takes account of the growth and development of a plant in course of time. It allows simulation of reality and therefore estimation of needs for irrigation water, yields, etc. Depending on its complexity, a model of this kind needs soil parameters, such as water reserves, rooting depth, saturated hydraulic conductivity, etc.

In a GIS, we will therefore distinguish data measured and spatially georeferenced from those that are deduced with the aid of pedotransfer functions. This will permit specification of the methods by which the information has been elaborated. For measured data, the standardization of measurement methods is essential for any comparison of information. For deduced data, definition of the mathematical functions or the rules of deduction are specified systematically and included in the database, particularly in order to assess the reliability of the final results.

**Temporal nature of soil data**

We can distinguish more or less permanent parameters (texture), those which change over the long term (content of heavy metals) and finally, those which vary rapidly with time, generally according to an annual cycle (water content, microbiological activity). The first set of parameters are important to define intrinsic soil properties and thus potentialities. The second set are important to measure anthropo-morphic changes (e.g. source or sink functions of soils in the production of CO₂). The third category facilitates the study of biomass production and also of drainage to the groundwater zone.

Following this terminology, temporal variability of soil parameters should be envisaged at different time-scales. Bearing in mind the strong spatial variability of soils, procedures to measure temporal changes require very precise definition. A spatial sampling error can introduce a false interpretation of the evolution of properties with time.

The development of measurement methods involving space and time together entails some major technical difficulties. The strong periodicity of some measurements implies that their number will be limited and therefore that there is a limitation for knowledge of their spatial variability. It is thus necessary to develop functional models which take account of phenomena varying in time.

**Conclusion on needs**

In the face of express demands for rational management of the productive functions of soils, and also the multiplicity of actions undertaken in the regions of member states, it is necessary that Community policy be supported by a harmonized soil information system. This particularly concerns the sectors where the Commission is called to play a role (e.g. guiding and supporting agricultural production or the definition of quality norms for the environment).

Inter-regional comparisons require definition of standards for information (measurements, statistical sampling, methods of spatialization and modelling). It is equally necessary to promote the acquisition of information in areas where it is deficient, in order to command a coherent system at the European scale. Finally the diversity of measurement and sampling techniques between member states makes the development of methods to control the quality of data produced indispensable. Taking account of the weakness of Community technical structures in the domain of data acquisition, it is evident that strong support from member states is desirable.

Levels of resolution and precision for soil information should be defined in relation to programmes over which the Commission has control. If most information is collected at the level of states and regions, a minimum information system to respond to the proper needs of the Commission must be envisaged. This would include basic measurements, methods of generalisation, comprising pedotransfer functions as well as models describing the evolution of changes in phenomena over time. Such a
minimum system should be defined in a co-ordinated manner involving the main programmes of the DGs and EEA. A unified system should avoid the duplication of effort.

**Priority actions**

The proposed actions were based on the preceding analysis (King and Thomasson, 1996). They concerned harmonization of information, co-ordination of programmes and the collection of new data. A further aspect was the management and use of existing and future data by creating a harmonized and nested information system for Europe. The following priority actions and needs were identified without prejudging the eventual administrative structures.

**Harmonization and co-ordination**

**Harmonization of information**

The needs for comparison of information at European scale necessitates data harmonization. Before a direct approach to this problem can be made, it is desirable to review already existing information in Europe and analyse its compatibility. Defined by the term “metadatabase”, such a system comprises the list of projects involving soil studies, in particular the national mapping programmes. For each of these programmes it is necessary to record the areas surveyed, the variables collected, the ownership of the data, the body managing the data and ease of data accessibility. Similarly, a review of work undertaken on pedotransfer functions and modelling would improve understanding of those soil parameters already accessible, against those where fundamental knowledge in modelling is still needed. The review should be established in parallel with work on standardization. Four types of standards should be defined in collaboration with international bodies already involved in this work (ISO, FAO):

1. Define sampling protocols (equally important for mapping and monitoring purposes).
2. Define protocols for field and laboratory measurements. In default of agreement, methods for correlation should be promoted. (These converge with the similar work on pedotransfer functions)
3. Promote research to develop scaling methods for handling generalization in space and time of locally acquired results. This converges with work on mapping methodology.
4. Set up norms for exchange and access to data according to the types of end-use and the confidentiality of the information.

These four priorities for harmonization of data are not linked to particular programmes of data acquisition. It is a matter of installing accepted norms and a common scientific culture at European level which encourages the exchange of information. Similar work towards harmonization of information is already in progress internationally. Consequently, implementation at a European scale is not technically challenging, but more a matter of political willingness.

**Co-ordination of programmes: need for a European Soil Bureau**

The harmonization of data is necessary but not sufficient to favour exchanges. It is also necessary to provide for co-ordination of programmes between DGs, within the Commission itself, and also between the Commission and its regional, national and international partners. It is essential to have a body able to focus information, to follow the development of programmes and advise the Commission. This body would also assure the guidance and motivation of the working groups described above.

It was therefore proposed that harmonization of information and co-ordination of programmes required the creation of a European Soil Bureau (ESB). This Bureau was created in 1996. Its role and constitution are detailed in “The European Soil Bureau” (Meyer-Roux and Montanarella, 1998).

**Collection of information**

Parallel to the work of harmonizing and exchanging information, it is necessary to forecast the needs of the Commission for accumulating and handling soil data. A first objective is to possess a minimum assemblage of immediately accessible data. A second objective is to develop a firm platform to discuss and test proposals for standardization conceived by the Working Groups.

Data can be collected either directly by measurement on the ground or indirectly from data already existing within member states. In both cases, participation of member states is necessary for the elaboration of the information system. Such a project must not duplicate regional actions but must find the appropriate level of information necessary for the overall administration of European territory.

Following the analysis presented above, we distinguish two main types of action corresponding respectively to spatial data for the improvement of soil maps and temporal data for monitoring soil conditions. Finally a linkage between these two approaches will be proposed.
**Soil mapping**

Elaboration of the 1:1,000,000 Soil Map has generated information for programmes monitoring crop performance (Vossen and Meyer-Roux, 1995) and estimating risk of environmental degradation (Giordano et al., 1991). From the record of these studies it is clearly apparent that in many cases information is insufficient. Work to revise and complete the database should therefore be undertaken. As a priority, extension of the database to cover the new EU countries and then the whole of continental Europe should be pursued in order to possess a complete and coherent decision support tool (Jamagne et al., 1994).

This work is ongoing and will remain a priority for countries bordering the EU. (See more details in Meyer-Roux and Montanarella (1998).) Equally, effort must be applied to the resolution of uncertainties at the 1:1,000,000 scale in order to identify areas with inadequate information.

Due to the limits of the 1:1,000,000 scale dataset, the development of a new mapping programme is suggested at a more detailed scale. It will be necessary in future to handle more precise information and to include the most recent knowledge. Many expert groups, as well as the Inter DG Group, have emphasised the relevance of the 1:250,000 scale (Hodgson, 1991; Dudal et al., 1993). Such an approach corresponds to identifying physiographical landscapes within which the structure and functioning of soil units can be described. It is also a scale where both a general continental overview can be presented, and a dialogue can be sustained by regional examples of specific problems. A scale carrying too much precise data would obscure major tendencies at continental level. Too general a scale, such as 1:1,000,000 is not adequate for regional experts in land management or environmental protection. The 1:250,000 scale forms an economical compromise between these extremes. Such a programme needs to develop a detailed methodology emerging from an international agreement. It must rest on work already realised in Europe and take into consideration international activities, particularly the SOTER project (Batjes, 1990; ISRIC, 1993); see Meyer-Roux and Montanarella (1998).

The report of the Inter DG Group indicates information needs at more detailed scales than 1:250,000. However, to envisage a systematic inventory of the EU at 1:50,000 scale would need enormous resources. Moreover, the time-span required would interfere with responses to changing demand. It would risk leading to a product constantly lagging behind the needs of the moment. In fact, implementation of more detailed programmes would seem to rest with member states and regions in response to their particular needs. In this framework, the Commission's preoccupation is mainly the data harmonization issue in order to facilitate comparison for future use. However, we should emphasize that, in certain cases, the need for precise knowledge of variability in soil properties is indispensable for understanding phenomena affecting large areas (e.g. the role of small wetland zones for denitrification). Also the use of models, as defined in the first part of this report, makes such supporting procedures essential.

To respond to these needs, the development of detailed analysis of small zones representative of larger landscapes is proposed. An assemblage of these zones would constitute a reference network. Such a network would allow the presentation of overall statistics at national scale, as has been done for crop forecasting.

A linkage between this network and the 1:250,000 programme is vital. On one hand, the representativeness of the areas will be assured through analysis of the 1:250,000 map. On the other, the detailed knowledge of the representative areas will resolve many uncertainties of estimations made for the 1:250,000 map. Creation of this network gives a degree of flexibility for actions in response to requests for information on new topics. It is easy to envisage a rapid turnaround for new measurements on a limited number of representative areas by use of systematic mapping procedures.

Finally, good liaison with 1:250,000 programmes is a rapid means of generalizing and presenting reliable responses for large areas (or at least those responses for which there is a good knowledge of the reliability of the information).

**Soil monitoring**

Soil constitutes a non-renewable resource within human perspectives and monitoring. Its quality is a priority of the same order as other essential elements of the environment (water, air, etc). Strong demographic pressure in many European regions, often the presence of ancient industrial installations and the practice of intensive agriculture, are among many arguments for the development of a soil monitoring programme at European scale. The problems of pollution do not recognise frontiers; standards are increasingly dictated at international level. It is thus logical to develop a monitoring programme at continental scale (FAO-ECE, 1993).

Such a programme should be settled in a concerted manner between member states. The principal problem is in the choice of parameters and the measurement methods to adopt. As for the preceding mapping programmes, it is
essential that the Commission holds a minimum assemblage of information in order to have an overall picture that the member states cannot achieve individually, and also to participate in technical or political dialogue.

It is not essential to monitor all soil properties and making heavy demands on equipment or manpower will need to be justified:

1. It is necessary to choose priority soil characteristics affecting real problems (heavy metals, critical loads, etc.)
2. Time steps must be defined. The less mobile elements call for longer time steps – hence they are of more interest to the Commission. More mobile elements with strong annual variability (e.g. nitrogen) need complex measurement techniques which are difficult to standardize and manage at the European scale (CEC, 1991)
3. A protocol for spatial statistical sampling must be provided. A priority task for a working group will be to evaluate options between intensive grid sampling, nested sampling and selection by representative properties.
4. Predefined site protocols are needed.

Use of remote sensing techniques can also be envisaged. Soil monitoring programmes could include more general studies of earth observation.

A programme of soil monitoring must not be limited solely to following changes in soil properties. It must introduce studies to forward understanding of the mechanisms behind the observed changes. Knowledge of the spatial and temporal dynamics is an indispensable link in the process of decision-making. This indicates the necessity of combining monitoring networks with research programmes on causal mechanisms. Similarly a good co-ordination of these programmes will help to orientate priorities for monitoring. This analysis leads also to a need for improved knowledge and harmonisation of modelling programmes.

**Linkages of the proposed programmes**

European projects in the soil domain suffer from excessive dispersion. It is essential therefore to envisage a close linking between the different actions proposed. These will require considerable inputs and feedback from working groups and consultation groups. Diversified demands originate from the DGs themselves. The Soil Bureau thus becomes the motive force to prevent excessive partitioning or dispersion of activities. The definition of a mapping programme at 1:250,000 scale is, for example, a good support to define a sampling strategy for a monitoring programme. The emplacement of a reference network is equally a support to test modelling procedures and to refine a monitoring network within areas chosen for their representative character.

The 1:1,000,000 project already constitutes an overall level of harmonisation. It can therefore serve to orientate priorities for the 1:250,000 mapping, either to choose zones for primary mapping, or to define soil parameters for inclusion in the databases. Finally the metadatabase is also a means to access information and must be linked implicitly to other databases.

The final objective should be a single, nested database (figure 1). It would be associated with an information interface able to seek, according to needs, the necessary data at different scales. A combination of data originating from different mapping or monitoring programmes can furnish a body of information, more valuable than the simple sum of their parts. For such a nested database, programmes to transfer results from one scale to the other are essential. They form part of on-going research on the formalization of mapping methodology and should offer a viable means to quantify reliability.

**Acknowledgment**

This paper summarises the conclusions of a report elaborated with the support of the Soil Information Focal Point of the MARS programme set up by JRC-Ispira. The authors thank all the members of the Soil Information System Development (SISD) working group, and particularly Drs P. FINKE, R. HARTWICH, J.J. IBANEZ MARTI, M. JAMAGNE and L. MONTANARELLA for their help in the discussion and progressive improvements of the proposal.
Figure 1: A nested soil information system for Europe
References


European Soil Database: information access and data distribution procedures

Summary

This paper describes the data distribution procedures proposed by the Information Access Working Group (IAWG) of the European Soil Bureau. The IAWG was set up in 1994 as part of the Soils Information Focal Point (SIFP), under the auspices of the Monitoring Agriculture with Remote Sensing (MARS) Project of the Joint Research Centre, Ispra (I). It is proposed that the IAWG will be retained to advise the Bureau on the access and distribution procedures for the European Soil Database.

The need for European soil data, to assist with planning the sustainable use of land, has grown steadily since the 1970s. This growth is expected to expand from the traditional areas of crop production and soil conservation into the utilities (water, gas and electricity supply) and the finance and environmental sectors. With this expanding market for soil data, availability and access have become important issues.

Data holdings are now viewed as valuable sources of income. Procedures for accessing the data should address ownership, intellectual property rights (IPR), controls and charges for commercial use. These procedures centre on the licensing of data, so a data licence has been drawn up. Its contents are summarised in this document, together with a full list of contributors and the proposed authorization process.

Soil research data distribution procedures require formalization if the long-term future of data collection and the resulting databases are to be assured. The model proposed here is thought to be the most appropriate for use in a European context.

Introduction

The Information Access Working Group (IAWG) was set up at the Soil Information Focal Point (SIFP) Meeting in Hannover in September 1994, in anticipation of European soil data being made available to a wider community. The SIFP itself evolved from the Soil and GIS Support Group of the Monitoring Agriculture with Remote Sensing (MARS) Project, Joint Research Centre, Ispra (I). The IAWG now forms part of the European Soil Bureau (Meyer-Roux and Montanarella, 1998) and will be retained to advise the Bureau on the access and distribution procedures for the European Soil Database. The membership is shown in Table 1.

The original Terms of Reference (ToR) for the IAWG were drawn up after the Hannover meeting in 1994. In consultation with the SIFP and other expert groups, it was agreed that the IAWG should draft Guidelines on Data Access and Distribution using the following ToR:

1. Data Availability
   CEC (JRC, DGs)
   Member State Institutions
   Third Parties (Industry)

2. Accessibility Data
   Format
   Media
   Administration
   Support

3. Data Control
   Conditions – licence agreement
   Monitoring data use
   Appropriate use – scale

4. Data Use
   Research – academic
   Development – R & D
   Commercial – e.g. agrochemicals industry.

R.J.A. Jones
Barbara Buckley
M.G. Jarvis

Soil Survey and Land Research Centre,
Cranfield University, Silsoe,
BEDFORD MK45 4DT, UK
Table 1: Information Access Working Group (IAWG)

<table>
<thead>
<tr>
<th>Members</th>
<th>Address</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr Jaume BOIXADERA</td>
<td>Departamenta d’Agricultura, Ramaderia i Pesca, Generalitat de Cataluña, Alcalde Rovira Roure 177, 25006 LLEIDA, Spain</td>
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<td>Staring Centrum-DLO, Postbus 125, 6700 AC WAGENINGEN, The Netherlands</td>
<td>Member</td>
</tr>
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<td>BGR, Stilleweg 2, 30655 HANNOVER, Germany</td>
<td>Technical Secretary</td>
</tr>
<tr>
<td>Dr R JA JONES</td>
<td>SSLRC, School of Agriculture, Food &amp; Environment, Cranfield University, SILSOE, Bedford MK45 4DT, United Kingdom</td>
<td>Chairman</td>
</tr>
<tr>
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<td>Member</td>
</tr>
<tr>
<td>Participants: specific meetings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr ANNONI</td>
<td>DAMAP, Italy</td>
<td></td>
</tr>
<tr>
<td>Barbara BUCKLEY</td>
<td>SSLRC, School of Agriculture, Food &amp; Environment, Cranfield University, SILSOE, Bedford MK45 4DT, United Kingdom</td>
<td>Meeting Secretary, 1st Meeting, Silsoe, UK</td>
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<tr>
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</tr>
<tr>
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<td>Meeting Secretary, 2nd Meeting, Budapest, Hu</td>
</tr>
<tr>
<td>Dr Jean MEYER-ROUX</td>
<td>Space Applications Institute, Directorate General Joint Research Centre, ISPRA (VA), Italy</td>
<td>Assistant Director</td>
</tr>
<tr>
<td>Dr Luca MONTANARELLA</td>
<td>Space Applications Institute, Directorate General Joint Research Centre, ISPRA (VA), Italy</td>
<td>European Soil Bureau</td>
</tr>
</tbody>
</table>

Four Information Access Working Group Meetings have been held, at:

1. SSLRC Silsoe (UK) 1,2 May 1995
2. RISSAC Budapest (Hu) 16 October 1995
3. SC-DLO Wageningen (NL) 29,30 January 1996
4. JRC Ispra (I) 5, 6 June 1996

Information Access has also been the subject of discussion during sessions at the Soil Information Focal Point meetings held in:

- FAO, Rome (I) 29-31 May 1995
- Agricultural University, Athens (Gr) 11-13 March 1996
European Soil Databases

The “European Soil Database” comprises the following data sets:

<table>
<thead>
<tr>
<th></th>
<th>Data Set</th>
<th>Version</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>European Soil Map Geographical Database</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Graphical (1:1M) Database</td>
<td>3.1</td>
<td>1996</td>
</tr>
<tr>
<td></td>
<td>(ii) Extended legend (1:1M) Database</td>
<td>3.1</td>
<td>1996</td>
</tr>
<tr>
<td>B</td>
<td>European Soil Profile Database</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(I) Analytical Database</td>
<td>1.0</td>
<td>1996</td>
</tr>
<tr>
<td></td>
<td>(ii) Morphological Database</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>EU Soil Methodological Database</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(I) Pedotransfer rules (PTR) Database</td>
<td>1.0</td>
<td>1996</td>
</tr>
<tr>
<td></td>
<td>(Contract No. 3392004 INRA - SSLRC – Gand)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>European Database of Soil Hydraulic Properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(I) Primary soil data</td>
<td>1.0</td>
<td>1997</td>
</tr>
<tr>
<td></td>
<td>(ii) Pedotransfer functions (PTF) Database</td>
<td>1.0</td>
<td>1998</td>
</tr>
</tbody>
</table>

Currently, three European Soil Databases are available for distribution in the near future (third quarter 1996):

- Soil Map Geographical database (soil map unit polygons) and Extended Legend (legend from paper map expanded) for EU, Central and Eastern European countries.
- EU Soil Profile Analytical Database
- EU Methodological Database – pedotransfer rules.

A fourth database, the European Database of Soil Hydraulic Properties (HYPRES), is at an advanced stage of compilation and should be available towards the end of 1997 or early in 1998. The morphological component of the EU Soil Profile Database has still to be compiled, but will eventually form an important part of the European Soil Database. It will contain the descriptive data, e.g. structure, that match the analytical data.

### EU Soil Map Geographical Database

#### Graphical (1:1M) Database

The EU Soil Map, published as a paper map (CEC 1985), was the result of a decade of collaboration amongst soil scientists in Europe. It was digitized by ADK, Denmark (Platou et al., 1989) for the CORINE Programme and the digital image was transferred to Birkbeck College, London, for checking and processing into ARC/INFO format. This version of the Soil Map (1.0) was not released to the research community at large because of disparities in edge matching (the map was originally published in seven sheets) and other problems. Corrections were made to the digital files to produce a version of the graphical database for release to the research community. This version had only a standard legend similar to that for the paper map.

The original EU (then EC) Soil Map was completed in the 1970s, since when, considerable amounts of new information have become available for many countries. In the early 1990s the Soil and GIS Support Group of the MARS Project began a systematic programme for updating the map (King et al., 1995b). Delineation of new map units was kept to a minimum, but improvements in defining map-unit contents and the addition of other map-unit related parameters such as land use were encouraged.

The work has been co-ordinated throughout by INRA, Orléans (F) and all the EU countries have participated. A new version (3.1) of the digital database is now complete and ready for distribution. This version includes data from the new EU states and Eastern European countries, but a new paper map will not be published. Future digital versions with other improvements (4.0 onwards) should follow under the guidance of the European Soil Bureau.
**Extended Legend (1:1M) Database**

The printed legend for the EU Soil Map is not easy to use and does not provide sufficient information for proper interpretation of the map units. Work on extending this legend was begun in 1990, also under the auspices of the Soil and GIS Support Group of the MARS Project. This work has been co-ordinated by soil scientists at INRA, Orléans (F) and will become available for the release of version 3.1 of the graphical database (King et al., 1995b). In anticipation of the need for more detailed soil data in Europe, a programme for producing a 1:250,000 soil map of Europe has been proposed (Dudal et al., 1993).

**European Soil Profile Database**

**Analytical (Level 1) Database**

A Soil Profile Database for the EU was proposed in 1986. Compilation began in 1991, co-ordinated by the Geographical Institute, Copenhagen University (DK), and SSLRC, Cranfield University (UK). The resulting EU Soil Profile Analytical Database contained representative information for the dominant soil in each map unit (at country level). It was compiled under the auspices of the MARS Project (Madsen and Jones, 1995) which required numeric data on the water-holding capacity of soils for forecasting crop production across Europe. This is a Level 1 database (Madsen, 1991).

Construction of the Soil Profile Database for the EU was proposed in phases (levels), and Levels 2 and 3 of this database should be produced in future. The principles of availability and access for Level 1 will also apply to these new versions of the Soil Profile Analytical Database.

A programme is currently under way to extend this database to the new EU states and the Eastern European countries. This extension will not be completed before the end of 1997.

**Morphological (Level 1) Database**

An EU Soil Profile Morphological Database was not required for the MARS Project, but it is still an important component of the Soil Profile Database. It is needed so that the relevant soil structural and other morphological information becomes available for future interpretations of the Soil Map.

**EU Soil Methodological Database**

**Pedotransfer rules**

A methodological database has been compiled to aid environmental interpretation of the Soil Map. The work was undertaken by scientists from from INRA, Orléans (F), SSLRC (UK) and University of Gand (B) under Contract No 3392004. This takes the form of pedotransfer rules for the estimation of appropriate soil parameters from the European Soil Database (Van Ranst et al., 1995).

**European Database of Soil Hydraulic Properties**

A project has been set up under the EU Human Capital and Mobility Programme to compile a European Database of Soil Hydraulic Properties. Some of the organizations contributing to this database are those that have already been involved in compiling the Soil Map Geographical and Profile databases. However, the study of soil hydraulic properties is a specialised activity and, in some countries, other organizations have become involved. The compilation of the database is being co-ordinated by the Winand Staring Centre (SC-DLO) in the Netherlands.

**Primary soil data**

These comprise soil water retention, particle size, density, organic matter and hydraulic conductivity measurements for a range of soil types in each country.

**Pedotransfer functions (PTF) Database**

Once the primary soil database is complete, this will be used to compute pedotransfer functions (PTF) for the prediction of soil water retention and hydraulic conductivity characteristics. The PTFs will complement and in some cases supersede the pedotransfer rules (EU Methodological database).

**Availability of data**

*Availability* means ‘where are the data and are they accessible?’ Catalogues, for example the European Land Evaluation Databases Catalogue (Norr, 1986), the traditional means of identifying data, are now increasingly being replaced by *metadatabases* that contain detailed information about availability of data but not the data themselves. The EU has now defined a standard for metadatabase content and compilation (CEN, 1996).

**Database availability**

The databases available for immediate distribution are:

1. *Soil Geographical Database (Soil Map) of Europe at 1:1,000,000 scale, version 3.1*
for 18 countries, including border harmonization (King et al., 1995b). This comprises: polygon boundaries, polygon attribute table, soil map unit (SMU) table, soil typological unit (STU) table, data dictionary describing the structure of the databases and the attribute descriptions, attribute values and definitions. Formats: ARC/INFO Export for the vector data, ungeneric format in ASCII. Media: CD-ROM.

2. **Soil Profile Analytical Database of Europe** (for use at 1:1,000,000 scale) for 12 EU countries (Madsen and Jones, 1995). This comprises analytical data for the main soil types portrayed in the Soil Geographical Database. At present it is not linked to the soil map units. There are two Proformas:

I. Estimated data for standard methods of analysis and averaged for the soil type.
II. Measured data from actual soil profiles

The format is currently an Excel spreadsheet. Media: 1.44 Mb IBM format diskette.

**Data Access**

There has been a radical change in attitude towards the availability of data in recent years, from an extreme viewpoint that “all data should be available free to everybody” to today’s concept of intellectual property rights (IPR) and the precept that “no data should be available without charge to anybody”.

**Access** requires permission from the owner. This permission is increasingly being granted through a formal agreement, such as a license to use the data. Distribution mechanisms go together with authorization and require an administrative framework and technical support, especially if there is a charge for use of the data.

Therefore, to protect IPR and copyright issues, data should be leased under licence, not sold. This is the overriding conclusion of the IAWG. The licence should define the proposed use of the data. It is proposed that all member countries should accept a standard form of licence.

Similarly, a standard scale of charges for data use should be adopted across the EU, and should be levied in ECUs.

**Licensing procedures**

There are a number of aspects to the licensing of data. These are described in the following sections.

**Ownership of data**

Ownership needs to be established and acknowledged and Copyright must be addressed in the licence agreement. However, it may not be a simple matter. The concept of Intellectual Property Rights (IPR) includes the knowledge of experts plus unique information encapsulated in an item of data, a data holding and/or a whole information system. The ownership or ‘property right’ rests with the initiator of the original idea to compile the data, the collector of the original data, or the sponsor of the primary data collection process. These principles apply to digital soil data in the same way as to any other data.

The working group (IAWG) agreed that the ownership of the national soil data provided for the European Soil Database rests with the contributing organizations (the Contributors). For the use of the European Soil Database it is, however, not practicable to ask the permission of all the contributing organizations every time the data are required. Therefore the IAWG recommends the nomination of one focal point, the European Soil Bureau, for the supply of European soil data. In order to allow the focal point to act as such, there should be an official document from the contributing organizations signed by the Director of each institute which will empower the European Soil Bureau to supply the European Soil Database on behalf of the Contributors.

Most of the licensing conditions are mentioned in the Licence Agreement itself. This is derived from licences in use at Cranfield University (UK), the Winand Staring Centrum (NL) and the Joint Research Centre (I). In this paragraph some additional comments are made. The licence is project-specific and the Customer will be expected to provide details on:

- the project for which the European Soil Database is to be used;
- the funding agency for that project;
- the type of use (e.g. academic research, part of a commercial application).

The licence is for the use of the complete European Soil Database. When parts of the database (e.g. two countries) are to be used for derived products, the Customer should obtain permission from the appropriate contributing organizations to ensure that there is no conflict of interest.

It is estimated that at least 10 million ECU has been spent on establishing the database, and this does not include the original collection of the data. It is the recommendation of the IAWG that the charging rates must at least reflect the input of investment in the data and should also cover the costs of distribution and administration.

The IAWG further recommends that a single organization within each member state should act as a focal
point for the provision of the member state’s soil and related data for the European Soil Database.

Protection of data

By their very nature, computerized information systems make large quantities of data available to a wide range of users. Organizational changes in most countries mean that there is less central government funding of research institutions than in the past. This is leading to the realization that the data holding of an institution needs to be carefully valued to exploit its income-generating capacity. Protection of data, i.e. guarding against unauthorized access or theft, is thus an important issue. Security procedures, both physical and electronic (passwords etc.), must be introduced and monitored for their effectiveness. These points were given careful consideration by the IAWG in formulating this data distribution policy.

Principles and Conditions of Licensing Data

Data should be released only under a licence that has legal standing. The Licence Agreement prepared by the IAWG defines the roles of the Licensor, the Contributor and the Customer. The Licensor is the owner or custodian of the data and/or Database, the Contributor is the contributing institute of the member state and the Customer is the receiver and/or user of the Database. The Licences will be made project-specific to simplify the specification of use and to facilitate control, thereby safeguarding both the Licensor and the Customer.

The basic principles of licensing data are:

1. All users of the European Soil Database (referred to hereafter as ‘the Database’), including the Contributors, must sign a Licence before being given access to the data, even if there is no charge.
2. The minimum period for a Licence to use the Database should be one year; the cost for the second and subsequent years can be lower than for the first year.
3. The Contributors shall each receive a full copy of the Database for internal use without charge for either media or data value.
4. For external use, i.e. commercial contract work, the Contributors can use the Database, but will be liable for the charges listed in Table 1.
5. EU institutes and other non-profit making organizations may also receive a copy of the Database without charge for the data, but the handling costs must be paid for.
6. EU institutes and other non-profit making organizations may also use the Database for external use, but at a higher charge than the Contributors.
7. All other users of the Database are considered to be commercial and there is a differentiation of charge for internal as opposed to external use.
8. The charges in Table 1 relate to licences for specific projects and the principle is that a new licence is required for each new project. Charges will be in ECU.
9. If an existing Customer wishes to use part of the Database for a new project, then the charges should relate to the proportion of the Database to be used. For very small projects, the charge could be a proportion of the total project budget. For example, in a small project, the charge could be a percentage of this budget (e.g. 5 per cent).

The conditions for licensing data, specified in the Licence Agreement (referred to hereafter as ‘the Licence’), can be summarised thus:

1. One focal point, the European Soil Bureau, based at the Space Applications Institute, JRC, Ispra (I), shall be nominated for supply of the European Soil Database.
2. A single licensing authority shall be empowered, on behalf of the Contributors, to issue Licences for use of the complete European Soil Database.
3. The Licence shall cover the use of all components of the Database as defined and specified in a detailed Licence Agreement.
4. The Licence shall specify the purpose, the limitations and the restrictions on the use of the data (e.g. project-specific, time-specific).
5. Limitations on use of the Database in the Licence shall specify conditions of use and be project-specific.
6. No customer shall be permitted to supply the original Database to a third party. The customer will have no right to sell, assign, rent, give or make available to others, or otherwise transfer or dispose of the Database without the prior written consent of the Licensor.
7. The production and/or distribution by a Customer of products derived from the European Soil Database, outside the conditions of the licence, is not permitted.

Licence agreement

A draft Licence Agreement has been developed by the IAWG. This draft Agreement is based on the data licence of Cranfield University, UK, with modifications added by the IAWG members and with reference to licences issued by the Winand Staring Centrum SC-DLO (NL) (Bregt, pers. comm.) and the Joint Research Centre Ispra (I) (Montanarella, pers. comm.)
Procedure for issuing licences

The procedure for issuing licences can be summarised thus:

1. Customer requests a copy of the Database from the European Soil Bureau (ESB).
2. ESB_IAWG evaluates Customer’s request.
3. In consultation with Customer, ESB_IAWG finalises Schedule A to the Licence Agreement.
4. Licence is signed by both Customer and ESB.
5. Copies of the licence, signed by both parties, are exchanged.
6. Customer is invoiced and pays ESB.
7. Database is supplied on standard media (magnetic tape, CD-ROM, diskette).
8. All transactions are documented and records kept.
9. Use of the Database as specified in the licence is monitored.
10. ESB issues an invoice annually or licence is terminated.

Data use

Users generally fall into the following categories: Education, Research, Government and Private/Commercial. Charges for data or their interpretation have to be worked out; this is not easy in an environment where soil data have traditionally been supplied without charge. Government is a special case because, in most countries, it funds much of the collection of natural resource data as well as being a major user. In a cost-recovery situation, charges must reflect this underlying support for the data collection process.

Data costs and pricing structures

The main digital data sets need to be carefully costed. Pricing should be realistic and in principle should take account of the following costs:

- collection (and compilation);
- initial processing;
- maintenance;
- extraction;
- data value;
- updating;
- administration & documentn.

Experience at this time suggests that a variable scale of charges is the best way to accommodate the different capabilities of potential users to pay for data. The model adopted in UK and NL (Bregt, pers comm.) has three tiers:

- zero charge – for a customer that sponsored the collection and computerization of the data;
- medium charge – for academic or non-profit making research organizations, essentially covering extraction and maintenance costs;
- high charge – reserved for commercial customers.

The data should be available free of charge to:

- the MARS Project; but only for the use for which they were originally commissioned; if MARS subsequently wished to use the data as the basis of a different project, an additional licence should be drawn up and possibly a charge made;
- the Contributors for internal use.

Other EU institutions should have access to the data, but conditions of use should be specified and an appropriate charge levied.

Charging rates should at least reflect the investment in the database and the running costs of the systems that would deliver the data. A simple model is to estimate the overall costs of compiling, processing, maintaining and updating the data, and divide by the estimated number of potential customers. Judgement has to be exercised here because, in the first instance, this calculation may result in a price that is too high for the market.

In a three-tier charging structure, non-EU institutions in the member states should have access to the data, with restricted conditions of use and possibly at a medium-level charge. Third parties (commercial companies, non-EU member state bodies) should have access to the data, but with restrictive conditions of use and at the highest charge.

Scale of charges

A scale of charges was discussed in depth and the proposed scheme is shown in Table 2. These charges relate to the complete Database. Many different categories of charge were suggested but subsequently rejected in the interests of simplicity.

Authorisation process

The European Soil Bureau, at the Space Applications Institute of JRC, will be authorized to distribute the European Soil Database on behalf of all the Contributors. Each of the Contributors will sign an Authority for the ESB to distribute the data on its behalf.

The process of seeking authorisation will be the despatch of an Authorisation Document and a sample licence to the appropriate authority in each Contributor organization and this will begin as soon as possible to prevent further delays to distribution of the data.
Table 2: Proposed charges for the European Database

<table>
<thead>
<tr>
<th>Type of user</th>
<th>Use</th>
<th>Data</th>
<th>Handling</th>
<th>Licence</th>
<th>Term</th>
<th>Limitations</th>
<th>Charge (ECU k)</th>
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<tr>
<td></td>
<td></td>
<td>Value</td>
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<td>5</td>
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<td>EU Institute and other non-profit making organisation.</td>
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<td>Yes</td>
<td>1</td>
<td>Acknowledge in publications</td>
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<td>Yes</td>
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<td>10</td>
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<tr>
<td>Other (i.e. commercial)</td>
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<td>1</td>
<td>Acknowledge source</td>
<td>20</td>
<td>7</td>
</tr>
</tbody>
</table>

**Internal**: Use within organisation for undertaking work in accordance with organisation's remit or mission.  
**External**: Use by an organisation for projects sponsored by an external organisation

**Copyright**

A statement of copyright, for use on documents and maps that will subsequently be produced from the Database, has been suggested along with the following text:

- © European Soil Bureau (ESB) on behalf of the Contributing Organizations [Digital versions of the European Soil Database are available under licence through the ESB].

A logo, for use on maps and documents, has been designed and produced by Joel Daroussin (INRA, Orléans, F).

**Conclusion**

There is a need to recognize the ownership of digital data, assess the value of the main data holdings, develop procedures for the supply of information to third parties and actively promote the databases that exist within the European Soil Bureau (ESB). Because soils are such an important part of the environment, the main aims in supplying users should be to encourage maximal use of soil data and to safeguard the ‘public good’.

The principles and procedures for releasing data and products from the European Soil Database under licence were tabled at the first European Soil Advisory Board Meeting, held on 13 June 1996 at the Joint Research Centre, Ispra (I). It was agreed that a draft Licence and Authorization Document should be distributed to all Contributors. Provided these documents are approved and signed by the contributing organisations, the Licence can be offered to outside organizations.

The existence of digital soil data in Europe is highlighted and more information on soil databases at European level is given in King et al. (1995a) and Le Bas and Jamagne (1996). The value of such data is becoming appreciated and the potential uses are wide and varied, extending well beyond the agricultural industry.

For the security of digital soil data to be ensured and their value fully realized, attention must be focussed on access procedures. In the context of the European Soil Bureau, these have been described in some detail and a Data Licence, issued by a Licensor to a Customer, is proposed as a central part of the whole process. The Licence must
clearly specify ownership of the data and, so that appropriate safeguards are built into the distribution process, the Intellectual Property Rights (IPR) of the owner must be recognized by the Customer.

Licensing of primary and manipulated soil and environmental data will become an important means whereby the funding needed to support future research activities can be generated at both national and European levels. Much of this research will be directed towards the sustainable use of land resources and therefore will be in the ‘public good’. However, it is essential that the release of the European Soil Database should satisfy the needs of soil research without compromising the financial viability of the organizations that have contributed so effectively to compilation of the database.

Acknowledgement

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References


APPENDIX

EUROPEAN SOIL DATABASE

This AGREEMENT authorises the European Commission Joint Research Centre, Ispra (I), to act as Licensor on behalf of the organisations contributing to the European Soil Database, hereinafter referred to in this Agreement as ‘the Contributors’. The European Commission Joint Research Centre (JRC), Ispra, is hereby nominated as the Licensor of the European Soil Database on behalf of the Contributors, under the following terms and conditions:

1. The parties wish to enter into this Agreement to regulate the terms and conditions for the European Soil Database, hereinafter referred to as the ‘Database’

2. The Contributors have agreed to the release of a licence in the terms and conditions set out in Schedule A to the licence for the use of the Database.

3. The Contributors agree that the terms of the standard licence relating to the release of each version of the Database shall be those set out in Schedule A or in such other form as may be agreed from time to time in writing between Contributors.

4. The Contributors agree that the Director of the Space Applications Institute, Joint Research Centre (JRC), is authorised to act on behalf of the Contributors to grant licences for the use of the Database provided always that any such licence shall be in the form agreed between the Contributors as provided by this Agreement.

5. The Director of the Space Applications Institute, JRC, agrees to keep a copy of each such licence granted under this Agreement to be available for inspection by the Contributors.

6. A signed licence must be in place before any data are distributed;

7. Any of the Contributors have the right to refuse the supply of data when such supply is likely to result in that Contributor’s interests being compromised by competing commercial applications, and such risk being clearly demonstrated.

8. Any of the Contributors can reserve the right to withdraw from this Agreement after notification in writing and after a minimum notice period of 12 months.

The JRC is empowered to organise the distribution of the data on behalf of the Contributors, and is empowered to subcontract all or part of this distribution. Each Contributor is entitled to receive a full copy of the European Soil Database free of charge for internal use only and shall be eligible to receive this copy on signing this Agreement and a licence defining the use. Internal use is defined as ‘use within the Contributor’s organisation for undertaking work in accordance with the Contributor’s main remit or mission’.
LICENCE AGREEMENT

This AGREEMENT is made the (DATE).....................................................................between

1. THE COMMISSION OF THE EUROPEAN COMMUNITIES (hereinafter called the Licensor), represented for the purpose of signing this contract by Professor Dr R Winter, Director of the Space Applications Institute, Joint Research Centre, TP 441, 21020 Ispra (Va), ITALY, on behalf of Contributing Organisations/Institutes listed in Schedule B (hereinafter called the Contributor) and

2. THE CUSTOMER/END USER (hereinafter called the Customer), whose registered office is at ––––, represented for the purpose of signing this contract by –––

WHEREAS the Licensor has commissioned the assembly and is the keeper of The European Soil Database and the associated software as described in Schedule A attached hereto and WHEREAS the contributors who together with the Licensor severally own the intellectual property rights in the Database have agreed together that the Licensor will issue licences in the following approved format on their behalf

WHEREAS the Customer desires to use the Database within its own organisation

The main section headings in the licence are listed below.

- Licence
- Proprietary rights and confidentiality
- Term
- Termination
- Title
- Responsibility and liability
- Warranty of right to licence
- Notice
- Controlling terms
- Conditions excluded
- Uncontrollable circumstances
- Modifications of conditions
- Governing law and jurisdiction

This Agreement shall be governed by and construed in accordance with the law of...............................................(insert name of customer’s/end user’s country)

SCHEDULE A Details of the Database to be supplied:

The database to be supplied is described in detail and the following are listed:

- Term, usually a minimum of 12 months
- Notice
- Purpose of use
- Limitation
- Royalty Payment/Charge for Data
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The European Soil Information System

Summary

In Europe, as in the rest of the world, a thorough knowledge of soil use and soil protection is of vital importance. The European Commission, in particular its Directorates General of Agriculture (DGVI), Environment (DGXI) and Research (DGXII), has supported several programmes with this objective in mind. The publication of the 1:1,000,000-scale Soil Map of the European Communities (EC) in 1985 is one result of these activities. This paper summarises the different stages of the elaboration of this map and the associated geographical soil database. It focuses on the potential use of this information and its limits. This information is currently an important source of data for agriculture and environmental projects.

Introduction

A global policy for management, evaluation and conservation of soil requires information harmonized both in space and time (Bouma and Bregt, 1989). This statement is particularly true for the European Union (EU) which at the time of writing has fifteen member countries.

The European Commission is the originator of several programmes aiming to acquire soil data (CEC-JRC, 1995). Associated with other sources of information (water, air, land management), these data are a valuable aid for decision support processes, in particular for the control of agricultural production (Vossen and Meyer-Roux, 1995), land management and environmental protection (Blum, 1990). The last major co-ordinated activity for soil information in Europe is the elaboration of the 1:1,000,000-scale soil geographical database. This information is now available thanks to many previous works.

Historical background

Since 1952, studies were made of the different soil classification systems in Europe, with a view to their eventual harmonization and common work. The first result was the publication of the FAO Soil Map of Europe at scale 1:2,500,000 (FAO, 1965). During the 1970s, work continued under the auspices of FAO on the Soil Map of Europe at scale 1:1,000,000, but because of financial problems, the work was stopped and the map has never been published. In 1978, the European Commission decided, with the agreement of the FAO, to revive the work for the countries of the European Communities. The Soil Map of the European Communities (EC) at scale 1:1,000,000 was published in 1985 (CEC, 1985), followed in 1986 by the Soil Map of Middle Europe, covering the territory of Austria and Switzerland (CEC-ISSS, 1986).

The main objective of the CORINE program (DGXI) was the creation of a Co-ordinated Information System on the state of the Environment and Natural Resources of the EC. This implied setting up a homogenous framework for collecting, storage, presentation and interpretation of environmental data on the EC countries (Briggs and Martin, 1988). Thus, the CORINE programme resulted in the computerization of the EC Soil Map in 1986, constituting the first spatialized soil database, called Version 1.0, (Platou et al., 1989). But only the data drawn on the paper map was used in this digitization. This database was rapidly applied to two major problems that required the use of multi-parameter combinations: a map of the buffering capacity (Chadwick and Kuylenstierna, 1990) and a classification of the southern part of the EC into zones of soils susceptible to erosion, associated with another classification of zones according to land quality (Giordano et al., 1995). Other uses of this information were attempted; not published but the number of studies remained small (Jamagne et al., 1993).

In 1987, the EC Directorate General VI (Agriculture) launched the MARS project (Monitoring Agriculture with Remote Sensing), to estimate crop surfaces in Europe and to monitor them by using remote sensing
This project was set up at the Joint Research Centre in Ispra, Italy (JRC-Ispra). As it is important to monitor crops without gaps, it was decided to use agrometeorological models to complete the remote sensing methods (Vossen and Meyer-Roux, 1995). Therefore, at an early stage of the MARS project, agrometeorological models were developed and these led to requests for soil and climate data.

The soil data in the computerized EC Soil Map were insufficient to supply values of the parameters needed by agrometeorological models. The Soil and GIS Support Group to the MARS project was created to improve the database created from the EC Soil Map (Burrill and King, 1993). The programme was enlarged to include environmental needs in the framework of the European Environmental Agency Task Force of DG XI.

To effect this improvement, the Soil and GIS Support Group suggested going back to the primary information, using three steps (according to availability) to obtain the data. The easiest data to access are the archives used to elaborate the EC Soil Map. The two other sources of information come respectively from the national experts and from the basic measured data of analytical soil profiles (JRC, 1995).

The archives of the EC Soil Map, stored in the University of Ghent in Belgium by Prof. Tavernier, co-ordinator of the original map compilation work, were used to update the computerized soil map (King et al., 1994a). The result is called Version 2.0. Very important variables such as parent material were added in this second version. Furthermore, data were added for each Soil Typological Unit within soil associations and not only for the dominant soil.

This first stage was still not sufficient to obtain the required information for agrometeorological modelling. It was therefore decided to go back to the soil scientists in the organizations that gathered the basic data for the map. Two sub-directions were suggested. The first was the development of a soil knowledge database with the support of DG XI (Van Ranst et al., 1995; Jones and Hollis, 1996). The idea was to formalize, as an expert system, the knowledge used to estimate unknown soil parameters from soil variables stored in the database. These estimations were called pedotransfer rules in reference to the concept of pedotransfer functions (Bouma and Van Lanen, 1986).

The second sub-direction was to update the soil mapping units in order to improve the description of soil variables, because those that are stored in the archives and version 2.0 are outdated. For this, version 2.0 was sent to all national correspondents asking for an update of the attribute values as well as of the graphics of soil boundaries. New attributes were added such as depth of an obstacle to roots, depth to textural change, water regime, etc. (INRA, 1995). This final version is called Version 3.1. The last task in progress is the border harmonization.

In order to have reliable data, the database was finally improved with basic soil profile data (Madsen and Jones, 1996). For each dominant soil unit, a representative soil profile was collected with main analytical data. Standard formats were developed for harmonizing the various analytical methods in Europe.

Since 1992, the soil geographical database is being extended to Central and Eastern European countries using the same methodology as for the EC countries. The basic data comes from the archives of the FAO work for the original 1:1,000,000-scale Soil Map of Europe that was never published. These basic data were computerized and some documents were then sent to the national correspondents for improvement. Figure 1 shows the present state of progress of the European soil geographical database, which is progressively being extended to cover the whole of Europe.

Structure of the present European Soil Geographical Database

The soil geographical database at present has four parts (Figure 2)

(1) the metadatabase;
(2) the so-called geographical database;
(3) the soil profile analytical database;
(4) the knowledge database.

Compilation of the metadatabase is still in progress. The objective is to gather information on the pedological studies in Europe. The database will provide a catalogue where users will be able to find more information on detailed national maps and datasets. An earlier programme was carried out (CEC, 1990) but no updates have been made for ten years.

The second part is the heart of the system. It includes the list of Soil Typological Units (STU), i.e. all soil types within the European Union which were mainly identified with the FAO-UNESCO legend (1974), revised by the CEC (1985). From a semantic point of view (non-spatial attributes), STUs are described by soil attributes with a harmonized coding: FAO soil name, parent material, slope, etc. From a geometric point of view, STUs are generally too small to be drawn on a map at the 1:1,000,000 scale.
Figure 1: State of progress of the soil geographical database in Europe
Figure 2: Simplified structure of the European soil geographical database
They are clustered in Soil Mapping Units (SMU) which are defined by isopleths and polygons. The “object SMU” is clearly related to the concept of soil association (Simonson, 1971).

The third part of the database contains soil profiles with physical and chemical analysis (Madsen and Jones, 1996). The difficulties in harmonizing all the various analytical methods led to the adoption of two data formats. The first is for measured data which come directly from real geo-referenced profiles. A code enables storage of the analytical methods used and missing values are accepted. The second format stores estimated data. The analytical methods are fixed for comparison of the values throughout the various countries of Europe. In this second format, the attributes must be fully completed by using guesstimation. About 300 soil profiles are available describing the most important STUs, but more are expected in the near future.

The last part of the database contains the pedotransfer rules. These are simple deductive functions that help in estimating new soil parameters from the available data (King et al., 1994b). This fourth part looks like an expert system constructed from expert evaluation by soil scientists and from literature (Table 1). Rules are applied at the STU level and values are mainly qualitative. Such a knowledge database enables the formalization of the empirical interpretations that are always made by using soil maps (Van Ranst et al., 1995; Jones and Hollis, 1996). The main advantage of this system is the possibility of updating the database in the light of new knowledge.

In Table 1, the columns on the left correspond to values taken by input attributes describing the Soil Typological Units. The central columns provide estimated values and their confidence level, i.e. the expert uncertainty. The right-hand columns contain management attributes: author, date of last update, marker for access to explanatory notes. The lines indicate the possible occurrence of the rules, based on the values (or combinations thereof) for the input attributes in the geographical soil database.

Table 1: Standard table for describing a pedotransfer rule.

<table>
<thead>
<tr>
<th>INPUT ATTRIBUTES</th>
<th>OUTPUT ATTRIBUTES</th>
<th>REFERENCE ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Codes</td>
<td>1 2 3 .... n</td>
<td>Class Confidence level</td>
</tr>
</tbody>
</table>

Recommendations for using the data

If spatial values for a soil parameter have to be estimated, several methods are possible. If the soil parameter is directly included in the description of the STU, the data can be directly extracted and used for modelling. If the soil parameter is not one of the STU attributes, the knowledge database can estimate it in many cases. If a representative soil profile exists within an STU, quantitative value can be estimated for this soil parameter. For example, if an agrometeorological model needs the Soil Water Available for Plants (SWAP) parameter (Thomasson, 1995), there is no value of this parameter in the STU file. In that case, one can use either the knowledge database to get a qualitative estimation per STU, or the soil profile database to directly obtain a quantitative local value. Comparison between the two methods will help to highlight the strongest discrepancies where it will be necessary to get more information from regional soil survey.

It was seen before that the main objective of such a database is to deliver parameters for modelling and also to produce derived maps. Most of the SMUs are complex associations and it is difficult to manage this variability on maps. However, it is easy to compute models at the level of the STUs. For example, by using all STUs within each SMU against the predominant STU, a water balance model decreases errors by 20% (Ngongo et al., 1993).

In a last stage, it is generally necessary to produce maps, either directly from the database (with or without the knowledge database), or indirectly as outputs of models. For example, in order to draw the SWAP parameter over the EU, three classes are chosen: high, medium and low. Only the dominant class within an SMU can be shown. However, in places, this dominant value is less than 50% of the total area of an SMU! In order to avoid erroneous interpretation, an automatic process draws a second map, called a “purity
Assessment of major soil constraints to crop production

This is an example of the use of the Soil Geographical Database for EC countries. The work was carried out during a Concerted Action (Laurent and Bowler, 1996), the aim of which was to build a multidisciplinary frame-work to analyse the consequences within the European regions of changing the Common Agricultural Policy (CAP). Natural resources can represent an important limitation to agricultural production, so understanding these limitations may thus explain some differences between regions. In a preliminary stage, we focused only on the soil limitations.

An expert system (Le Bas and King, 1996) was designed so as to estimate the soil constraints to crop production. This expert system was built using the Automated Land Evaluation System (ALES) (Rossiter and Van Wambeke, 1994), an expert system shell that enables users to build expert systems according to their own knowledge.

As requirements vary according to the crop, it is necessary to consider several types of crops. In a first step, we focused on the main important agricultural productions in Europe and chose three types of crops: cereals (wheat, maize, barley, etc.), root crops (potatoes, sugar beet), and cultivated or permanent grasslands.

The estimation was made at the Soil Typological Units level, using parameters extracted directly from the soil geographical database (soil name, the toposoil textural class, the dominant slope, phase), or parameters estimated by pedotransfer rules (available water capacity, Cation Exchange Capacity, maximum rooting depth, depth to a gleyed horizon). As soil may limit crop production in several ways, we considered only the main constraints i.e. moisture availability, physical rooting conditions, oxygen availability to roots, natural chemical fertility, and conditions for mechanization. The estimated value for each constraint will change according to the requirements of each type of crop.

The constraint variables are then passed on, for a given type of crop, to a second expert system that assesses the overall suitability of each STU. The constraint and suitability variables are qualitative, and are subdivided into three classes: suitable (no limitation to slight limitations), acceptable (moderate limitations) and unsuitable (severe limitations). Finally, the output variables describing each STU are added to the description file of STUs within the GIS. This makes it possible to map them at the SMU level with GIS procedures.

Figure 4 shows an example of such maps. The first map shows the dominant value within the Soil Mapping Units for the constraint variable “conditions for mechanization” calculated for “cereals”. “Dominant” is defined here as the value that applies to the highest percentage of area within the SMU. This percentage is shown in the second map, which gives an idea of the purity of the information shown by the first map.

Independently from the accuracy of this expert system, the work shows the difficulties in using the soil database. It highlights some problems in the soil data, and notably in the harmonization of these data between countries. To date the analysis has been done only with Version 2.1 of the soil geographical database, but in the near future, we will apply the expert system to the new Version 3.1, enabling a comparison of the results.

Conclusion

The development of the 1:1,000,000 European Geographical Soil Database was a good initiative to increase contacts between soil scientists, to exchange information across national borders and to create a first platform for decision makers. A usable Soil Geographical Database at 1:1,000,000 scale is now available at the EU level and several projects and organizations are requesting to use it. Information in such a database can be regularly updated as new knowledge becomes available or new territories are added. Management of this information is undertaken by the European Soil Bureau.

Together with the soil geographical database, new modules such as the knowledge database and the soil profile analytical database constitute the European Soil Database. New projects such as the 1:250,000-scale database are now emerging, offering new challenges in the future for the European soil science community.
Figure 3: Examples of a purity map and a confidence level map
Figure 4: Dominant constraint class for mechanization conditions for cereals at the SMU level, and corresponding purity map.
References


Towards a European Soil Profile Analytical Database

Summary

In 1985, the Commission of the European Communities (CEC) – now the European Union – published a soil map at a scale of 1:1,000,000. This map, covering the 12 Community countries, was digitized so that it could be manipulated in a Geographical Information System. In order that the full potential of the map could be realized, the Commission also funded the compilation of a Soil Profile Analytical Database that would contain data about the main soil types distinguished on the map. Compilation began in 1992 and was more or less completed in 1995.

Profile data for some soil types were not provided for various reasons but, during 1995-97, a contract to expand the database to include similar data from Central and Eastern Europe and Scandinavia was given to the authors by the Commission. A programme to expand the soil map database to include geographical data from these countries as well had already been initiated in 1992 and was still in progress in 1995.

The resulting soil map and profile database will constitute the most comprehensive soil information base for Europe. The first phase of compilation of the soil profile analytical database, for the 12 Community Countries, is described in detail elsewhere (Madsen and Jones, 1995a, 1995b). However, this account outlines the background to the database, its compilation for the 12 Community countries, and the future potential for expansion to provide a basis for environmental interpretations.

Introduction

During the twentieth century, national or regional soil surveys were undertaken in Europe with the result that today national soil maps at large scales (1:25,000, 1:50,000 and 1:100,000) exist in several European countries. In the other countries, only small areas have been surveyed though some soil maps have been published. The national soil maps for some of the European countries have been digitized and the resulting data sets stored in computer databases. For example, this has been accomplished for Belgium, Denmark, The Netherlands and UK. As the map scales, survey methods and soil classifications used differ from one country to another, it was not possible simply to combine the national maps together to create a soil map for the whole of Europe.

In the 1960s, the use of different soil survey methods and classifications was a problem in other parts of the world as well and, in an attempt to overcome the problem, an international soil classification system was developed. Using this classification as a basis, soil maps at a scale of 1:5,000,000 were drawn up by FAO (FAO-Unesco, 1974) at the beginning of the 1970s. A total of 106 soil types were defined and each map unit is defined as an association of these soil types.

EU Soil Map at scale 1:1,000,000

Work on compiling a soil map of the European Common Market countries began in the early 1970s. In 1978, a working group on land use and rural resources of the European Communities proposed that a soil map of the member states should be prepared at scale 1:1,000,000 using the FAO legend and data already collected by FAO. In practice, these data were augmented by soil survey organisations in the member states. In 1985, the soil map for the entire
European Community (EC) was published, in seven coloured map sheets and two legend sheets (CEC, 1985). This EC Soil Map portrays the distribution of more than 120 different soil types, most of them defined in FAO-Unesco terminology (1974); about 40 new soil types were defined.

Each map unit, an association of soil types occurring within the limits of a discrete physiographic entity, is given a number and a colour on the printed map. Each association is composed of a dominant soil unit and of subdominant associated soils, each of the latter covering at least 10% but less than 50% of the area. Important soils which cover less than 10% of the area are noted as inclusions. The percentage share of the dominant soil type, the associated soil types and the inclusions are generally indicated. The texture class of the dominant soil and a slope class are given for each association. Phases are used where indurated layers of hard rock occur at shallow depth and to indicate stoniness, salinity, alkalinity, a high content of stones or concretions. As a part of the CORINE Project (Briggs and Martin, 1988), the EC Soil Map was digitized in 1986 (Platou et al., 1989).

In 1987, the MARS Project – Monitoring Agriculture with Remote Sensing – was initiated, with the main contractor being the Joint Research Centre (JRC), Ispra Establishment. The most important action with respect to soil data is the use of agrometeorological models to establish a system for forecasting the yields of the principal crops in the Community countries. To achieve this requires data on the water-holding capacities of soils and some means of spatially extrapolating the data. A Soil and GIS Support Group to the MARS Project was formed in 1990 with its objective being the study of pedological parameters that, when combined with other environmental data at a scale covering the 12 EC countries, would enable the yield forecasting models to operate.

Expansion of the EU Soil Map database

The construction and update of the original EU Soil Map is described by Jamagne et al., (1995). Soil map (graphical) data from Central and Eastern Europe and Scandinavia are being incorporated using the same principles as adopted previously. Because FAO has published a revised legend (FAO-Unesco, 1990), it was decided that the soil maps of these countries should be based on the revised legend. There is no plan to publish a new European Soil Map in paper form but the European Soil Bureau (Meyer-Roux and Montanarella, 1998) and other organizations with a licence to use the data, will be able to print copies of the map on a large format plotter. The copyright of this information will be protected by licence (Jones, Buckley and Jarvis, 1998).

The computerization of the European Soil Map and the associated soil profile data has several advantages. It will be relatively easy to undertake spatial analyses of the expanded map and to reproduce soil maps at different scales. It will also be possible to produce various thematic maps based on the soil data; for example, in the past maps of land suitability and environmental risk assessment have been produced by Lee (1984), Briggs et al. (1989), Jones and Biagi (1989), King and Daroussin (1989), Madsen et al. (1989), Proctor et al. (1989), Van Lanen et al. (1989), and Verheye (1989).

Furthermore, it will be possible to update the soil map relatively easily as and when new knowledge becomes available. For example:

1. new soil map units have been constructed for Denmark (Madsen and Jensen, 1996);
2. a new soil map has been produced for Germany that includes the former German Democratic Republic (Eckelmann and Adler, 1994, Hartwich et al., 1995);
3. the soil attributes based on archive studies and data from national representatives have been expanded for the whole of Europe (King et al., 1995).

Thus the printing of soil maps of the EU and neighbouring countries has become outdated as a means of dissemination and interpretation for today’s needs.

However, a comprehensive soil profile analytical database connected to the EU Soil Map is needed to maximise the opportunities for interpreting the soil information it portrays, for example by transforming soil units into different themes using pedotransfer functions. The same will be true for an expanded Soil Map of Europe.

Soil profile analytical database

A methodology for compiling a soil profile database was agreed in Brussels (1988), following a series of meetings of the Computerization of Land Data Group. These meetings took place
throughout the 1980s to discuss the general availability of land data in computerized form throughout the European Community and to advise the Commission on future programmes for data collection.

It was agreed that the database should be compiled in phases, firstly at Level 1, secondly at Level 2 and so on. The procedures were approved by the Computerization of Land Data Group, at a meeting in Wageningen, November 1988 (Van Lanen and Bregt, 1989), and endorsed by the Heads of Soil Surveys of the European Community countries, at a meeting in Silsoe (UK), December 1989 (Hodgson, 1991). In general, the lack of compatibility between the soil profiles collected across Europe was overcome by defining standard Proformas for recording the data. The procedures for the first phase (Level 1) are described in detail elsewhere (Madsen and Jones, 1995a, 1995b); these are summarised below.

1. The member states have been treated as separate regions; in later phases the member states will be divided into sub-regions.
2. A typical soil profile description and associated analytical data have been identified for each soil type present within each state.
3. Data have been compiled for the dominant soil types only; in later phases, it is proposed that soil types present as associations and inclusions will also be included.
4. Profile descriptions (morphological information) have been given according to the FAO system and the soil analytical data recorded according to international standards.

5. Typical soil profiles have been identified and simplified descriptions compiled by local experts from national soil survey or soil science research organisations. The analytical data have been compiled using measured data from selected soil profiles (recorded on Proforma II), though in cases where this is absent or deficient, estimated mean values for typical soil profiles (Proforma I), have been generated by the same experts.

6. If the land use type agriculture exists on at least some part of the dominant soil type, data for a farmland soil were chosen.

7. The Proforma I data may result from transformation of measured data or on the basis of expert knowledge (Madsen and Jones, 1995b). They are important because they allow comparisons across the entire European Union.

8. Proforma II allows data measured according to national standards to be included for later transformation if necessary. However, it is accepted that data will be missing for some analyses or even for whole profiles in the Proforma II database.

A number of pedotransfer functions or rules for mapping soil properties such as the available water content in the root zone, soil density, etc. have become available for environmental interpretations of the EU Soil Map from parallel research (King et al., 1994; Van Ranst et al., 1995).

**Compilation at Level 1**

The proformas were constructed as spreadsheets in Microsoft Excel and, together with the guidelines, were originally circulated in summer 1992. The system was tested in the autumn of that year, with the receipt of some completed proformas from the member states. The proformas and guidelines were again circulated with minor revisions following the Soil and GIS Support Group in Madrid in December 1992. The final versions were produced at the end of February 1993 and distributed to all the proposed contributors for compilation of the database. The proformas and guidelines are published in full by Madsen and Jones (1995a, 1995b).

Figures 1 and 2 show the data for an orthic podzol in Denmark. Proforma I is completed in full, according to the recommendations, whereas some data are missing from Proforma II, as the properties have not been measured or recorded. All data so far received have been checked and minor errors corrected. In the few cases where data are missing from Proforma I, it is proposed that appropriate data from similar soils in neighbouring countries are used.

Compilation of the profile database has paralleled that for the USDA-SCS database, the ISRIC-ISIS database (Van Waveren, 1987; Van Waveren and Bos, 1988), the WISE database (Batjes, 1993) and the FAO-SDB database (FAO, 1993; Van Engelen and Wen, 1989). In March 1995, with the Level 1 database more or less complete, the project ‘Extension of the European Union Soil Profile Database’ was started with the aim of collecting soil profile data for the following European countries: Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria, Switzerland, Austria, Norway, Sweden, Finland, Estonia, Latvia, Lithuania, Slovenia, Croatia and Albania.
By October 1996, data had been received from Bulgaria, Czech Republic, Romania and Finland. The collection of data from the other countries listed above has been somewhat delayed because of various problems; for example in some cases the soil map at 1:1,000,000 scale has not yet been finalised for those countries or in others the national soil survey organisation has been disbanded. Furthermore, very limited funds were available for completing the proformas at national level and this made it extremely difficult for some experts to reschedule national soil research programmes quickly enough to meet the proposed timescales. The whole question of ownership of the expanded database remains open to debate.

Future work

The extension project has one more year to run and it is hoped that the Proforma I database will be completed in 1998. It will then include data from 29 countries (at Level 1) compared with the 12 EU countries in 1995. However, the database should be continuously updated in the future; this process should be closely co-ordinated by the European Soil Bureau.

The current soil profile analytical database is a Level 1 database, which means that data are only available for soil types that are present as the dominant soil type in an association. No data are included for other associated or included soils. There are about 300 dominant soil types for the EU-12 Soil Map and by including data for associated soils and inclusions the number of profiles will more than double (>750). A database that includes all soil types present in associations will be a Level 2 database (Madsen, 1991).

It is important to emphasise that further work is needed to ‘link’ the level-1 database with the EU-12 Soil Map. This is because the profiles were chosen in-country, by the national experts, as representative of the dominant soil types. There were insufficient resources in the project to make extensive checks of whether the chosen profiles are truly representative of the Soil Typological Units (King et al., 1995). Furthermore, the geo-referencing of the soil profiles is not the best way of spatially extrapolating the profile data. Some work on how the profile data can be related to the EU Soil Map has been done by Souchère, King, Daroussin and Le Bas (1997, pers. comm.).

In modelling regional agricultural or environmental problems, Level 2 database will produce more reliable results than at level-1. This is demonstrated in the following example: a map unit consisting of 50% orthic podzols, 30% eutric gleysoils, and 20% orthic luvisols (Table 1) will have an irrigation need that should be calculated proportionally from 100 mm, 0 mm, and 20 mm respectively.

By using the Level 1 database, the orthic podzols will be assumed to cover the whole map unit and the irrigation need will be estimated as 100 mm. By using a Level 2 database, the irrigation need will be computed as (0.5 * 100mm + 0.3 * 0mm + 0.2 * 20mm) = 54 mm, or almost half of that calculated from the Level 1 database.

It is therefore very important that, when the extension of the European Union soil profile database is complete, the European Soil Bureau initiates the next stage – establishment of a Level 2 soil profile analytical database.

The expert meetings, convened at the end of the 1980s, to advise the Commission on the establishment of a soil profile analytical database connected to the EC Soil Map recommended the establishment of a database containing soil profile morphological data (coded from soil descriptions) as well as analytical data (for chemical and physical properties). The following information is ultimately envisaged for inclusion:

General:
- parent material
- drainage
- depth to groundwater table
- presence of surface stones and rock outcrops
- present of salt and alkali

Individual soil horizons:
- horizon symbol
- upper and lower depths
- colour of matrix
- colour of mottles
- texture
- structure
- consistence
- cutans
- cementations
- content of rock and mineral fragments
- content of mineral nodules
- pans
- content of carbonates, soluble salts, etc.
- nature and boundary with horizon below

The soil profile analytical database as currently compiled contains no such data, but the final phase of compilation should include them because they are vital for complete interpretation of the spatial soil data for Europe.
Table 1. Data from a map unit consisting of orthic podzols, eutric gleysols and orthic luvisols.

<table>
<thead>
<tr>
<th>Map unit</th>
<th>Coverage</th>
<th>Irrigation need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Po</td>
<td>50%</td>
<td>100mm</td>
</tr>
<tr>
<td>Ge</td>
<td>30%</td>
<td>0mm</td>
</tr>
<tr>
<td>Lo</td>
<td>20%</td>
<td>20mm</td>
</tr>
</tbody>
</table>

References


Elaboration of a European forest soil database to monitor atmospheric pollution

Summary

Public concern for the European forest ecosystems has resulted in an extensive forest soil condition monitoring programme set up by the European Commission (EC) and the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The inventory aims to provide basic information on the soil chemical status and on the soil properties which determine its sensitivity to air pollution. Forest soils were sampled at the intersection points of a transnational 16km x16km grid. General information on the observation points consists of plot number, observation date, plot co-ordinates, altitude code and FAO soil unit. The organic top layer is sampled separately from the mineral soil which is sampled at two or three fixed depths between 0 and 20 cm. Reference analysis methods are described for pH (CaCl₂), Org. C, N and total amounts of P, K, Ca and Mg. Measurement of total amounts of Na, Al, Fe, Cr, Ni, Mn, Zn, Cu, Pb and Cd in the organic layer and of cation exchange properties in the mineral layer are optional. Sampling and analysis were carried out by the national focal centres (NFCs). The analysis results are stored in a common geographical database at the Forest Soil Co-ordinating Centre (FSCC) in Gent (Belgium) and will be presented in a “Report on the European Forest Soil Condition” in 1997. Of the 31 countries, participating in the European forest soil condition inventory, 23 have completed their national survey activities. To ensure a high quality of the data stored in the database, several screening procedures were performed on the submitted data files. Once loaded, the data are subjected to a number of analysis steps: (1) new parameter values, such as nutrient ratios, are calculated, (2) parameter values are classified for presentation on maps, (3) plots with similar soil properties are grouped for statistical analysis, and (4) statistical analysis is aimed at recognising significant differences in soil condition between groups of plots. A trans-boundary interpretation of the soil condition results is hampered by differences in methods of sampling and analysis. The soil condition is mainly evaluated in terms of nutrient availability for trees and the capacity to neutralise acids deposited from the atmosphere. In the future, a major challenge will be the investigation of cause-effect relationships of air pollution and other damaging agents on the condition of forest ecosystems.

Introduction

Forest ecosystems are subject to natural and anthropogenic stresses that act singly or collectively to affect forest health. When forests are damaged by insects, diseases, fire, or climatic events, they are probably only temporarily unhealthy because they are adapted to these stresses and can recover from them. Stresses such as air pollution or climate change may permanently damage forest health, because forests have not adapted to these additional stresses (NAFC, 1996).

A possible reason for the loss of vitality of the European forests is the persistent input of atmospheric pollutants. Beside the direct effect of gaseous pollutants (“dry deposition”) and solutes (“wet deposition”) on needles and leaves, air pollution might affect forests indirectly through changes of the soil (Matzner and Murach, 1996). The most important air pollutants are SO₂, NOₓ, O₃ and NH₃, H⁺ and H₂O₂. Deposition from fog and...
low clouds may be considerable at high-altitude sites. Spatial and temporal gradients in metal concentrations in top soils and lake sediments can also be related to long-range atmospheric transport from anthropogenic sources (Andreae, 1996).

Because most soils have a certain buffering capacity, it usually takes some time before negative effects become apparent. The buffering capacity of soils can be described as the capacity to allow contents of compounds, once present at optimum level, to increase without actual occurrence of negative effects. Several potentially hazardous compounds, such as Cu and Zn, are also prerequisites for good soil functioning and show a positive effect at low concentration level (de Haan, 1989). The buffering capacity is a function of the nature of the pollutant and of many soil properties.

Soil buffering processes against acidification result in the removal of basic cations from exchange sites on humic compounds and clay minerals. Furthermore, aluminium ions released into the soil solution during $H^+$ buffering processes compete with these cations for the occupation of exchange sites. Although the observed forest decline is mainly linked to the stressor soil acidification, the resulting disruption of nutrient cycles is likely to be enforced by high metal levels in top soils (Andreae, 1996).

If N mineralisation is assumed to be equal to litterfall, the availability of mineral N to tree roots might today be 50 % higher than without N deposition (Matzner and Murach, 1996). From the start of industrialisation to the last decade, N deposition had a stabilising effect by promoting tree growth. Unfortunately, it now shows adverse effects on ecosystem stability (Ulrich, 1995). Possible causes (Ulrich, 1995; Matzner and Murach, 1996) are:

- the reduction of total fine root biomass relative to shoot biomass and of mycorrhizal activity following high N inputs;
- the stronger promotion of the growth of competitors;
- an increased drought susceptibility because a high N supply in the top soil favours the development of a shallow rooting system.

The occurrence of acid stress is restricted to soils being already strongly acidified and is controlled by $SO_4^{2-}$ and $NO_3^-$ dynamics of the specific soil and ecosystem. There are indications that in areas with low acid stress and high soil water availability, N surplus results in an increased growth. The observed increase in above ground growth is in accordance with the higher N availability. The growth increase may, however, be destabilising with respect to drought and wind throw susceptibility of forests (Matzner and Murach, 1996).

Research on the effects of air pollution on forest ecosystems is seriously hampered by the lack of background information on a regional scale. Monitoring the state of the health of the forests is done by assessing the condition of tree crowns to determine what if anything is damaging them. In order to study cause-effect relationships, information on soil condition, weather and atmospheric deposition, should be documented preferably at the same observation points.

This paper describes the implementation of the first pan-European forest soil condition inventory in the framework of a large-scale programme for the protection of forests against atmospheric pollution.

### Forest soil condition monitoring programme

At a meeting organised by the United Nations Economic Commission for Europe (UN/ECE) at ministerial level, held in Geneva in 1979, a convention on Long-Range Transboundary Air Pollution (LRTAP) was signed. This convention, which lays down the general principles of international co-operation for air pollution abatement and brings together research and policy, was the first internationally binding instrument to deal with problems of air pollution on a broad regional basis. The convention constitutes a framework within which international actions are undertaken. The International Co-operative Programme on Assessment and Monitoring Air Pollution Effects on Forests in the UN/ECE region (ICP Forests) was established in 1985 in response of the widespread damage to forests observed in the late 70s and early 80s. This was achieved in close co-operation with the European Commission.

### ICP forests

ICP Forests has the following three main objectives:

- gaining knowledge of the long-term and large-scale development of forest condition in Europe;
- contributing to a better understanding of the impact of air pollutants and other
damaging agents on forest ecosystems and the cause-effect relationships involved;
• providing deeper insight into cause-effect relationships in the sense of ecosystem analysis.

As each of these major objectives required a different monitoring approach, respective monitoring intensity levels (Levels I, II and III) were conceived. For the first objective, Level I was implemented as a continuous and harmonised systematic crown condition assessment that started in 1986. Today, this crown condition assessment is carried out annually on more than 600,000 trees of about 33,600 sample plots of national grids of different density in 34 countries.

Besides results at national scale, results at European scale are also reported. This is achieved by means of a so-called transnational survey which is conducted on a subsample of about 4800 plots forming the more uniform 16km x 16 km transnational grid. Most participating countries are performing soil chemical analyses (31 countries) and partly also foliar analyses on the same 16km x 16km grid.

For the more intensive monitoring programme, Level II harmonized methods for increment, deposition and meteorological measurements and soil solution analysis are developed. The implementation of the ecosystem analysis related Level III programme is currently under discussion.

ICP Forests is supervised by its Programme Task Force, which is chaired by Germany as the lead country, with the assistance of the UN/ECE Secretariat and the various bodies of ICP Forests. The backbone of the structure of ICP Forests are the National Focal Centres (NFCs) which submit data to the Programme Co-ordinating Centres. Four expert Panels are involved in the development of methods for monitoring activities related the forest condition. These are the Expert Panel on Soil, the Expert Panel on Foliar Analysis, the Expert Panel on Increment Changes and the Expert Panel on Deposition.

Fig. 1. The structure of ICP Forests.

Forest soil expert panel

At the annual Task Force Meeting of ICP Forests in 1989 the establishment of a Forest Soil Expert Panel (FSEP) was mandated. Having carried out a pan-European survey of forest condition based on the network of Level I plots for a number of years, it was felt that it was time to implement a soil programme. At the next Task Force Meeting the FSEP presented a report that contained a summary of national forest soil activities and a set of recommended parameters and soil layers for a pan-European soil condition survey. In 1992 the final version of a sub-manual on methods and criteria for the monitoring of forest soils was adopted. The submanual contains a selection of mandatory and optional parameters (Table 1) and outlines reference procedures for sampling, analysis and reporting.
For the processing of the data of this soil inventory a Forest Soil Co-ordinating Centre (FSCC) was set up in November 1993 at the Laboratory of Soil Science of the University of Gent. The major activities of FSCC are storage, interpretation and presentation of collected data on Level 1 plots after a quality control. The reported data are stored in a relational database linked to a GIS. A first report on the forest soil condition in 23 countries will be presented in 1997. The results of eight more countries will become available later. The report will provide insight into the nutrient condition in relation to trees and will help to identify soils with a high susceptibility to soil degradation processes, such as soil acidification.

FSCC collaborates with other Expert Panels of the ICP Forests and the European Commission in the field of the protection of forests against damage caused by atmospheric pollution. It is further responsible for the organisation of Forest Soil Expert Meetings.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Reference method</th>
<th>Organic layer</th>
<th>Mineral layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>extractant: 0.01M CaCl₂ measurement: pH-</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Org. C</td>
<td>g/kg</td>
<td>dry combustion</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Total N</td>
<td>g/kg</td>
<td>dry combustion</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>P, K, Ca, Mg</td>
<td>mg/kg</td>
<td>digestion in <em>aqua regia</em></td>
<td>M</td>
<td>O</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>g/kg</td>
<td>calcimeter (if pH&gt;6)</td>
<td>O</td>
<td>M</td>
</tr>
<tr>
<td>Weight of the organic layer</td>
<td>kg/m²</td>
<td>volume (cylindrical) - dry weight</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Na, Al, Fe, Cr, Ni, Mn, Zn, Cu, Pb, Cd</td>
<td>mg/kg</td>
<td>digestion in <em>aqua regia</em></td>
<td>O</td>
<td></td>
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<tr>
<td>Exchangeable acidity (AcExc)</td>
<td>cmol(+)kg</td>
<td>titration of a 0.1M BaCl₂ extraction to pH 7.8</td>
<td>O</td>
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</tr>
<tr>
<td>Acid exchangeable cations (ACE)</td>
<td>cmol(+)kg</td>
<td>sum of Al³⁺, Fe²⁺, Mn²⁺ and H⁺ measured in a 0.1M BaCl₂ extraction</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Basic exchangeable cations (BCE)</td>
<td>cmol(+)kg</td>
<td>sum of Ca²⁺, Mg²⁺, K⁺ and Na⁺ measured in a 0.1M BaCl₂ extraction</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Cation exchange capacity (CEC)</td>
<td>cmol(+)kg</td>
<td>BCE + ACE, or BCE + AcExc</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Base saturation</td>
<td>%</td>
<td>100 x BCE/CEC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Forest soil condition survey**

**Objectives and Implementation**

The purpose of this large-scale soil survey is the assessment of basic information on the soil chemical status and on properties which determine the soil vulnerability to air pollution. The aim is to determine whether the forest damage observed throughout Europe is related to soil conditions and particularly to soil changes induced by atmospheric pollution.

Soil sampling and analysis were carried out by the NFCs. The results of the national surveys were submitted to FSCC before 31 December 1995, where they are stored in a common database.
Pedological characterization of sample plots

The pedological characterisation is optional for level I study plots. It includes at least one detailed profile description and is carried out before starting soil measurements. It provides background information on the concerned soil in order to improve the interpretation of other data collected at the plot location. It is mandatory to classify the soil at the study plots according to the FAO Soil Legend (1988). Such a soil classification requires information on several items that are observed during profile description. Soil profile description is carried out according to the FAO guidelines (FAO, 1990) on a location that is representative for the sampling area.

Soil sampling and analysis

The sampling area is selected in a homogeneous part of the study plot. The sampled soil should be representative for the forest stand at the study plot.

The organic top layer is sampled separately. A distinction is made between O- and H-horizons, defined in the FAO guidelines for soil description (FAO, 1990).

After removal of the litter, the mineral soil is sampled following genetic horizons or by layers with predetermined depths. The method using predetermined depth layers is preferred because it facilitates comparison between plots. If sampling is done by fixed depth, results are reported for the following layers:

- the M01 layer from 0 to 10 cm; it is advised to sample M05 (0 to 5 cm) and M51 (5 to 10 cm) layers separately;
- the M12 layer from 10 to 20 cm

If samples are taken according to horizons, depth and thickness of the horizons are also recorded as observed during the profile description.

For every sampled layer or horizon, one representative composite sample or several subsamples were collected; the number of subsamples collected is reported. In the composite depth sampling method the whole soil core is homogenised and a sub-sample is taken for laboratory analysis. The collection of an amount large enough to allow for a part of it to be stored for eventual re-analysis in the future was recommended.

Macroscopic roots and stony material are manually removed at the sample location. In the laboratory, the samples are air-dried at a temperature not higher than 40°C. After drying the samples are ground and sieved through a 2 mm sieve. The fraction < 2 mm (“air-dry fine earth”) is homogenised and constitutes the material that is subjected to the laboratory analyses.

The calculation of the results of soil analysis is done on the basis of “oven-dry” soil. The moisture content of air-dry soil is determined prior to soil analysis by overnight heating of an accurately weighed subsample in an oven at 105°C.

Results on mandatory parameters will be available for most of the participating countries (Figure 2). The optional parameters have been measured in about half of the countries or less.

Fig. 2. Data availability, presented by the number of participating countries (total = 31) that have measured each soil condition parameter.
Data submission

The forest soil condition results are submitted to FSCC in digital format (Annex I). A file with plot information contains plot coordinates, altitude code and FAO soil unit. The chemical parameter results are submitted in separate files for mandatory and optional parameters, respectively. Supplementary information on parent material, soil texture class, bulk density and coarse fragments content is submitted on a voluntary basis in another file. Table 2 presents the number of observation plots in the 23 countries of groups 1 and 2 and the reported parameters.
Table 2: Availability of forest soil condition results in the 23 countries presented in the 1997 European report.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of soil plots</th>
<th>Soil unit</th>
<th>pH, C_Org, N</th>
<th>CaCO₃</th>
<th>P</th>
<th>K, Ca, Mg</th>
<th>Optional aqua regia extractions</th>
<th>Cation exchange properties</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Org</td>
<td>Min</td>
<td>Min</td>
<td>Org</td>
<td>Min</td>
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<td>0</td>
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</tr>
<tr>
<td>Sweden</td>
<td>1249</td>
<td>(1)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Switzerland</td>
<td>48</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>67</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

1: available parameter; (1): available for a selection of plots; 0: unavailable; Org: organic layer; Min: mineral layer
Three groups of countries are distinguished (Figure 3):

1) the plot locations of the soil condition inventory in Austria, Finland, Norway and Sweden do not coincide with the 16km x 16km grid intersections. These countries had initiated a national soil survey before the start of the ICP programme, using a different grid system. It is also unfortunate that sampling and analysis methods often differ from reference methods. For the European database, only data of those plots located nearest to the 16km x 16km grid intersections were retained. In this way a plot density that is similar to the predetermined Level I density is simulated. Where soil horizons instead of fixed depth layers were sampled, the parameter results were recomputed to the approved layers;

2) countries that have submitted data on plots coinciding with the 16x16 grid intersections;

3) other participating countries that could not meet the deadline for data submission.

As such, there are tables that store descriptions of the used codes (e.g. soil unit code, parent material code, etc.). Other tables contain information on national sampling and analysis methods.

The primary key attribute is plotid, which is a concatenation of the attributes plotnr and country (e.g. plot number 56 in Austria, country 14, has plotid 5614). The primary key attribute links the data tables with the plot information table and plays an important role in the GIS linkage.

A procedure was written to load the data from their original ASCII files, corresponding to the input forms (Annex I), into the database. To ensure a high quality database, several screening procedures are performed on the data submitted by the NFCs, before they are loaded in the database.

Data integrity check

The national forest soil condition data are subjected to a step-wise integrity check:

1) A visual examination of the data files checks whether all requested information is provided in the correct data format:
   • use of spaces for data field separation (no tabs are allowed);
   • number of decimals;
   • position of each data field.

2) A first automatic integrity check detects illegal characters, undefined codes, impossible dates or coordinates and stores them in so-called “bad record files”. The following checks are performed:
   • presence of text characters in numerical data fields;
   • incorrect country code;
   • impossible date records (e.g. 301394);
   • impossible latitudes and longitudes (e.g. +523260);
   • altitude code outside accepted range;
   • soil unit code;
   • parent material code;
   • texture code;
   • BaseSat ≤ 100.

Data files that are purged of undefined codes and impossible values can be loaded in the database.

After loading the corrected data files in the database, the coordinates of the soil condition plots are compared with the coordinates of the annual crown condition databases, stored at Programme Co-ordinating Centre West (PCC West) in Hamburg. In view of cause-effect studies, relating results of crown condition, soil condition and foliar analysis, links between the respective databases should be made possible. For this purpose, each Level I plot should have a unique number and a unique georeference.

A final integrity check is performed by applying a number of expert rules to the data. The expert rules detect improbable parameter results. When handling large amounts of data, there is a constant danger of errors. Simple typing errors are often difficult to detect, especially when the reported value is within the accepted range. Even parameter values submitted in an incorrect unit can sometimes slip through the usual data check routines. The verification of improbable values detects values outside the expected range. The verification
is based on simple relationships between individual soil properties (defined further in this text). The relationships are defined in a set of rules that are applied on the database. These limits are based on the outermost values in the submitted soil condition data.

Most rules do not check all the data in the database but only in a subset of data, i.e. that a certain condition(s) should be fulfilled for the rule to apply. For example, certain rules only apply on organic layer results. Four types of rules are distinguished:

- **Type A**: rules that check whether the ratio between two parameters, such as C/N and C/P, are within acceptable limits.

- **Type B**: rules that check whether parameter results are within the required range in the presence of a certain soil property. For example, Mollic and Umbric properties require an organic carbon concentration above 6 g/kg in the top soil.

- **Type C**: rules that detect abnormal changes between overlying layers. These can be verified by setting a maximum permissible absolute difference (MPAD) between parameter values of overlying layers. When a parameter has a large range of possible results, the MPAD has to be set quite high in order to tolerate natural variations in the high value range. For example, it is not abnormal to measure a difference in Ca concentration of 10,000 mg/kg in overlying mineral layers of a calcareous soil. However, rules based on absolute value differences will not detect an abnormal change between layers, having parameter results in the low value range. The same difference in Ca concentration in non-calcareous soils is quite unusual. Therefore, another set of type C rules checks the ratio between parameter results of overlying layers. This ratio is > 1, when the value in the overlying layer exceeds the value of the underlying layer. Parameters for which this is expected, such as C_Org and N, the maximum permissible ratio (MPR) is set relatively high compared to the minimum permissible ratio (mPR);

- **Type D**: rules that verify whether CEC and BaseSat are correctly determined.

Whenever anomalies are detected in the submitted data, the NFC has to be contacted and asked to verify the correctness of the data and, if necessary, to submit new, corrected, information.

**Data analysis**

The data, once loaded in the database, undergo a number of procedures, before they can be usefully presented in the report. This data analysis involves:

1) Calculation of derived parameter values: in order to evaluate the nutrient status of soils, measured concentrations need to be expressed in terms of nutrient availability. Total nutrient amounts in organic layers, expressed in mass per unit surface, can be calculated by multiplying the measured concentrations with the weight of the organic layer. For example, the calculation of total amount of phosphorus \((P_{total})\) in the organic layer in g/m² involves:

\[
P_{t} = P \cdot \text{OrgLay}
\]

where \(P_t\) is the concentration of \(P\) (in g/kg). The weight of the organic layer \((\text{OrgLay})\) is expressed in kg/m².

Results of mineral soil analysis are given on basis of the oven-dry fine earth fraction. From the viewpoint of soil-plant relationship, it has often been argued that it is more relevant to express values on a soil volume basis rather than the usual soil weight basis. For the conversion to volume, the mass of fine earth is first determined using the layer thickness, bulk density and content of coarse fragments. For example, the availability of nitrogen \((N_i)\) in the topsoil, expressed in g/m² is determined by weighing the nitrogen concentrations in the individual mineral layers \((N_i)\) according to their mass of fine earth:

\[
N_i = \sum_{i=1}^{n} N_i \cdot \Delta d_i \cdot BD_i \cdot (100 - CF_i) \cdot \frac{1}{100}
\]

where \(n\) = the number of layers in the topsoil

\(N_i\) = nitrogen content (in g/kg) of layer \(i\)

\(\Delta d_i\) = thickness (in m) of layer \(i\)

\(BD_i\) = bulk density (in kg/m³) of layer \(i\)

\(CF_i\) = coarse fragments (in vol%) of layer \(i\)

2) Derivation of soil properties from the attribute soil unit: the soil information provided by the FAO classification name can be translated to the presence or absence of diagnostic horizons and properties, used in the classification procedure. For example, a soil classified as a Vertisol has all the characteristics required for
Vertisols, but also lack the characteristics that are diagnostic for soil groupings that appear earlier in the FAO key, namely Leptosols, Anthrosols and Histosols. As a consequence, judgements can often be made on the presence of horizons or properties diagnostic for soil groupings that were eliminated by the key.

The soil condition survey only deals with topsoil properties. However, the FAO classification system often uses the presence or absence of properties occurring in the subsoil as criteria to distinguish between classes, at a higher level than properties occurring in the surface horizon. For example, a soil classified as Solonetz requires the presence of a Natric B horizon, while the kind of surface horizon (Mollic or Ochric) is only introduced at soil unit level. However, the nutrient status in the upper 20 cm of a Mollic Solonetz will probably show more similarities with other soils having a Mollic A horizon than with soils classified as Solonetz having an Ochric A horizon. For our purpose it would be more useful to regroup the soils in classes based on their topsoil properties, than using the FAO soil groupings.

Relevant topsoil properties have been defined in terms of diagnostic horizons and properties defined by FAO given in italics.

<table>
<thead>
<tr>
<th>Property</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mollie</td>
<td>having a Mollie A horizon</td>
</tr>
<tr>
<td>Umbric</td>
<td>having an Umbric A horizon</td>
</tr>
<tr>
<td>Ochric</td>
<td>having an Ochric A horizon</td>
</tr>
<tr>
<td>Humic</td>
<td>having more than 1.4g organic C per 100g fine earth as a weighted average over a depth of 100 cm from the surface</td>
</tr>
<tr>
<td>Spodic</td>
<td>having a Spodic B horizon</td>
</tr>
<tr>
<td>Albic</td>
<td>having an Albic E horizon</td>
</tr>
<tr>
<td>Calcareous</td>
<td>containing at least 2% CaCO₃ or showing strong effervescence with 10% HCl in at least one horizon within 125 cm of the surface</td>
</tr>
<tr>
<td>Gleyic</td>
<td>having gleyic properties within 100 cm of the surface or stagnic properties within 50 cm of the surface or plinthite within 50 cm of the surface</td>
</tr>
<tr>
<td>Rock</td>
<td>having continuous hard rock or highly calcareous materials or a continuous cemented layer within 30 cm of the surface, or having less than 20% of fine earth over a depth of 75 cm from the surface</td>
</tr>
</tbody>
</table>

(3) Assessment of weathering classes: one of the key processes in soil nutrient cycling is the release of ions by weathering of mineral constituents (Olsson, 1994). Elements are released and soil acidity is buffered through weathering. Weathering rates are dependent on soil mineralogy as well as on other site factors.

Parent material codes were regrouped in 5 classes using the approximate weathering rate of the constituting minerals as criterion (de Vries et al., 1992). Sverdrup and Warfvinge (1988) estimated field weathering rates using reaction rate coefficients of rocks and minerals derived from laboratory studies. Carbonates (calcite, dolomite, magnesite) are considered as the fastest weathering minerals. Calcareous parent materials are therefore attributed to weathering class 4. Other readily weatherable minerals are olivine, anorthite, garnet, diopside and nepheline. Parent material types dominated by these minerals are attributed to weathering class 3. Parent materials dominated by minerals such as biotite, chlorite, amphiboles, pyroxenes, plagioclases (except anorthite) or apatite have an intermediate weathering rate (class 2). Acidic parent materials consisting of very slow weathering minerals (K-feldspars, muscovite, etc.) and inert minerals (quartz, rutile, etc.) are attributed to class 1. An additional class (class 0) is reserved for organic parent materials.

(4) Classification of parameter values: presentation of the results of the soil condition parameters on maps requires the selection of classes. The number of classes is limited to 5 for all parameters. The class limits are selected in function of the frequency distribution of the parameter results.

Most results are not normally distributed. The distributions are often positively skewed, showing a tail towards larger values (see also Figure 5). In order to obtain a distribution
of results among the classes similar to normally distributed parameters, the difference between upper and lower class limits gradually increase. Class 1 has the narrowest range, class 5 the largest (Figure 4).

(5) Statistical analysis: in order to discover population differences, the results of subgroups taken from the entire population of results are statistically compared. Because the assumption that the subgroups are samples from a normally distributed population is mostly not met, distribution-free or non-parametric tests are used to check the significance of differences between subgroups.

The Kruskal-Wallis Test checks the hypothesis that independent samples come from populations having the same frequency distributions. All cases from the different subgroups are combined and ranked. For each group, the ranks are summed and the Kruskal-Wallis H statistic is computed from these sums. The H statistic has approximately a chi-square distribution supposing the subgroups have the same underlying distributions. The smaller the observed significance level, the more significant is the difference between the subgroups.

The Sample Median Test is used to determine whether populations have the same median. The samples are combined and the median for the total distributions is calculated. The number of observations above this median, as well as the number of observations less than or equal to this median, is counted for each sample. The test statistic is based on these counts.

![Figure 4. Class distribution of the results of K concentration (mg/kg) in the organic layer (O) and the 10-20 cm mineral layer (M12).](image-url)
Presentation of results

The processed soil condition data are presented in several ways. The use of a GIS permits map display of the classified data stored in the database. A geographical presentation of the results enables the evaluation of spatial patterns. A bar chart shows the class distribution of the parameter values at the observation plots (Figure 6).

Summary statistics (mean, standard deviation, count) of subgroups of plots having significantly different results are tabulated (Table 3). The identification of soil groups showing a specific range in results for a certain parameter is a major step towards obtaining insight in the chemical condition of the European forest soils. Conclusions reached for groups of plots can be extrapolated to areas with the same conditions that were used to distinguish the group.

Table 3: Average pH results in soils having Spodic properties compared to non-Spodic soils and the overall population.

<table>
<thead>
<tr>
<th>Property</th>
<th>Statistic</th>
<th>Horizon</th>
<th>O</th>
<th>M05</th>
<th>M51</th>
<th>M01</th>
<th>M12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spodic</td>
<td>Average</td>
<td>3.4</td>
<td>3.5</td>
<td>4.0</td>
<td>3.7</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Dev.</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Count</td>
<td>985</td>
<td>312</td>
<td>344</td>
<td>695</td>
<td>794</td>
<td></td>
</tr>
<tr>
<td>Non-Spodic</td>
<td>Average</td>
<td>4.2</td>
<td>4.6</td>
<td>4.7</td>
<td>4.5</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Dev.</td>
<td>1.1</td>
<td>1.4</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Count</td>
<td>2017</td>
<td>1067</td>
<td>1046</td>
<td>1167</td>
<td>1786</td>
<td></td>
</tr>
<tr>
<td>All soils</td>
<td>Average</td>
<td>3.9</td>
<td>4.4</td>
<td>4.5</td>
<td>4.3</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Dev.</td>
<td>1.0</td>
<td>1.3</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Count</td>
<td>3269</td>
<td>1540</td>
<td>1428</td>
<td>2389</td>
<td>3240</td>
<td></td>
</tr>
</tbody>
</table>
Interpretation

Data quality and transboundary comparison

The survey results reflect the spatial variability of the forest soil condition in Europe. Care must be taken, however, in the interpretation of these results in order to avoid incorrect interpretations. The risk for misinterpretations is particularly great when results between countries and regions are compared without regard to the problem of intercalibration. Observed differences may be simply due to differences in methods of sampling or analysis.

In order to control the quality of the collected data of the Forest Soil Condition Inventory, the Soil Expert Panel decided in 1991 to proceed with a First Intercalibration Exercise. Twenty two countries participated in this study that was finalised in November 1992. It assessed the amount of variation introduced by using different analysis methods and established the need for harmonisation of the methodologies. The participating laboratories received 4 standard soil samples, two acidic mineral soil samples, one calcareous mineral soil sample and one organic layer sample from a

Fig. 6. pH in the mineral layer M12 (the final maps will be in color).
calcic soil. It was recommended to repeat the analyses of each sample at least three times.

Due to missing information and inaccurate method descriptions, the First Intercalibration Exercise was restricted to a comparison of groups of results obtained with similar analysis methods. In a first stage, all reported methods of each parameter were grouped. Next, the results obtained by the same method group were clustered. The statistical analysis consisted of an analysis of variance (ANOVA) and of Tukey's honest significance test.

The variation between the results obtained by different methods was high (Van der Velden and Van Orshoven, 1992). Several national methods were identified as producing strongly deviating results. As a consequence, certain countries decided to use the recommended methods instead of national ones or adapted their national methods in order to improve the harmonisation of the pan-European soil condition survey.

However, even laboratories using the same analysis method often recorded strongly differing results. In 1993, the Soil Expert Panel decided to proceed with a Second Intercalibration Exercise. A new set of two standard samples was sent to the laboratories of the participating countries of the soil condition inventory. Sample A was taken from a Podzolic B horizon enriched in organic matter in a soil on cover sands. Sample B was collected from a Bt horizon of a loess soil. These samples had to be analysed together with the collected samples of the inventory plots, hereby enabling a constant quality control of the submitted data.

![Second Intercalibration Exercise](chart.png)

**Fig. 7.** Reported base saturation results of similar standard samples in the First and Second Intercalibration Exercises (laboratories reporting results obtained with the reference method are marked with a *).
In spite of the efforts towards a harmonisation of national analysis methods since the First Intercalibration Exercise, the variation of the standard sample results in the second ring test remains high. The problem of interlaboratory comparison is illustrated by the results obtained for base saturation for similar soil samples during both ring tests (Figure 7). The variety of extracting solutions used for the determination of cation exchange properties is reflected in the base saturation results of the First Intercalibration Exercise. The average result of one of the acidic mineral samples of the first ring test was 47%, but values as low as 8% and as high as 87% were reported. Results obtained with the reference method show much less variation. During the Second Intercalibration Exercise less results were reported, but their quality improved. Due to the application of more harmonised methods - only unbuffered salt solutions were used for the extraction of exchangeable cations - the overall variability decreased markedly.

**Evaluation of soil condition results**

**Nutrient availability**

Plant nutrient availability in soil depends greatly on the amount and nature of nutrients in the soil solution and their association with nutrients adsorbed by or contained within the solid phase of the soil (Barber, 1995). This first large-scale inventory assesses the present nutrient status of the solid - both organic and mineral - phase of forest soils in Europe.

Total nitrogen concentrations, measured in both organic and mineral layers, give an indication of the soil reserve of this major plant nutrient. *Aqua regia* extracted P, K, Ca and Mg from the organic layer reveal nutrient deficiencies. Interpretations of the *aqua regia* extractions should be made with care, because elements present in inorganic forms may also be extracted. The same is true for micronutrients, like Cu and Zn. Measured amounts include elements taken up by plants and returned to the soil as litter, elements deposited by the atmosphere and elements present in minerals, both in exchangeable form as in the lattices of minerals that are destroyed by the *aqua regia*. Calculated nutrient ratios, such as C:N, C:P, Ca:Mg:K, provide information on the quality of the organic matter in the soil.

The cation exchange capacity, determined for the mineral soil layers, is a measure of the soils’ capacity to retain positively charged nutrients in a position available to plant roots. The proportion of the cation exchange capacity occupied by exchangeable basic cations (base saturation) and the sum of these basic cations (BCE) are important parameters in the evaluation of nutrient availability.

Relationships are investigated between nutrient content and exchange properties on the one hand and site characteristics, such as soil type and derived soil properties, parent material, texture class, etc. on the other hand. Observations made at the soil condition plots can be translated toward forest areas having similar site characteristics.

**Acid neutralising capacity**

The emission of acidity in Europe reached its maximum in the early 1970s with an emission density of
several kmol H\(^+\) ha\(^{-1}\) yr\(^{-1}\) in many parts of Europe (Ulrich, 1995). Soil acidification due to acid deposition might result in leaching of nutrients, mobilisation of toxic metals and a retarded decomposition of organic matter.

The acid neutralising capacity of a soil is determined by the soil pH and the presence of constituents in basic form that can buffer against a decrease in pH. Simple constituents with a well defined acidic strength have a narrow field of buffering. More complex constituents, such as organic matter, clay minerals and other silicates do not react as bases at a well defined pH, but over a broad pH range. Because these pH ranges overlap each other, different buffering processes often act simultaneously in the soil. Humic substances and clay minerals have a negative surface charge that is neutralised by exchangeable cations. The buffering activity of these constituents consists of the replacement of these cations by H\(^+\). The weathering process of silicate minerals buffers against acidification by breaking Si-O-M bonds and expelling cations (M\(^+\)) from the silicate structure (De Coninck and Van Ranst, 1993).

Soil buffering processes against acidification result in the removal of basic cations from exchange sites on humic compounds and clay minerals. Furthermore, aluminium ions released into the soil solution during H\(^+\) buffering processes compete with these cations for the occupation of exchange sites. With its small diameter and high charge, Al\(^{3+}\) gradually supersedes the other cations, causing a further decrease of base saturation. It is to be expected that the leaching of Mg, Ca and K from soil and the increase in Al concentration result in a decrease of the cation nutrient status of the trees. At base saturation <15% the soil passes from cation exchange buffer range to Al buffer range, causing high concentrations of Al\(^{3+}\) and Mn\(^{2+}\) in soil solution (Ulrich, 1995).

Expected effects of acid deposition on measurable soil properties are decreases in:

- exchangeable basic cations;
- base saturation;
- soil pH.

The vulnerability of forest soils to acid stress is evaluated in terms of the soil reserves of basic cations and its present conditions of pH and base saturation.

Critical loads of acidity are estimated as a function of atmospheric deposition, of SO\(_2\), NO\(_x\), NH\(_3\), Cl and basic cations, nutrient uptake, weathering, precipitation and evapotranspiration (Sverdrup and de Vries, 1994). Comparison of present loads of acidity with critical loads calculated for forest soils showed important regional differences (de Vries et al., 1992). Critical loads are largely exceeded in many countries of Central Europe. This is in accordance with reports on declining forest vitality in this area.

### Future activities

The results of the large-scale forest soil condition survey may contribute in revealing the role of air pollution as an important stress factor for forest ecosystems. However, to assess soil changes induced by atmospheric deposition soil condition measurements should be repeated at regular time intervals. At the start of the forest soil programme, it was recommended to repeat the soil condition assessment every ten years. Several countries have already begun with revisiting the Level I observation plots for a second run of soil sampling and analysis.

Future activities of ICP Forests will be mainly aimed at a better understanding of the cause-effect relationships of air pollution and other damaging agents on the condition of forest ecosystems. The benefits from the assessment on the large-scale grid are a more accurate knowledge of the extent, dynamics and spatial distribution of forest damage, the soil condition and the foliar nutrient balance. The general deterioration of forest condition is not easily explained by site conditions and natural damaging agents alone. Results of several national studies show that there is a considerable impact of air pollution on the chemical composition of foliage, soil and soil solution. Symptom-specific studies suggest that most effects of air pollution on forest condition are likely to be indirect.

Since the implementation of the Level II programme of ICP Forests in 1994, 770 intensive monitoring plots have already been established in 29 European countries. Instead of using a systematic network covering the total forest area, plots are selected in a way that all important forest ecosystems are represented. In order to recognise factors and processes affecting forest condition, more parameters will be assessed more frequently and with a higher intensity at a lower number of plots than in the Level I programme.
Crown condition assessment, soil and foliar analysis on Level II plots are very similar to the Level I approach. In addition, harmonized methods for deposition measurements, increment measurements and soil solution analysis have been worked out. Pan-European assessments of ground vegetation and weather conditions will be added to the programme at a later stage (ICP Forests, 1996).

The implementation of Level III (under discussion) is aimed at a deeper insight into interactions between compartments of forest ecosystems on a small number of plots. The objective of the intensive monitoring activities, requiring an interdisciplinary approach, are to fill up the gaps in knowledge on:

1. processes characterising forest ecosystems under air pollution stress;
2. relationships between spatial and temporal variation of forest condition and site parameters including deposition

References


ULRICH, B (1995). The history and possible causes of forest decline in Central Europe, with particular attention to the German situation. Environmental Reviews, Canada, Invited Paper.

Section 2: Progress and Recommendations
Welcome speech from Dr. Fischer, Minister of Economics, Technology and Transport of Lower Saxony

Hannover, 20 November 1996

President

Ladies and Gentlemen,

On behalf of the government of Niedersachsen, it is my pleasure to warmly welcome you to Hannover.

As Niedersachsen's Minister of Economics, it is especially pleasing to see the high level of interest in this meeting, which brings together experts from all over Europe. Without harmonising the interests of economics and ecology, it will not be possible to tackle the tasks facing us in the future.

In recent years, numerous environmental problems have led to an increasing awareness of the importance of environmental issues in all areas of daily life. People are waking up to the fact that taking care of the environment is a vital factor in safeguarding future development. And the message is also getting across to business and industry that a healthy environment is a significant factor in the quality of industrial and commercial locations.

Despite all the technological and economic successes in modern industrial societies, we still depend for our existence on the careful treatment of the environment, including the soil. The demands on land are increasing, as are the associated conflicts of interest. Geoscience plays a key role in solving these problems. Geoscientific knowledge is required to harmonise the ecological and economic demands made by the exploration and production of mineral resources, the development of energy sources, soil and water protection, the disposal of waste, and the remediation of contaminated sites. This knowledge is required to create unanimously acceptable and environmentally compatible solutions.

The geoscientific research and development work carried out in Niedersachsen is internationally renowned. Numerous companies, universities, and the national and state geological institutes located in Niedersachsen carry out basic and applied geoscientific research. The government of Niedersachsen attaches a great deal of importance to promoting this geoscientific potential, especially in the light of the changed socio-economic conditions in Central Europe, such as the creation of the European internal market, and the political and economic opening up of Central and Eastern Europe.

I therefore particularly welcome this meeting which is primarily concerned with the sustainable use and long-term protection of land productivity, and will present a European-wide cross-section of the methods and techniques currently applied to achieve these objectives.

Against the background of the continuing loss of “soil” through building, the development of land-saving utilization concepts, which can be successfully incorporated into planning at all levels, is of great significance.

The Federal Republic of Germany faces a very urgent problem in this regard in connection with the upgrading of the former East German infrastructure. This involves harmonizing society’s needs and the demands of soil and
environmental protection at an unprecedented scale. A problem such as this can only be tackled when the information available on the soil can be readily accessed by all the institutions participating in the land utilization planning process. The up-to-date soil information must be made available in the form of soil maps and digital soil information catalogues, and this information must be put to use.

A decision was made early on in Niedersachsen to create a statewide soil information system compiling all the relevant soil information bases. This system was developed by the Geological Survey of Niedersachsen, and numerous scientific institutes and regulatory agencies are working on this system in interdisciplinary groups. State-of-the-art computer support is a vital factor in setting up and using this information base because of the variety and complexity of the soil.

At a scale unique in the Federal Republic of Germany, this information system can quickly and economically provide the data and evaluations required for soil protection and the sustainable use of land resources. This allows the causes of pollution, contamination and destruction to be recognised at an early stage, and for the necessary measures to be taken. In my opinion, this work also makes an important contribution to the protection of soils and sustainable land use.

The recognition of the vital ecological importance of soil as a life-support system, for food production, as a water filter and reservoir, as mineral deposits, and the provision of land for residential and industrial areas, has fostered the need for all states to collect and evaluate information on soil distribution, its properties and changes.

However, soil protection and sustainable land use are no mere local issues. These are problems which need to be solved at an international level.

Significant progress has been made in Europe in recent years in this regard. I am thinking here in particular of the efforts, which involved many of you attending this conference, to create a uniform European-wide digital soil map, not to mention the joint efforts of the pedological institutes in Europe to standardize method bases and databases and to improve co-ordination for soil and environmental protection. For Europe to grow together, it is essential that uniform standards are also developed in this field, to ensure the proper exchange of information.

The “European Council Guidelines of 7 June 1990 on Free Access to Environmental Information” is another step in making available to all, the information required to protect land resources.

Because the protection of soils is the responsibility of all, and impinges on nearly all our basic needs, it is most important that there is a dialogue between science, research, and the private and public sectors. This is particularly so because policymakers require accurate information; information which enables the technical aspects to be fully considered and a balance to be found between the legitimate economic demands on land use and the needs of soil protection. And most importantly, to play a substantive role in safeguarding economic efficiency, at the same time as maintaining the highest standards of environmental protection.

These efforts will only be successful if it is possible to ensure the in-depth transfer of knowledge at a European level. The importance of your conference could therefore not be higher. It makes a vital contribution to establishing important contacts, compiling the results of work carried out by specialists in many countries, and providing a platform to discuss problems and develop solution strategies. Even in the multimedia era, personal contact between experts still remains a crucial factor for success.

With this in mind, I wish you all a most successful meeting.
Summary of Progress and Recommendations

Introduction

This volume contains a large number (45) of papers on the subject of soil and land information systems and their application for planning the sustainable use of the land resources of Europe. The Proceedings are divided into 8 sections. Section 1 gives The European Perspective on the compilation, management, distribution and application of soil and land-related databases. The background to the establishment of the European Soil Bureau is described.

A framework for a European Soil Information System is put forward. The concept of data ownership is introduced and data distribution procedures are proposed. There is also a report on a forest soils database for monitoring atmospheric pollution at EU level.

The National Perspective in Europe is presented in Section 3 – 17 papers from all over the continent – and some trends are emerging. For example, ARC/INFO is becoming a standard for GIS on mid-range systems (running UNIX) with ArcView on Intel platforms. ORACLE is the preferred relational database management system (RDBMS), under UNIX at present but probably Windows NT in future, for managing soil and land attribute data. On PC-based systems, a number of RDBMS packages are being used, including xBASE and MS-Access.

Section 4 contains 11 papers on Techniques and Technologies. The application of Fuzzy Logic and the integration of GIS and RDBMS will undoubtedly play a significant part in future developments. The use of information systems for solving practical problems is a major goal, and Section 5 comprises 8 papers describing Environmental Applications. Soil and land information has always been used for Land Evaluation and this is the subject of Section 6.

Developments in the EU and neighbouring countries

The advanced state of conventional soil mapping in Europe is exemplified by numerous papers on this subject (Section 3). Progress towards capturing data digitally and developing systems for accessing and manipulating the resulting soil and land information is occurring in most countries. New methods of interpreting and applying soil and land information are widespread and there is a real commitment in many countries to this approach for tackling hitherto intractable agricultural and environmental problems.

Co-ordination and harmonisation of national networks

There are now many national systems for database management (DBMS), soil information (SIS), decision support (DSS) and geographical information (GIS) but there is an urgent requirement for a standardized and harmonized approach. This standardization and harmonization should apply to:
1. Data quality and control
2. Computer operating systems
3. Modelling for problem-solving and policy initiatives
Such harmonization will be essential to support Europe-wide initiatives for the protection of water supplies, for soil conservation and for ensuring biodiversity.

**Ongoing European initiatives for soil information**

The 1:1,000,000 scale EU Soil Map will require continuous efforts to improve and facilitate its usability as the main all-Europe land database. These efforts have involved, and will continue to involve, cartographic and semantic elements and the establishment of the Soil Profile Analytical Database linked to the defined mapping units.

A programme of 1:250,000 soil mapping in selected regions of Europe is proposed over the next few years. This is essential to standardize field procedures and data management between EU countries. It will involve a Reference Network for monitoring changes in soil conditions in response to environmental and management factors.

**Major gaps in land information**

During the workshop, the lack of a metadatabase of soil and related information for the European Union was highlighted. The problem can be simply expressed: it is that potential users, and even practitioners, cannot easily discern what information is available outside their own patrimony, particularly its quality and spatial resolution. Furthermore, the availability of data needs clarifying and procedures for distribution need implementing.

The lack of harmonized (compatible) information handling systems – DBMS, GIS and links to Remote Sensing (RS) – is to be expected at this stage of an international project. Details of the underlying hardware and software architectures – e.g. RISC (Reduced Instruction Set Computer) as opposed to CISC (Complex Instruction Set Computer) platforms, and the application of object-oriented software development techniques – cannot be addressed until there is widespread agreement on the overall shape of a European Land Information System. Figure 1 gives a database-centric view of the technologies that are likely to be involved in such a system. The database is central because this is the key to the quality of any outputs. Without good quality data at the appropriate resolution, the results obtained will not be adequate for decision support and policy-making. Clearly more dialogue will be required before finalising the way forward.

Many delegates raised the need for a database of hydrologic (and/or hydraulic) properties of European Soils (HYPRES). This will be essential for more spatial modelling of agricultural and environmental processes, e.g. nitrification and acidification, pesticide pollution, soil degradation. The required measurements include soil water retention, saturated and unsaturated hydraulic conductivity, and relationships to soil texture, structure and horizonation.

**Outstanding issues and recommendations**

There is a need for vigorous support and adequate resourcing of the European Soil Bureau. Measures to ensure a productive relationship with the European Environment Agency’s Topic Centre for soil, for addressing environmental issues, are also vital.

A strong initiative to establish firm, agreed procedures for controlling access to and distribution of data (DDP) involve:
1. an authorisation process
2. a standardised charging structure
3. legal enforcement

Further development and enhancement of the European Soil profile and Analytical Database is essential. The minimum additional type profiles required are:
1. land use variants
2. regional variants
3. heavy metal data for dominant units on the 1:1,000,000 EU Soil Map.

Improved information on hydrologic properties of European soils (HYPRES) is vital to refine pedotransfer functions for general modelling and allow more confident use of soil map units for spatial environmental modelling. This project should include Eastern European and Scandinavian countries as well as the European Union.

It is essential to recognise the need for on-going projects to acquire new spatial land data in addition to improved handling of archive data (the main theme of the workshop). Serious imbalance will result in
future from excessive concentration on data manipulation at the expense of data acquisition. In the past, the process of making land inventories has concentrated on the acquisition of new data and failed to address problems of manipulation, interpretation and application of existing data. A reverse imbalance with over-emphasis on the processing of archive data must now be avoided. It is sobering to reflect on how little effort is now being expended on collecting primary soil and land data in Europe. If we are not careful we will be restricted to reinterpreting land data that have been collected long in the past. We will then lose the will, the expertise and the momentum to monitor what is actually happening to our land.

**Postscript**

Figure 1 summarises many of the aspects of information systems that have been used and reported in many of the papers in these Proceedings. Its database-centric view of information systems development is a plea to all practitioners, managers, and policy makers not to lose sight of the importance of land data – their accuracy, integrity and security – in the quest to develop sustainable exploitation of our resources in the future. There is a danger that our information technology (IT) will obscure the true meaning of what we are trying to analyse and portray. We have a duty to succeeding generations to maintain our sense of proportion about the earth on which we live, and not to allow the picturesque representations of ‘virtual reality’, produced so efficiently by our modern IT systems, to distract us from the real issues of sustainable land use.

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*Figure 1:*

**Information Systems Schema**

[Diagram of Information Systems Schema]

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Section 3: The National Perspective
Section 3: The National Perspective

Development of the soil information system BORIS in Austria
N. Arzl, A. Dvorak, A. Riss, Ingrid Schreier, Sigrid Schwarz

From Soil Survey to quantitative land evaluation in Belgium
L. Hubrechts, K. Vander Poorten, M. Vanelooster

Capture, updating and evaluation of field and analytical data for Bulgarian soils
I. Kolchakov, B. Georgiev, D. Stoichev

Development of the Soil Information System for the Czech Republic
J. Kozak, J. Nimek, O. Vacak

Second-generation soil maps of Denmark – a case study from Western Zealand
Ege Lau Frandsen, H. Breuning-Madsen

Development of soil information systems in the Federal Republic of Germany - status report
H.J. Heineke, W. Eckelmann

The FISBo BGR Soil Information System: State of the Art

Land information systems in Greece: past, present and future
T. Lelentjis, J. Alatas, L. Toulios, S. Floras, G. Kapetanak

A database for sustainable agriculture and environmental protection in Hungary
G. Váralgyay, J. Szabó, L. Pásztor, E. Michéli

LOSIS – Lombardy soil information system for sustainable land management
L. Andreoli, S. Brenna, M. Brigatti, D. Fasolini, R. Rasio, A. Rudini, U. Zecca

The Lithuanian Soil Database for sustainable Land Use: developments and planning
Vanda V. Buivydaite

Using a soil information system to combat soil erosion from agricultural lands in Norway
Åge A. Nyborg, O. Klakegg

Creating an FAO-compatible soil map of Poland
S. Bialousz

Romanian Soil & Land Information System – an overview
C. Raşa, V. Vlad, I. Munteanu, S. Cărstea, M. Dumitru, R. Lăcătusu, C. Simota, Ruxandra Vintilă, D.M. Motelică

ROMSOTER-200: a Digital Soils and Terrain Database for Romania
I. Munteanu, C. Grigoras, Sorina Dumitru, C. Simota, Elena Dobrin, Victoria Mocanu, C. Iordachescu

The Soil Information System of Slovakia and its utilization in land evaluation
J. Hraško, J. Kobza, V. Linkeš

Land information systems for sustainable development in the UK
M.E. Proctor, P.A. Siddons, R.J.A. Jones, P.H. Bellamy, C.A. Keay
Development of the soil information system BORIS in Austria

Objectives

Soil is the most important sink for pollutants in terrestrial ecosystems. Since, due to high costs and low efficiency, rehabilitation of contaminated soils is hardly possible, soil – a basis for life – is endangered and can only be preserved by means of preventive measures. In order to carry out effective soil protection, reliable and nationwide information on condition, contamination and vulnerability (critical loads) of the soils is necessary. Therefore the basic aim of BORIS is the Austria-wide uniform capture and combination of existing and future soil data.

These data provide the basis for systems of assessment and prognosis, particularly in respect of soil quality in the sense of effective soil protection (see Figure 1).

General Aspects

Despite the existence of a good basis as far as amount and quality of soil data are concerned, Project BORIS is the first attempt to create a nationwide soil information system in Austria, although the need for an Austria-wide soil information system had been voiced repeatedly (by Federal Government, the Ministry of Agriculture and the Ministry for the Environment).

The experience gained from the pilot study μ-BORIS provided the basis for the BORIS project.

From the pilot study μ-BORIS to the Soil Information System

In 1991 the Austrian Federal Environment Agency launched the pilot study μ-BORIS in order to verify the feasibility of an Austria-wide soil information system. The main question was to what extent primary heterogeneously established data could be combined and whether or not common storage, administration and evaluation were possible.

The main achievement of this project, which was completed at the end of 1994, was the development of a data model and a clearly defined interface as well as the creation of a user-friendly interface.

The common evaluation of data combined from five independent investigations, in which a limited number (38) of parameters (basic soil parameters, nutrients and pollutants) were assessed, confirmed the feasibility of the project. Available data were standardised by means of code lists attributed to the individual fields of the data bank and the parameters. In order to make the work easier, fields and parameters were classified by means of a hierarchical numerical scheme.

Data were derived from the Upper Austrian Soil Condition Survey (Amt Der Oberösterreichischen Landesregierung, 1993), the Forest Soil Condition Survey (Englisch et al., 1992) as well as from local investigations carried out by the Federal Environment Agency (Weiss et al., 1992) and the Municipal Authorities Linz (Aichberger, 1989; Hofer et al., 1990).

The experience gained from the pilot study μ-BORIS provided the basis for the BORIS project.
Data availability in Austria

General Aspects

In Austria, soil and soil protection are within the competence of the provincial governments. Until 1989 there was no standardized procedure for the collection of soil data within the framework of soil condition surveys carried out by the individual provinces. This explains the large number of heterogenous data available in Austria, the only exception being data from forest soil investigations for which a standardized procedure was fixed some time ago (Blum et al., 1986).

In 1989 guidelines for carrying out soil condition surveys were established in Austria (Blum et al., 1996, 2nd edition). This has improved the situation as far as comparability of available data is concerned, but there is still a lot left to be desired, as these guidelines are recommendations and not legally binding for the provinces.

In order to guarantee comparability there has to be a standardized procedure for the collection and processing of data. This standardization is achieved by the Datakey Soil-Science (Dvorak, 1996).

With survey standards lying within the remit of the provincial authorities, there is a great need for voluntary co-operation between federal and provincial governments to provide data for the Federal Government to operate the soil information system (covering such questions as funding, responsibilities, legal situation, etc.).

Figure 2 shows the databases currently available in Austria. A distinction is made between point and area data and between analog and digital data. Depending on the scale of the survey, data are either suitable for general-purpose surveys or for detailed analyses. The following description of the data records was made according to scientific and data-processing criteria. Copyrights, data transfer, data protection, and rights of access are not dealt with in this paper. Nor does this listing claim to be exhaustive. Table 1 shows the parameters drawn up in the course of the various investigations.
Potential databases for a soil information system in Austria

Figure 2: Potential data bases for a soil information system in Austria
Table 1. Parameters investigated in the course of federal and provincial soil surveys

<table>
<thead>
<tr>
<th>SURVEY</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nationwide</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest Soil Condition Survey</td>
<td>D</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X*</td>
<td>P</td>
<td>514</td>
<td></td>
</tr>
<tr>
<td>Soil Mapping</td>
<td>G</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>A, P</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Provincial</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Condition Survey Lower Austria</td>
<td>D</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>P</td>
<td>1449</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Condition Survey Upper Austria</td>
<td>D</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>P</td>
<td></td>
<td>880</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Condition Survey Salzburg</td>
<td>D</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>P</td>
<td></td>
<td>462</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Condition Survey Styria</td>
<td>GD</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>P</td>
<td>519</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Condition Survey Tyrol</td>
<td>DTS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>P</td>
<td></td>
<td>658</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Condition Survey Vorarlberg</td>
<td>R</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>P</td>
<td></td>
<td>435</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest Soil Condition Survey Lower Austria</td>
<td>D</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X*</td>
<td>P</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
1. Sampling: G - according to genetic horizons
   D - according to uniform depths
   T - topsoil; S - subsoil; R - rooting depth
2. pH-value
3. Cation exchange capacity
4. Soil organic matter
5. Carbonate (CaCO$_3$)
6. Nitrogen
7. Sulphur
8. Nutrients
9. Heavy metals
10. Particle size: * at a depth of 30-50 cm
11. Kind of sampling:
   P - Point data
   A - Area data
12. Number of sampling sites
Nationwide surveys

Forest Soil Condition Survey (FSCS) of the Federal Forestry Research Institute (FFRI)

Between 1988 and 1991 the FFRI carried out an investigation of 514 forest sites in a 8.7 x 8.7 km grid. The investigated parameters are given in Table 1. Data are stored in the data processing system of the Forest Soil Condition Survey (Englisch et al., 1992).

Agricultural Soil Mapping

For the last 20 years the Federal Institute and Research Centre for Agriculture has been establishing maps of Austria’s agricultural land on a scale of 1: 25 000 (in part 1: 5000). About 80 % of the field work has already been completed. A large part of the results is presented in maps and accompanying information booklets. As far as the methodology is concerned, for each soil unit one soil profile had been analysed in the laboratory (see Table 1).

Soil Taxation

In the course of an extensive soil taxation programme, the tax authorities of the individual provinces investigated various soil parameters on arable and grassland soils all over Austria. Data are analog and presented in soil taxation maps with accompanying texts. The investigation is carried out in relation to land ownership and thus provides a valuable basis for detailed land use planning.

General Soil Survey Maps

At present, the Federal Environment Agency is digitizing the FINK soil map of Austria (Academy of Science, 1979) at scale of 1:750 000.

At the Institute for Soil Research of the University of Natural Resources Science, a soil map is being reworked to be compatible with the FAO methodology. This map will be available in digital form and could be integrated into BORIS in the future.

In 1989 the Institute drew up a map (scale: 1:1,000,000) of all areas affected by soil degradation to provide a basis for establishing a soil conservation concept.

Geological Maps

At the Geological Survey Institute of Austria, small-scale general maps of all Austrian regions are available, as are geological maps on a scale of 1:75,000 covering about half the Federal territory. Additionally, in the course of the last few years more than 40 map sheets were drawn to a scale of 1:50,000 and 12 maps were digitized.

Geochemical Atlas of the Republic of Austria

In connection with raw material prospecting in the Bohemian Massif and the central area of the Eastern Alps, the Geological Survey Institute of Austria investigated river sediments of the fraction < 180 μm for their heavy metal contents (Thalmann et al., 1989). Data are digitized and are available in a database together with site co-ordinates.

CORINE Landcover

Within the frame of the CORINE Landcover Project, the Federal Environment Agency participates in a standardised Europe-wide survey of soil and land uses carried out on the basis of satellite images. The EU land cover nomenclature used distinguishes between 44 classes. Areas are considered from a size of 25 ha onwards, mapped on a scale of 1:100,000 and registered in the GIS. This survey was completed in 1996.

Land Use

The Austrian Central Statistical Office carries out land use surveys on a regular basis. Difficulties with spatial attribution arise from the fact that data are a priori attributed to the headquarters/main domicile of a given enterprise. Data are available in analog and digital form.

Caesium Map

The Cs$^{137}$ contents of the soil samples taken at about 2000 sampling sites located all over Austria are stored in the GIS of the Federal Environment Agency. These data are furthermore represented in a general map showing the caesium contamination of Austrian soils. (Bossew et al., 1996)

Register of Suspected Contaminated Sites

The Register of Suspected Contaminated Sites lists all abandoned waste disposal sites as well as derelict industrial sites, which, according to the provisions of the Law for the Clean-up of Contaminated Sites, were notified by the provincial governors to the Federal Ministry for the Environment, Youth and Family Affairs. These sites represent a possible threat to the environment. At present, the register contains about 2,480 derelict industrial sites or sites contaminated by former waste disposal activities. These data could also be usefully included in the soil information system (Schumann et al., 1996)
Register of Contaminated Sites

At present, the Federal Environment Agency has registered about 100 derelict industrial sites, which according to the guidelines of the Law for the Clean-up of Contaminated Sites are considered contaminated sites needing clean-up. These sites are documented in the form of a text database, GIS, Map of Austria 1:50,000 and data sheets (Schamann et al., 1996).

Austrian Wetlands Protection Catalogue

A survey on the location and size of Austrian wetlands was carried out on behalf of the Federal Ministry for the Environment, Youth and Family Affairs. Data are stored at the Federal Environment Agency in a database and in the GIS (Steiner, 1992).

Areas under Nature Protection

All areas placed under nature protection by the provincial governments are recorded in a database at the Federal Environment Agency. Information on nature reserves can additionally be obtained from the GIS (Tiefenbach et al., 1993).

Soil Condition Surveys (SCS) Commissioned by the Provincial Authorities

In 1996 all the provinces completed their preliminary investigations for the soil condition surveys. In some cases, corresponding follow-up investigations have already been carried out. With a few exceptions (Tyrol, Vorarlberg) these investigations were already carried out according to a standardized procedure laid down in the Recommendations on Carrying-Out Soil Condition Surveys in Austria. Following a harmonisation of the datasets extensive information from about 4500 sampling sites could be managed together, which has already been realized in part (Styria, Vienna). Table 2 shows the distribution of the investigated sites according to land use types.

Forest Soil Condition in Lower Austria

In Lower Austria forest soil condition is being assessed on the basis of data derived from the 97 Lower Austrian sampling sites taken from the national grid plus an additional 90 sites which are investigated according to the same guidelines. All data are stored in the database of the Institute for Forest Ecology of the Federal Forestry Research Institute (Amt Der Nieder-österreichischen Landesregierung und Forstliche Bundesversuchs-anstalt, 1991).

Soil Monitoring Areas

Now that the brochure on standardising the procedure for the carrying out of soil condition surveys is completed (Blum et al., 1996), the provincial governments are in charge of implementing the investigations and methods recommended therein. With the implementation of monitoring programmes all over Austria, data from intensively sampled and investigated sites (parameters including soil physics, chemistry, microbiology and zoology) will be available for integration into a soil information system.

Table 2. Number of soil condition survey sites per province and type of land use (as of 1996)

<table>
<thead>
<tr>
<th>PROVINCE</th>
<th>Tyrol</th>
<th>Salzburg</th>
<th>Upper Austria</th>
<th>Lower Austria</th>
<th>Styria</th>
<th>Vorarlberg</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>263</td>
<td>177</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>590</td>
</tr>
<tr>
<td>Agriculture</td>
<td>47</td>
<td>14</td>
<td>439*</td>
<td>1151</td>
<td>150</td>
<td></td>
<td>1691</td>
</tr>
<tr>
<td>Grassland</td>
<td>139</td>
<td></td>
<td>441**</td>
<td>298</td>
<td></td>
<td></td>
<td>1121</td>
</tr>
<tr>
<td>extensive</td>
<td></td>
<td></td>
<td>137</td>
<td></td>
<td>243</td>
<td></td>
<td>137</td>
</tr>
<tr>
<td>intensive</td>
<td></td>
<td></td>
<td>134</td>
<td></td>
<td></td>
<td></td>
<td>134</td>
</tr>
<tr>
<td>Alpine pasture</td>
<td>209</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>209</td>
</tr>
<tr>
<td>other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td>2</td>
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<tr>
<td>TOTAL</td>
<td>658</td>
<td>462</td>
<td>880</td>
<td>1449</td>
<td>519</td>
<td>435</td>
<td>4412</td>
</tr>
</tbody>
</table>

* arable and horticultural land
** grassland including alpine pastures, pastures and other green areas
Local projects

In the course of the last years a number of local and regional investigations were carried out (see Figure 2). The data obtained could be stored and processed in a common database, provided the data are properly prepared. Objectives and ways of procedure varied widely with each of the individual investigators (collection of soil geochemical data, legal provisions for environmental control, etc.).

Data key soil science

The data key soil science with its parameter and code lists provides the basis for entering data into the BORIS soil information system. It was developed to guarantee uniform data storage. In establishing these parameter and code lists a number of soil-relevant concepts were taken into consideration:

- Soil Condition Survey, recommendations towards a standardized procedure in Austria (Blum et al., 1996)
- Austrian Forest Soil Condition Survey (Kilian and Majer, 1990)
- Austrian Soil Mapping (Federal Institute and Research Centre for Agriculture)
- Austrian Soil Taxation (Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft, Heft 32)
- Soil biological working methods (Schinner et al., 1993)
- Instructions for the field work with the Austrian Forest Inventory (Forstliche Bundesversuchsanstalt, 1994)

Work on the development of the data key is still ongoing, the individual drafts being continuously reconsidered and compared to each other in order to provide a data key accessible to as wide a circle of users as possible.

The parameter lists describing sampling sites and soil profiles and the data obtained correspond to the current state of work. Parameters as yet unlisted are given a new code and added to the existing list.

Each parameter is attributed a four-digit code, which allows easy and clear identification. This is especially important with parameters with different designations as well as with many organic pollutants with long and complicated names. The first digit of the code is always a letter indicating the code’s affiliation to a specific table of the database:

- “S” for parameters for site description of the table SITE
- “P” for parameters for soil and profile description of the table SAMPLE
- “B” for parameters which were analysed in the laboratory and which can be found in the table MEASURED VALUE

The following list is a selection of existing parameter lists. One can see that the parameters were put together in no particular order. They are not listed according to their codes nor do the numbers refer to any classification system.

<table>
<thead>
<tr>
<th>Site parameter</th>
<th>Sample parameter</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>S100 Designation</td>
<td>P101 Sampling date</td>
<td>B101 Dry bulk density g/cm³</td>
</tr>
<tr>
<td>S106 Date-Site description</td>
<td>P102 Investigator</td>
<td>B102 Clay %</td>
</tr>
<tr>
<td>S107 Author</td>
<td>P103 Original sample number</td>
<td>B104 pH</td>
</tr>
<tr>
<td>S108 Original site number</td>
<td>P104 FAO - Diagnostic Horizons</td>
<td>B105 CaCO3 %</td>
</tr>
<tr>
<td>S109 Type of investigation</td>
<td>P105 FAO - Soil Horizons</td>
<td>B106 Corg</td>
</tr>
<tr>
<td>S111 Latitude</td>
<td>P109 Boundary</td>
<td>B107 N %</td>
</tr>
<tr>
<td>S112 Longitude</td>
<td>P110 Rock quantity</td>
<td>B108 Ca %</td>
</tr>
<tr>
<td>S115 Source of co-ordinates</td>
<td>P112 Colour moist</td>
<td>B109 Mg %</td>
</tr>
<tr>
<td>S118 Municipal code</td>
<td>P119 Carbonate content</td>
<td>B110 K %</td>
</tr>
<tr>
<td>S120 Altitude in m</td>
<td>P123 Pores</td>
<td>B125 Cr mg/kg</td>
</tr>
<tr>
<td>S121 Source of altitude</td>
<td>P124 Roots</td>
<td>B126 Pb mg/kg</td>
</tr>
<tr>
<td>S123 Exposure</td>
<td>P131 Texture</td>
<td>B127 Cd mg/kg</td>
</tr>
<tr>
<td>S125 Topography</td>
<td>P132 Triangular diagram (soil texture)</td>
<td>B128 Fe mg/kg</td>
</tr>
<tr>
<td>S128 Mesorelief</td>
<td></td>
<td>B129 As mg/kg</td>
</tr>
<tr>
<td>S144 Land use</td>
<td></td>
<td>B183 2,3,7,8-T4CDD ng/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B184 1,2,3,7,8-P5CDD ng/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B185 1,2,3,4,7,8-H6CDD ng/kg</td>
</tr>
</tbody>
</table>
Data are stored in three different formats:

- Numerical value: e.g. S 111 Latitude 123456.987654
- Text: e.g. S 100 Designation Playground Resselpark
- Code: e.g. S 144 Land use 32000

For each parameter there is a corresponding code list, which in most cases consists of numerical codes in order to avoid possible mistakes from the use of capital and small letters or from abbreviations. For example: S 144 Land use

The code lists – like the parameter lists – are “open” and can be amended if need be. Work on the code lists is still ongoing. In some cases they still need to be compared and adjusted according to existing lists.

<table>
<thead>
<tr>
<th>Code</th>
<th>Code text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>Forest</td>
</tr>
<tr>
<td>2000</td>
<td>Agricultural land</td>
</tr>
<tr>
<td>2100</td>
<td>Arable land</td>
</tr>
<tr>
<td>2200</td>
<td>Grassland</td>
</tr>
<tr>
<td>2203</td>
<td>Meadows</td>
</tr>
<tr>
<td>2206</td>
<td>Mountain pasture</td>
</tr>
<tr>
<td>2207</td>
<td>Mountain hay meadow</td>
</tr>
<tr>
<td>2208</td>
<td>Pasture</td>
</tr>
<tr>
<td>2300</td>
<td>Temporary Grassland</td>
</tr>
<tr>
<td>2400</td>
<td>Vineyard</td>
</tr>
<tr>
<td>2500</td>
<td>Fruit plantation</td>
</tr>
<tr>
<td>3000</td>
<td>Other uses</td>
</tr>
<tr>
<td>3100</td>
<td>Housegarden</td>
</tr>
<tr>
<td>3200</td>
<td>Playground/sports field</td>
</tr>
</tbody>
</table>

The data processing aspect of BORIS

**General**

All data (site and profile descriptions, measured values, code lists) are stored in a relational database (RdB-database in an Alpha/VMS environment). For queries and evaluations a client-server-application is being programmed under Windows 95.

There is the possibility in the future of taking the results over into a word-processing package (MS Word) and a spreadsheet (MS Excel), as well as into the statistical programs package SPSS.

As a further development, a link to the GIS is planned.

**Central data organisation of BORIS**

The central data organisation of BORIS (Figure 3) shows the basis of modelling the Austrian soil information system. It lists the single objects, shows the concrete relationship between them and thus provides the basis for the physically installed database.

The site, sample, measured value, and literature represent the main tables of the database.

The table SITE includes the site number which allows clear identification of a given soil sample, details from the corresponding soil profile descriptions (e.g. structure, sampling depth, etc.).

MEASURED VALUE contains the values obtained from laboratory analyses including the corresponding measuring methods and giving at the same time the appropriate sample number (macronutrients, heavy metals, organic pollutants, etc.).

In the LITERATURE table the titles of the corresponding investigations are registered, thus guaranteeing a complete list of all data sources used. Each reference is referred to by means of a literature number which is linked to the respective site numbers. It is possible that one site is documented by more than one reference. The interdependence of each element can be described as follows (see Figure 4):
For each MEASURED VALUE there has to be an input in SAMPLE and SITE, respectively, for each input in SAMPLE there has to be an appropriate input in SITE. Each registration of LITERATURE requires an appropriate SITE description. On the other hand SITE entries can be made without corresponding inputs in the tables SAMPLE, MEASURED VALUE, and LITERATURE. This does not violate the integrity and consistency of the data.

All programs (evaluation, application and interface programs) are based on this concept.

**Logical Data Model (Entity Relationship)**

Based on the conceptual data model, the logical data model describes the structure in which the data are processed. Figure 4 shows how the tables of the database and their contents are linked. Apart from the main tables described above, the following tables are of particular interest:

- **PARADESCR** (parameter description): Detailed information is given on all parameters of the database: parameter number, designation, group affiliation (metals, general soil parameters) and type (code, number or text). The field “synonym” allows a choice between various variants of parameter descriptions (symbol or full name of chemical elements, foreign languages, etc).

- **SAMPLING DESIGN**: a 6-digit code is used to create a link between the measured values and the respective sampling methods. This code gives information on the sampling procedure (point / area sampling), sampling device, number of samples, and if need be, number of the parallel sample.

- **SAMPLE PREPARATION**: in the form of a 6-digit code this table provides information on the treatment of samples from being taken in the field until their analysis (cooling of the samples during transport and storage, grinding, sieving and drying of the samples).

- **MEASURING METHOD**: The MEASURING METHOD is stored in the form of a 6-digit code to create a link between the measured values and the measuring method applied. This code contains information on the extraction procedure as well as on the device used for analysis.

- **LIMIT VALUE**: this table contains not only limit values but also intervention and background values from different investigations for the parameters of the database to allow assessments of exceedances.

In order to guarantee the precision of the data sets, so-called KEY FIELDS (characterised with a * in Figure 4) were defined which must not be eliminated. Furthermore, there are key fields which, by definition, must not be identical at a certain point in time (UNIQUE-clause).
Queries, evaluations, and applications

Queries, evaluations, and applications are determined as individual menu options on the user interface (Figure 5).

Queries

Planned queries are determined in the menu option CONTENTS. It will give access to all available data on sampling sites, samples and measured values for the whole of Austria, and for the individual provinces, respectively.

Furthermore the sub-menu option LITERATURE will provide information on all the surveys already completed and entered into the database. Order criteria are Province, Year and the Institute carrying out the soil investigation. These data are included in the Literature number. Upon the user’s request, data such as

- objective of the survey
- number of investigated sites
- investigated parameter groups
- single parameters

are provided.

Due to the a.m. structure of the data model which consists of the main tables

- LITERATURE-
- SITE-
- SAMPLE-
- MEASURED VALUE

queries concerning the tables Site, Sample, and Measured Value can be made in the same way as with Literature. The same order criteria, i.e. Province, Year and Investigating Institute, will be applied with the table Sample Number and in part with the table Site Number. Thus, according to the needs of the user, it will be possible to select specific periods of time and geographic areas, allowing clear representation (on the screen and in print) of the extracted data.

A link to SQL will allow to design queries according to the users’ needs.

Evaluations (development still in progress)

The planned evaluation options (Menu EVALUATIONS) are the following:

- General soil parameters (C/N ratio, C/S ratio, content of humus,...)
- Heavy metals (summarised heavy metal percentages)
- Organic pollutants (toxicity equivalents, total amounts,...)

The data sets to be evaluated shall be selected via masks, if possible using the path LITERATURE → SITE → SAMPLE → MEASURED VALUE.
Figure 4. Logical Data Model BORIS
Applications

The link to various application programs such as packages of statistical programs (SPSS), Microsoft Office and Tools guarantees further options as far as the extraction and further processing of selected data packets is concerned.

Figure 5. User Interface of the PC application of BORIS – Pull-Down-Menus

<table>
<thead>
<tr>
<th>CONTENT</th>
<th>EXTRACTS</th>
<th>CODELISTS</th>
<th>PARAMETER DESCRIPTION</th>
<th>LIMIT VALUE</th>
<th>TOOLS</th>
<th>EVALUATIONS</th>
<th>INFORMATION</th>
<th>END</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Checklists</td>
<td>Measuring Method</td>
<td>Site</td>
<td>Display</td>
<td>Excel</td>
<td>Selection</td>
<td>Statistics Austria</td>
<td></td>
</tr>
<tr>
<td>Literature</td>
<td>Reports</td>
<td>Laboratory weight</td>
<td>Sample</td>
<td>Measured Value</td>
<td>Edition</td>
<td>Word Edition</td>
<td>SQL</td>
<td></td>
</tr>
<tr>
<td>Site</td>
<td>Reports</td>
<td>Reference weight</td>
<td>All</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample</td>
<td>Reports</td>
<td>Sample preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured</td>
<td>Sample</td>
<td>Sampling design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>SiteNo</td>
<td>Horizon description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiteNo</td>
<td>LitNo</td>
<td>ParaGroup</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LitNo</td>
<td></td>
<td>Institute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further prospects

Geographic Information System (GIS)

Another main objective of project BORIS is to create a link to the geographic information system Intergraph storing and integrating basic geographic data in digital form (FINK Soil Map of Austria, Geological Survey Map of Vettters on a scale of 1: 500 000, topographic maps of Austria 1: 50 000, satellite images – a collection of data which could still be enlarged by including the map material already available in digital form at the Federal Environment Agency).

In this connection the determination of geographical relations (accumulation of sampling sites showing violations of the limit values), the relationship between point and area data (elevated heavy metal concentrations and identification of geographical zones according to major soil groupings), the transformation of point data into area data (interpolation) to determine new trends (nationwide modelling of the soil caesium concentrations) and last but not least the establishment of geographical relations (layering of sampling sites with topographic maps or satellite images) play an important role.

Internet

In line with the aim to make and keep environmental data as transparent as possible, the most important parameters of the soil information system (i.e. heavy metals, pH-value, most important organic pollutants) will be made available on the Internet. The World Wide Web site will allow processing of the data in a user-friendly way and provide the opportunity to make specific queries.

References


From Soil Survey to quantitative land evaluation in Belgium

Summary

The Belgian territory was surveyed and mapped at detailed scale of 1:5,000 from 1947 through the early seventies. The map so produced has a morpho-genetic legend which makes it easy to comprehend for soil scientists but less readily useable for laymen. The map is supported by a huge database, containing data on 13,033 soil profiles. Analytical data are available for 34 variables of some 69,600 soil horizons. Attempts have been made with a certain degree of success to translate these maps into thematic maps which are readily understandable by potential end users.

The problem, however, is that certain parameters such as the soil moisture retention characteristic or the soil hydraulic conductivity curve, are missing in the database. As the option of a new sampling campaign would be prohibitively expensive, research in the late eighties and early nineties focused on the development of 'pedotransfer functions'. These simple equations make it possible to estimate unknown but essential soil parameters from data which are available in the database.

This paper presents the state of the art of the Belgian soil database, and the development and use of pedotransfer functions. Furthermore, modern applications of the Belgian Soil Map in environment-oriented studies are presented.

Introduction

The objective of most soil survey investigations is to provide data for the rational planning and adjustment of land use. The data consist basically of geo-referenced soil characteristics which are recorded in the field, determined in the laboratory and/or extracted from remotely sensed imagery. They are used to resolve landscapes into mappable areas in which the soil is less variable than in the overall landscape (Beckett and Webster, 1971). These areas are presented as mapping units on soil maps. The soil characteristics which are involved in the definition of the mapping units are denoted as diagnostic, definitive, discriminating or envelope characteristics. They are selected according to the purposes, the scale and the budget of the survey.

Systematic field surveys are mostly conducted for non specified, multipurpose, rural land use planning issues. The diagnostic criteria for this type of survey are often based on pedological soil classification systems as the latter are assumed to allow interpretation for various types of application with acceptable accuracy (Dent and Cook, 1987). Soil maps are then constructed by first classifying the recorded sets of soil characteristics for specific locations according to the selected taxonomic system.

In the second stage, the taxonomic identifications are spatially extrapolated based on land surface features. When the field data are compiled for presentation on a reduced scale, a proportional reduction of the information content through generalisation occurs. Classification and generalisation give rise to soil maps which are to be considered as geographic soil inventories containing qualitative information, condensed in legend classes. They are not meant to be functional – ready to use – documents. It is clear that a lot of inference is necessary to obtain statements about mapping units, which are sufficiently precise to plan land use for a specific purpose. Another feature of many general-purpose soil surveys is that, once...
classified, the original field observations are most often neglected in the further map construction process and lost for use in interpretation studies (Burrough, 1986; Bregt, 1992). The Belgian soil map which results from a field survey, conducted at the scale of 1:5,000 and published at the generalised scale of 1:20,000 presents all these features.

A challenging goal for agro-ecological land evaluation is the design, planning, comparison and final evaluation of soil management systems that allow optimal, sustainable agricultural production while minimising adverse environmental consequences. The expected output of such studies consists of map and text documents displaying and reporting on agricultural suitability and ecological vulnerabilities of land units. General-purpose soil maps are potentially suitable for interpretation in terms of suitabilities and vulnerabilities. This interpretation, however, requires considerable field expertise and an advanced knowledge of soil behaviour under different conditions of climate and management. While in the agricultural domain important expertise might be available, especially on general or common topics, it is often lacking for more specific problems and for environmental issues.

An increasingly accepted alternative approach in land evaluation is the use of numeric models to assess land qualities (Burrough, 1989; Wagenet et al., 1991). A lot of research has been devoted particularly to the establishment of deterministic simulation models to quantify hydrodynamic land qualities which often are preponderant for physical land performance. Examples of such land qualities are crop water deficit, cumulative drainage at the bottom of the root zone and number of workable or trafficable days for machinery for seedbed preparation and harvest activities (Van Lanen et al., 1992).

Model-based assessment of hydrodynamic and/or other land qualities requires geo-referenced and quantitative soil information on, for example, bulk density, soil moisture retention and conductivity, soil thermal conductivity and diffusivity among others. Soil maps do contain geo-referenced soil information. However the qualitative and generalised nature of this information prohibits its straightforward use in models. The extended characterization of soil map units through linkage of quantitative properties which are observed, measured, monitored or computed in other data collection exercises than the formal survey, is therefore an interesting possibility for meeting the data requirements of the models. This upgrading of soil maps for use in combination with simulation models results in the establishment of model-specific simulation maps. The latter only contain the geometrical and attribute soil information which is necessary to operate the simulation model (Wösten et al., 1985; Bregt et al., 1989).

In this paper, in addition to an overview of available information resulting from the intensive soil survey of the Belgian soil heritage, the development of pedotransfer functions for the generation of second level soil information on its hydraulic behaviour and the use of simulation models for the assessment of the dynamic physical soil behaviour are described. The development, comparison and evaluation of procedures for conversion of soil maps in general, and the Belgian soil map in particular, into simulation maps for hydrodynamic land qualities using GIS, will also be discussed.

Available information on the Belgian soil heritage

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100,000 soil horizons (Van Orshoven et al., 1993). Physical and chemical analyses on about 16,000 surface soil samples were also carried out and the resulting information was stored in a digital database. Basic survey data were also interpreted to provide information on the soil suitability for different field crops.

In the frame of the COBIS project, carried out at the Institute for Land and Water Management (ILWM), this information was stored in a number of well-structured and eventually related (soil profile and soil horizon) digital databases using the dBaseIIIplus (Ashton Tate Corporation, 1986) and the dBaseIV-software (Ashton Tate Corporation, 1988). After thorough scrutiny, only information on 13,033 soil profiles and on 69,600 soil horizons could be accepted for storage in the digital databases.

**Pedotransfer functions**

Knowledge of the moisture retention curve (MRC) and of the hydraulic conductivity curve (HCC) is indispensable in describing soil water processes. Recently, these processes have been modelled quite routinely for the better understanding of water movement in porous media. Most of the modelling attempts in this field make use of the MRC and the HCC. Both physical properties, however, are seldom available, especially when operating at a regional scale. The relationship between easily measurable soil properties, often monitored during past or actual soil survey campaigns, and the MRC and/or HCC is therefore of major importance. Equations, relating existing sets of properties can give a strong incentive to the interpretation and use of soil maps and to the applicability of simulation models at field and regional scale.

**The Moisture Retention Curve (MRC)**

The need exists to have a mathematical expression describing the MRC, in order to perform easily mathematical operations needed for the solution of flow processes in the soil. Information regarding the MRC relation is, however, often lacking. Vereecken et al. (1989) established relations for estimating the parameters of a modified Van Genuchten equation from basic soil properties on the basis of 182 measured MRCs. A model comparison technique was used on an identification set to define the optimal number of parameters in the Van Genuchten equation.

The original model (Van Genuchten, 1980), having five parameters, could be almost perfectly fitted to the measured moisture retention curves. From different modifications tested, it was found that the model with the m-parameter equal to 1 resulted in an equation performing as well as the original Van Genuchten formulae. This form of the Van Genuchten equation was accepted as adequate in generating the MRC and was therefore fitted to the entire data set of measured MRCs.

The results of non-linear regressions enabled evaluation of the link between such readily available soil data as bulk density, carbon content and particle-size distribution, and the estimated values of the four model parameters for a wide range of textures. It has been shown that the model parameters can reasonably well be estimated as a function of those soil properties. In coarse-textured soils, detailed information on the particle-size distribution seemed to be of major importance in obtaining a reasonable explanation of the level of variance for the parameters defining the shape of the MRC (α and n). The developed regression models were tested for their stability and predictability, applying the double cross-validation technique. It was found that the signs of the partial regression coefficients of determination were stable.

**The Hydraulic Conductivity Curve (HCC)**

An appropriate empirical model was selected for the K(h) relationship (Vereecken et al., 1990) and the relationship between the model parameters and other soil properties was established: 182 K(h) relations were measured on a wide range of soils, of which only 127 were found physically sound. Part of the observations were used to identify which of the different models retained was capable of describing the K(h) curve best. The statistical test applied revealed that Gardner’s three-parameter model (Gardner, 1958) was the best performer. From a sensitivity analysis applied on the parameters of this model log(Ksat) and log(b) were found to be relatively insensitive parameters. The latter is primarily due to the incapability of the crust technique (Bouma et al., 1983) of predetermining the pressure head at which the hydraulic conductivity can be measured. A second problem is the large gap occurring between the measuring range of the crust and the hot-air method (Arya et al., 1975).
The Gardner equation was fitted to the 127 observations, and the parameters were estimated. Regression equations between those parameters and soil properties at four information levels were assessed. The log(n) parameter could be assessed up to 56%, being dependent only on soil texture. Increasing information regarding the textural composition of the soil did not improve the predicting capacity of the regression equation. Log(b) could be estimated up to 70% using the maximal amount of soil information. The measured saturated hydraulic conductivity and the nine textural fractions were particularly important predictors. Log(Ksat) cannot be estimated reasonably when using simple soil properties like textural composition in three fractions, organic carbon content, and dry bulk densities. Detailed information on the textural composition does not improve the estimate. Via double cross-validation the stability of the regression coefficients and prediction level of the regression equations derived is underlined.

At present, attempts are made to assess pedotransfer functions for estimating the saturated hydraulic conductivity as well as the soil thermal conductivity and capacity characteristics. To determine the moisture content dependence of thermal soil properties, the 'cylindrical probe method' was used. Derivation of respective transfer functions revealed that, as well as information on particle size distribution, (dry) bulk density and organic matter content, there is also a need for quantified information on soil structure which is often lacking. The use of the CAT (Computer-Aided Tomography) technique and its probable contribution in generating such quantified information is currently under investigation at the ILWM.

To improve or assure the performance of the equations in estimating the model parameters, it is believed that additional soil information, quantifying the soil structure, must be monitored first.

Assessing hydrodynamic land qualities from soil survey data

Van Orshoven (1993) carried out a study on the assessment of hydrodynamic land qualities from soil survey data. This study focused on the development, comparison and evaluation of procedures for conversion of soil maps in general and the Belgian soil map in particular, into simulation maps for hydrodynamic land qualities. Its scope was limited to the construction of simulation maps for deterministic process-base water flow models which are based on the Darcy equation and more specifically on its application to transient cases of one-dimensional water movement in unsaturated soil systems, as expressed in the Richards' flow equation (Richards, 1931; Feddes et al., 1988). The basic soil attributes needed for the computation of the terms of the soil water balance by numerically solving this equation are the soil moisture retention characteristic and the hydraulic conductivity-pressure head/water content relationship. Deterministic pedotransfer functions for the MRC and the HCC of Belgian non-stony and non-clayey soil horizons, proposed by Vereecken et al. (1989 and 1990), were used in this study.

Soil maps and associated soil survey data have a direct link with a position on the earth's surface and are therefore suitable for being processed using GIS technology. The objective of the study was to review the Belgian soil survey and its outcome in terms of the applicability using GIS-techniques. The study also aimed to define the concept of 'hydrodynamic land quality', reviewing methods of assessment and describing the link between the available soil survey data in Belgium and the desired information about the hydrodynamic behaviour of the land.

Considerable effort was devoted to the use of available soil survey data for the recognition and quantification of soil variability within map units, and to the integration of this variability in the assessment of hydrodynamic land qualities. Uncertainty related to the use of deterministic transfer functions and simulation models and its effects in land quality assessment is discussed. The procedure, developed by Van Orshoven (1991) to derive statistically representative profile data for map units, was evaluated for simulation purposes. This procedure may offer good scope for reducing the computational effort in quantified regional land evaluation studies by replacing the multiple profile observations with one effective simulation soil profile per map unit.

A number of concepts are discussed to overcome the lack of profile data for obtaining complete geographic coverage of northern Belgium in matters of soil map interpretation.

In the above study, a procedure has been described, illustrated and evaluated to assess the hydrodynamic
qualities of semi-detailed land units in Belgium. Hydrodynamic land qualities have been defined in this respect as functional attributes of land describing its long-term average soil-water regime and the temporal variability of this regime. The procedure makes use of the Belgian soil survey data and of a deterministic simulation model of one-dimensional transient water flow in the unsaturated zone of cropped soils. The SWATRER-model (Dierckx et al., 1986) is used as a representative of this group of models.

Due to the involvement of simulation models, the procedure can be categorised as a method for quantified land evaluation. The applicability of the outlined quantitative method, in terms of data requirements and expected output, has been compared to qualitative and semi-quantitative approaches for the assessment of soil-water related land qualities. The method is an alternative to the expertise built up by soil surveyors. Its additional advantages are the possibility of assessing the required inputs, spatial and temporal patterns of the land qualities and potential situations, e.g. for impact prediction.

Basic steps in the procedure are:

1) The delineation of land units by soil map unit boundaries (scale 1:20,000) and their characterisation with the information content of the soil map legend and with information on the vegetative cover and on the climate and hydrological regime in which the unit is situated.

2) The extended characterisation of each studied land unit with observed soil profile descriptions, including geographic location and classification accompanied by data on depth, thickness, particle size distribution and organic matter content of the occurring horizons.

3) The transformation of the selected soil profiles into simulation profiles through the estimation of the soil hydraulic functions for each distinct horizon, using the horizon characteristics as predictor variables in transfer functions.

4) The calculation for each simulation profile of the vertical water flow and the daily terms of the water balance for the considered crop and for a representative number of years or growing seasons.

5) The interpretation of the simulation results (daily terms of the water balance and the evolution of the state parameters moisture content and pressure head) as hydrodynamic qualities of each soil profile.

6) The processing of the individual soil profile quality figures into average land qualities of the map units together with measures of spread.

Vital features of each step are:

1) Soil units on the 1:20,000 map have to be considered as associations of soil series and phases. The dominant series or phase is the one which is eponymous to the map unit. Time series of measured daily precipitation and calculated reference evapotranspiration are retrieved from meteorological stations which are representative for the region in which the studied land units occur. The daily fluctuation of the phreatic water table is preferably assessed from time series of measurements over different years in similar land units or, if this detailed information is lacking, is interpreted from the mapped morphological drainage class.

2) The major source of profile data in Belgium is the collection of profile descriptions which have been gathered on a free survey basis, in the frame of the national survey programme. Subsets of this collection are attributed to the studied map units based on:

(a) corresponding classifications for both, i.e. by class matching; (b) the geographical position of the profile location within the polygons of the map unit, i.e. geo-matching; or (c) a combination of class- and geo-matching, eventually using pre-set weights for the dominant unit and the impurities. Local and regional variants of these matching techniques have been distinguished based on the recruitment area for profile descriptions. This area can coincide with or exceed the project or study area respectively. The regional variant is useful when too few profile descriptions have been made within a (small) project area. The class-matching technique is simple and appropriate when only the dominant component of the map unit is considered. Geo-matching is more suited to account for impurities within map units but requires a spatially random or systematic profile collection to yield representative spatial extents. A combination of class- and geo-matching profiles makes optimal use of all available information while the use of pre-set weighting factors for both groups of profiles increases the
accuracy of the spatial interpretation.

3) The only available transfer functions for the MRC and the HCC for a wide range of Belgian soils use particle size fractions, organic matter content, bulk density and saturated hydraulic conductivity as predictor variables. Whereas particle size distribution and organic matter content were routinely determined in the soil survey programme and are hence incorporated in the profile data set, for bulk density and saturated hydraulic conductivity, no soil series or horizon-specific values can be given. In this study one typical value has been used for all soils and horizons.

4) Crop-specific parameters should be measured and/or retrieved from literature. Notwithstanding the vital importance of those parameters for sensible simulation, literature sources are scarce. At least 20 to 30 years have to be simulated so as to include a wide range of climatological situations. In order to account for the interdependency between crop growth (root development and evolution of leaf area index) and crop water consumption on the one hand, and meteorological and hydrological antecedents on the other, integrated crop growth models, including a water balance model as submodel, better present the scope.

5) In this study, water balance terms and daily evolution of pressure head have been interpreted as five hydrodynamic land qualities: crop transpiration deficit, relative crop transpiration, cumulative net water flux through the 90 cm depth plane, and trafficability in spring and autumn. Other definitions, threshold values and time periods may be applicable and more appropriate for other land units or crops.

6) At semi-detailed scale, spatial correlation of soil properties and quality figures of profile collections is hard to assess. Hence, the profile data can be processed as spatially random variables to yield typical values and measures of spread. Similarly, probabilities of exceedance or susceptibilities for land quality values of a given magnitude can be computed.

Analysis of variance (ANOVA) is a powerful technique in land evaluation to examine differences in hydrodynamic behaviour of land units.

Using fixed effects it has been pointed out that in general the main effects of three map units ('Abal', 'Abp', and 'Zcm', respectively 'Haplic Luvisol, eroded plane', 'Eutric Regosol' and 'Fimic Antrosol') on most of the five hydrodynamic land qualities, are mutually significantly different regardless of the matching procedure used. However, the importance of the appropriate choice of matching procedure and of the appropriate recognition of impurities within map units is illustrated by the fact that for transpiration stress the 'Abp' unit is comparable to the 'Abal' in the case of class-matching while it is rather similar to the 'Zcm' when impurities are involved. Local or regional matching did not alter pairwise comparison of the studied map units so that profiles may be selected in a larger area when they are lacking in the project area.

The factor 'soil profile' representing the land unit and the factor 'climate year' can be considered to display random effects as they form a sample from a population of possible soil profiles and of possible years. Random or mixed effects ANOVA models are therefore theoretically more sound for the examination of differences between hydrodynamic quality values of land units than fixed effects models.

Random or mixed models generate tables which are identical to those from fixed models. However, the Fisher's F-statistic in random ANOVA models is interpreted as a test for the null hypothesis of no differences between all possible factor levels and not merely between the sample of examined or experimental levels. Random or mixed models present the interesting property that the variance fraction of the dependent land quality which is explained by the variance of the population of levels of a random factor can be assessed and compared with the variance contribution of the other random factors and of the error term, through a variance component analysis.

By incorporating all factors of a deterministic numerical experiment in the ANOVA model, the error term is non-existent. This, in turn, provides the possibility to assess the contribution of the uncertainty in hydraulic parameter estimates using transfer functions. The unexplained variance which is obtained after analysis of data
from Monte Carlo simulations is fully attributable to this uncertainty if the simulation profiles arise from reference profiles of which the parameters of the hydraulic functions are randomly and conditionally perturbed. The variance-covariance structure of a dataset of observed and normalised residuals between optimised parameter values and those estimated with the transfer functions provides a good basis for this random and conditional determination of parameter perturbations.

The effect of model weakness can be assessed in a similar Monte Carlo approach, using residual values between simulated and measured qualities, and subsequent adding of randomly drawn land quality residuals to the previous simulation results. It can also be derived directly from the variance of the model residuals when these residuals can be considered to be independent from the other effects. Reliable measured land quality data can sometimes be obtained with lysimeters.

For the three studied map units, the combined effect of uncertainty in parameter estimates and model structure account for 74% of the total variance on the transpiration deficit (TDEF), 66% of which is due to uncertain hydraulic parameter estimates and only 8% to model weakness. For water transport across the bottom boundary of the root zone (CFL90), these combined effects account for 40% of the total variance. 26% is now due to the model disfunctioning. These relative figures also depend on the particular map unit being studied. These results lead to the conclusion that the performance of transfer functions and simulation model has to be evaluated with respect to the particular land unit and the specific hydrodynamic land quality. However, the general finding is that both applied tools (transfer functions and simulation models, the latter with associated submodels and input data) still require substantial improvement in order to distinguish statistically land units where it is known that their hydrodynamic behaviour is different. Therefore, research directed towards better model performance should first focus on associated factors such as the collection of more reliable meteorological and soil hydraulic data.

Variance on water in- and outflow is mainly determined by variable climate conditions within and over the years. Climate variability is less of a determining factor for the variance on transpiration deficit.

Particularly for the CFL90 quality and to a lesser extent for the TDEF, variability of the soil profile characteristics has a relatively weak influence on the variability of the simulation results when also transfer function uncertainty and model deficiencies are accounted for.

However, also in routine studies where transfer functions and models are considered to be deterministic, the soil effect is small for many applications. Therefore, it may be acceptable to replace the multiple profile observations by single representative profile descriptions to characterize the land unit. This reduces the computing effort and upgrades the proposed procedure towards practical applicability in physical land evaluation. The statistically representative profiles which are evaluated in this respect do not yield results which differ substantially from the average simulation results for individual profiles.

For the class matching case, no objection at all was found for use of the statistically representative profiles. For the geomatching and mixed cases, deviations become larger and the appropriateness of use of the statistically representative profiles should be evaluated with respect to the use proposed for the simulation results.

It is, however, important to base land quality assessments on a sufficiently long series of climate years. The figures of 20 to 30 consecutive years which is mentioned in literature was found to be sound in this respect. Hence, unlike for soil profiles, the use of ‘typical’ or representative years to replace individual years in land evaluation studies is to be avoided.

In order to keep regional quantified land evaluation studies feasible in terms of time, manpower, and costs, it is advisable to follow the Dutch example and to develop simple transfer functions between soil, climate and crop data on the one hand and hydrodynamic land qualities on the other, from a large set of a priori simulations with a wide range of input data.

Soil variability within land units, as recognisable from soil survey information, does not have a major influence on the relative and absolute hydrodynamic behaviour of land units. This finding presents scope for grouping land/soil map units in order to obtain a more complete areal coverage in the interpretation of the soil map for study areas, using available
profile data. The legend of the Belgium soil map is well suited for generalization or grouping of map units. Generalisation rules might consist in the grouping of class levels for drainage and variants of the parent material and the elimination of the class variable for variants of the profile development and for depth phase. By selecting profiles outside the study area but within the locality, areal coverage can be dramatically enhanced while representativity remains acceptable.

Establishment of compound map units by simplification of the soil map legend, together with a regional class-matching exercise, also enables the derivation of statistically representative profile data. In order to make full use of available information and respect basic knowledge on soil characteristics and their variability within and across geological and pedological strata, a two-component procedure is proposed to generate such statistically representative profile data. Horizon sequences and horizon characteristics are determined for different groups of soil series within soil zones, soil associations and groups of soil associations, and combined in a second stage.

Belgian soil survey data are increasingly being integrated in operational spatial databases.

A further enhancement of the use of the data can be achieved if more application-specific models become available for interpretation of the data in terms of answers to practical problems related to planning, consolidation and management of land. The transfer function concept will remain invaluable for upgrading the soil map and meeting the model input requirements in this respect. Nevertheless, high quality field data still need to be collected and correlated with soil map units to obtain model parameters which are difficult to estimate or which are too sensitive for a rough estimation.

In the study of Van Orshoven (1993), the lack of reliable piezometric data for soil map units in contrasting topo-geo-hydro-pedo-environments has been encountered as the most limiting factor for sound physical land evaluation. It is believed that the costs for obtaining functional information on the dynamic drainage status of a wide variety of soil map units through a systematic long-term monitoring programme are counterbalanced by the potential benefits for the agro-ecological management of rural areas.

Conclusions

A vast amount of geo-referenced soil information has been collected from the Belgium territory during the survey of the soil heritage which was eventually published at a scale of 1:20,000. This information has been computerised and is now available at the fingertips of modern soil scientists, modelers, and other disciplines to use for new applications.

Whereas the first customers of the soil map were the Belgian farming community, at present a strong demand has come from the community at large with queries about environment, new claims on land for recreation, geo-medical issues etc. Policy- makers have been alerted, driven by cross-border pollution problems, global change issues, and the set-aside policy, to name a few. The problem is that the general public is now wanting answers from a geo-referenced database for issues it was never designed to address. This is very much the case with soil maps. The Belgian surveyors had agricultural production in mind when they went out into the field and tried to systematise their knowledge. Their efforts have resulted in a morpho-genetic soil map which gives a fairly accurate overview of our soil resources, but unfortunately is missing essential information which is required to solve new problems.

As systematic collection of missing parameters, such as the physical soil characteristics, would be prohibitively expensive, shortcut solutions have been explored. This has led to the calibration of pedotraffer functions. Though a breakthrough was reached in this line of investigation, especially for the MRC and the HCC, important developments are eagerly awaited in new functions which will predict the saturated hydraulic conductivity as well as the thermal soil characteristics. It is also realised now that, though very difficult to assess, soil structural information has to be formalised systematically and included in the calculations. Clearly, there is much research needed before we shall be able accurately to characterize our major soil units in order to upgrade our soil maps into simulation maps.

A methodological breakthrough has been observed in the characterization of soil map units by linking it to the geo-referenced relational databases. From this research it became clear that it is possible to generalize soil maps first and then calculate land qualities after linkage of a representative profile to the
dynamic information layers. The latter procedure results in an enormous time saving when probability functions have to be calculated on the basis of soil maps and real-time climatic scenarios.

In the context of a soil map of the EU, it will be of paramount importance that efforts be coordinated internationally so as to come to a more powerful expert system, which will not only guide EU policy-makers in their land management decisions, but will also be a very valuable tool for researchers to focus future topics of investigation.

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Introduction

The collecting, preserving, analysing, updating, and use of soil information is a subject of profound scientific research — soil survey, analysis, diagnostics, classification, mapping, and so on. These activities have practical application in agriculture, urbanization, road construction, etc. In different countries of the world, depending on scientific potential, social relationships and financial possibilities, the approaches to problems involving pedology have specific characteristics and are developed to different extents.

The aim of this study is to show the methodology and practical application of data capture, updating and evaluation for the main Bulgarian soil units.

Collecting, updating and storing soil data

The great soil scientist N. Poushkarov started the organised systematic study of Bulgarian soils in 1911. In 1931, a soil map of Bulgaria at a scale of 1:500,000 was created to show the geographic distribution of the main soil units. The 1956 soil map of Bulgaria, published at a scale of 1:200,000, showed a significantly larger number of soil units, compared to the 1931 map.

The monograph “Soils of Bulgaria” was published in 1960. This book collected together all morphological, physical, chemical and physico-chemical characteristics of the main soil units.

A new soil map of Bulgaria at 1:400,000 scale was published in 1968. The information on this map was based on the soil survey of over 65% of the country at a scale of 1:25,000. On this map 67 soil units were defined at the levels of group and subgroup, particle size distribution classes and erosion degree. In the same year, after generalization of the 1:400,000 scale map, a soil map at a scale of 1:1,000,000, which included 45 soil units, was created and published.

Current status of soil information

The whole territory has now been mapped at a scale of 1:25,000, and 87% of the territory at 1:10,000.

According to the extended systematic list of the soils, 200 soil units have been defined, each of them carrying coded information about the profile depth, the degree of erosion, particle size classes, stoniness classes, parent materials, slope and land evaluation. The defined soil units have been characterized with profile descriptions, texture, total amount of carbon, pH, carbonate content, total nitrogen, and total phosphorus on the bases of 50,000 main soil profile data. In addition to this, information for more than 250 profiles, representing the main soil varieties of the different regions, have been completed by analytical data that include: humus content, water properties, chemical composition, Fe and Al status, CEC, base saturation and so on.

From basic documents such as soil survey journals, remote control information, laboratory data forms, climatic parameters and so on, administratively-maintained archives have been created. This information is kept in special Soil Survey Books in the forms of manuscripts, tables and maps.

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Sample of information in the Soil Survey Books

- Settlements included: Kuklen, Brestnik, Krumovo, Ruen, Belastitza, Branipole.
- Soil map scale: S 1:10,000.
- Agricultural territory: 7,473 ha.
- Number of soil units: 25.
- Number of soil profiles: 254.
- Number of sampled soil profiles for laboratory investigations: 49.

- **Geology, Geomorphology and Hydrology:** Soils around the studied settlements are developed on Quaternary materials, represented by alluvial deposits of the rivers Maritza and Chaia, alluvial and diluvial fan-like soil covers. A very small part of the soil cover is formed on pre cambic crystalline schists, and the layered structure of alluvial deposits is also manifested to a different extent. From the geomorphologic point of view, the studied territory is positioned on part of the river terraces, on adjoining north slopes of valleys and on small plains. The rivers Maritza and Chaia are associated with shallow ground water levels of between 1 and 5 m in northern parts, but are deeper (from 5 to 10 m) in the remaining part.

- **Vegetation:** On the southern side of the district studied, part of the forest is still preserved. In the remaining part the natural vegetation is willow and poplar trees around the rivers, and in the places with higher levels of ground water, it is represented by grass-boggy and boggy vegetation. Cultivation in the district is mainly grains, vegetables and perennial plants.

- **Climate:** The district is in the Thrace climatic region. The climate is temperate with a weakly pronounced Mediterranean influence. In Table 1 the average monthly and annual air temperatures and precipitation are presented for the Plovdiv station for the period 1916-1980. Plovdiv’s elevation is 160 m, longitude 24° 45’, and north latitude 42° 9’. It has to be admitted that the average sum of the precipitation, 515 l/m², is 135 l/m² lower than the average for the country.

During the last 5-6 years the existing soil information was adapted for machine processing, computerized and added to the topographic base at the scale of 1:10,000. Information about the anthropogenically influenced land pollution (heavy metals and toxic substances) is now being updated. All these data form the digital soil archives of Bulgaria. In Figure 1 an example of the Bulgarian digital archive is shown.

Table 1. Mean monthly and annual temperature of the air and precipitation amount for the period 1916-1980, station Plovdiv

<table>
<thead>
<tr>
<th>Months</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>t°C</td>
<td>0.2</td>
<td>2.0</td>
<td>6.4</td>
<td>12.4</td>
<td>17.2</td>
<td>21.1</td>
<td>23.6</td>
<td>22.8</td>
<td>18.8</td>
<td>12.9</td>
<td>7.2</td>
<td>2.2</td>
<td>12.2</td>
</tr>
<tr>
<td>Precipitation l/m²</td>
<td>39</td>
<td>32</td>
<td>36</td>
<td>42</td>
<td>54</td>
<td>62</td>
<td>47</td>
<td>35</td>
<td>36</td>
<td>40</td>
<td>48</td>
<td>44</td>
<td>515</td>
</tr>
</tbody>
</table>

Description of the soil unit N° 8 - Calcaric Fluvisol (FAO):

Soil code 10.1.16.3.0.1. (only for Soil Survey Book according to Bulgarian agricultural soil grouping), where:

10. - code of soil group; 1. - code of soil sub-group; 16. - soil unit code;
3. - particle size classes code; 0. - code of stoniness degree; 1. - code of parent materials.

The soil unit described occupies river terraces. Its total area is 403 ha or 5.40% of the studied territory.
Description of Profile 200:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth (cm)</th>
<th>Color</th>
<th>Texture</th>
<th>Structure</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0 - 30</td>
<td>Grey-brown (10 YR-5/2)</td>
<td>Dry, dense, sandy loam</td>
<td>Granular structure, roots, slightly calcareous, clear smooth boundary.</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>30 - 55</td>
<td>Grey-brown (10 YR-5/2)</td>
<td>Fresh, slightly dense</td>
<td>Sandy loam, subangular blocky structure, calcareous, gradual boundary.</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>55 - 80</td>
<td>Grey-brown (10 YR-5/2)</td>
<td>Fresh, dense, loam</td>
<td>Subangular blocky structure, calcareous, gradual boundary.</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>80 - 110</td>
<td>Dark brown (10 YR-3/3)</td>
<td>Fresh, dense, clay loam</td>
<td>Subangular blocky structure, calcareous, gradual boundary.</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>110 - 132</td>
<td>Dark brown (10 YR-3/3)</td>
<td>Fresh, dense, loam</td>
<td>Subangular blocky structure, calcareous.</td>
<td></td>
</tr>
</tbody>
</table>

Analytical data for Profile 200 are shown in Tables 2 and 3.

Figure 1 represents only one part of the soil map for Bresnik. The original map is at a scale of 1:10,000, but for the purposes of this study it is reduced to a scale of 1:25,000. The example from the archive, description of profile 200, concerns an Alluvial meadow soil (Calcaric Fluvisol), that is located in the south-east part of the map, very near to a heavy metals production plant.

The soil-unit map number 8 is expressed with the formula:

\[
\text{AAAD}^{301}_{42}
\]  \hspace{1cm} (2)

where, above the line:

- \( \text{AA} \) soil name code;
- \( D \) thickness of profile code;

and below the line:

- \( 3 \) particle size (\( \Sigma < 0.01 \) mm) classes code;
- \( 0 \) stoniness code (no stones or very few stones cover < 0.01% of the area);
- \( 1 \) parent material code (alluvial deposition);

multiplier:

- \( 42 \) land categories code (according to the Bulgarian land evaluation system);

Recently a new, improved formula for soil coding in Bulgaria was introduced:

\[
\begin{align*}
\text{N}^a & \text{L}_{1,2,3,\ldots}^{1,2,3,\ldots} \text{N}^b \\
N^a & \text{ land category (according the Bulgarian land evaluation system)}; \\
L_{1,2,3,\ldots} & \text{ codes for soil description; } \\
N^b & \text{ field index (according the Bulgarian land evaluation system); } \\
N_{1,2,3,\ldots} & \text{ codes for particle size classes, stoniness, parent materials etc. }
\end{align*}
\]  \hspace{1cm} (3)

All “N’s” are numbers, and all “L’s” are letters.

As can be seen in Figure 1, there is an industrial plant-pollutant in the studied region. Analytical data, concerning heavy metal pollution of soils located a few kilometres eastward from the discussed example, are presented in Table 4.
Table 2. Profile 200. Calcaric Fluvisol (FAO). Particle size distribution data, as a percent of air-dry soil

<table>
<thead>
<tr>
<th>Horizon (layer) depth in cm</th>
<th>Loss with HCl (%)</th>
<th>Particle size classes (mm)</th>
<th></th>
<th>0.25 - 0.05</th>
<th>0.05 - 0.01</th>
<th>0.01 - 0.005</th>
<th>0.005 - 0.001</th>
<th>Σ &lt; 0.001</th>
<th>Σ &lt; 0.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 0 - 30</td>
<td>2.2</td>
<td>21.1</td>
<td>30.5</td>
<td>16.8</td>
<td>4.6</td>
<td>5.0</td>
<td>12.2</td>
<td>21.8</td>
<td></td>
</tr>
<tr>
<td>II 30 - 55</td>
<td>0.0</td>
<td>14.6</td>
<td>33.5</td>
<td>21.5</td>
<td>4.5</td>
<td>5.0</td>
<td>11.9</td>
<td>21.4</td>
<td></td>
</tr>
<tr>
<td>III 55 - 80</td>
<td>6.0</td>
<td>20.7</td>
<td>31.2</td>
<td>16.5</td>
<td>5.2</td>
<td>3.6</td>
<td>12.0</td>
<td>20.8</td>
<td></td>
</tr>
<tr>
<td>IV 80 - 110</td>
<td>0.0</td>
<td>15.3</td>
<td>28.7</td>
<td>18.5</td>
<td>6.4</td>
<td>5.9</td>
<td>17.0</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>V 110 - 132</td>
<td>1.2</td>
<td>17.0</td>
<td>35.2</td>
<td>23.9</td>
<td>3.1</td>
<td>3.9</td>
<td>9.6</td>
<td>16.6</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Profile 200. Calcaric Fluvisol (FAO). Some physical and chemical properties

<table>
<thead>
<tr>
<th>Horizon (layer) depth in cm</th>
<th>Hygroscope moisture (%)</th>
<th>Humus (%)</th>
<th>pH in KCl</th>
<th>Carbonates (%)</th>
<th>Total N (%)</th>
<th>Total P (%)</th>
<th>pH in H₂O</th>
<th>Electroconductivity mmhos/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 0 - 30</td>
<td>2.76</td>
<td>1.07</td>
<td>7.50</td>
<td>5.95</td>
<td>0.051</td>
<td>0.139</td>
<td>7.85</td>
<td>0.26</td>
</tr>
<tr>
<td>II 30 - 55</td>
<td>2.88</td>
<td>0.80</td>
<td>7.50</td>
<td>7.16</td>
<td>0.047</td>
<td>0.110</td>
<td>7.90</td>
<td>0.20</td>
</tr>
<tr>
<td>III 55 - 80</td>
<td>2.87</td>
<td>0.55</td>
<td>7.40</td>
<td>2.87</td>
<td>n. d.</td>
<td>n. d.</td>
<td>7.90</td>
<td>0.20</td>
</tr>
<tr>
<td>IV 80 - 110</td>
<td>4.26</td>
<td>0.58</td>
<td>7.30</td>
<td>5.75</td>
<td>n. d.</td>
<td>n. d.</td>
<td>7.90</td>
<td>0.21</td>
</tr>
<tr>
<td>V 110 - 132</td>
<td>3.36</td>
<td>0.43</td>
<td>7.30</td>
<td>4.22</td>
<td>n. d.</td>
<td>n. d.</td>
<td>7.90</td>
<td>0.18</td>
</tr>
</tbody>
</table>

104
Table 4. Calcaric Fluvisol (FAO). Some soil data and concentrations of Zn, Pb, Cd and Cu in the soil (map number 12 near to the factory)

<table>
<thead>
<tr>
<th>Horizon (layer)</th>
<th>Depth cm</th>
<th>Humus %</th>
<th>pH in H₂O</th>
<th>CaCO₃ %</th>
<th>Zn mg/kg</th>
<th>Pb mg/kg</th>
<th>Cd mg/kg</th>
<th>Cu mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A¹</td>
<td>0-25</td>
<td>1.3</td>
<td>7.7</td>
<td>12</td>
<td>400.0</td>
<td>225.0</td>
<td>3.32</td>
<td>122.0</td>
</tr>
<tr>
<td>II</td>
<td>25-45</td>
<td>0.9</td>
<td>7.7</td>
<td>12</td>
<td>300.0</td>
<td>101.0</td>
<td>1.50</td>
<td>91.0</td>
</tr>
<tr>
<td>III</td>
<td>45-60</td>
<td>0.8</td>
<td>7.8</td>
<td>13</td>
<td>94.0</td>
<td>45.0</td>
<td>0.10</td>
<td>42.0</td>
</tr>
<tr>
<td>IV</td>
<td>60-80</td>
<td>0.5</td>
<td>7.7</td>
<td>7</td>
<td>89.0</td>
<td>33.0</td>
<td>0.12</td>
<td>34.0</td>
</tr>
<tr>
<td>V</td>
<td>80-100</td>
<td>0.5</td>
<td>7.7</td>
<td>12</td>
<td>84.0</td>
<td>30.0</td>
<td>0.10</td>
<td>38.0</td>
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<tr>
<td>VI</td>
<td>100-135</td>
<td>0.4</td>
<td>7.7</td>
<td>12</td>
<td>73.0</td>
<td>29.0</td>
<td>0.12</td>
<td>35.0</td>
</tr>
<tr>
<td>VII</td>
<td>135-150</td>
<td>0.4</td>
<td>7.7</td>
<td>12</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
<td>n. d.</td>
</tr>
</tbody>
</table>

Table 5. Final scale of Bulgarian classification – land suitability for agricultural use

<table>
<thead>
<tr>
<th>Groups</th>
<th>Categories</th>
<th>Land index values</th>
</tr>
</thead>
<tbody>
<tr>
<td>I very good lands</td>
<td>1</td>
<td>&gt; 90</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>80 to 90</td>
</tr>
<tr>
<td>II good lands</td>
<td>3</td>
<td>70 to 80</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>60 to 70</td>
</tr>
<tr>
<td>III moderately good lands</td>
<td>5</td>
<td>50 to 60</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>40 to 50</td>
</tr>
<tr>
<td>IV bad lands</td>
<td>7</td>
<td>30 to 40</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>20 to 30</td>
</tr>
<tr>
<td>V unsuitable lands</td>
<td>9</td>
<td>10 to 20</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0 to 10</td>
</tr>
</tbody>
</table>

The manuscripts, tables, map archives and digital archives are at the disposition of the N. Poushkarov Institute, Agricultural Academy, Ministry of Agriculture and other Institutions. Currently this information is used to support the agricultural lands cadastre and agricultural reform currently in progress in Bulgaria, land evaluation, agricultural economic activities, road construction, urbanization activities, and so on. In the near future this information will serve the organization and regulation of the land market, as well as the forthcoming regrouping of land in Bulgaria.

The collected and updated soil information enables an estimation of the agricultural lands on the basis of the actual and the potential suitability of the different land use types to be made. In our country this approach is parametric and it is in very close agreement and compatible with the main principles of FAO. A final classification scheme (Petrov et al, 1988) is shown in Table 5.

Conclusion

A short review of the scientific ideas and the practical application, concerning the capture, preserving, updating and estimating of the field and analytical soil data in Bulgaria was carried out. Historical and contemporary aspects were briefly elaborated.

The soil science archives in Bulgaria and the updated investigations will enable a successful joint international project, concerning soil diagnosis, classification, mapping and land evaluation, to be implemented.
References

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TANOV E. and KOINO, V. (1956): Soil map of Bulgaria S 1:1,000,000. Sofia.
Development of the Soil Information System for the Czech Republic

Introduction

The recent decline in systematic soil surveys, often solely of agricultural land, is the result of cuts in the funding of agricultural research and of reduced soil investigations aimed at the soil productivity. The cuts in funding have stemmed directly from the existence of surpluses of agricultural products in developed countries creating a perception that soil productivity is no longer a problem in Europe and North America. There has been a simultaneous shift of soil information needs from the collection of data for recognising soil units to the quantification of soil properties that affect the ecologically relevant soil functions.

Thus today, soil information is increasingly being used for the protection of soils against degradation and pollution.

Soil information systems have developed quickly over the last 30 years. Developments in the Czech Republic, until the end of the 1980s, are described by Nimeèek (1981). Planning the sustainable use of land resources from our point of view should be based on rationally designed categorisation of soil cover. All of the suggested categories should reflect the differences in preferred ecological and non-ecological functions of the soil. This fact highlights the need to determine the limits for soil management, and to implement the necessary legislative, economic and administrative measures.

The following categories of soil conservation have been suggested for the Czech Republic:

- soils of the large-scale and small-scale protected areas
- soils of zones of hydrosphere protection, exploited in a forest way
- soil of zones of hydrosphere protection, exploited in an agricultural way
- soil of forests with protective function
- agriculturally high productive soils
- soils of intensively exploited forests
- soils endangered by water erosion
- low productive agricultural soils
- soils contaminated by persistent contaminants
- forest soils strongly affected by acid emissions
- urban soils in industrial areas and soils likely to be further affected by industrial use
- new formed anthropogenic soils of mining areas

Such a categorisation could be hardly succeed without a well functioning of soil GIS. PUGIS, the soil information system designed by our Department, includes the areal and pedon components linked to soil quality and behavioural interpretations for soil degradation, pollution and productivity estimation and modelling. In general, a complete soil GIS should include:

- digitised information from soil and environmental maps (reference based), especially geomorphology and slopes
- soil characteristics (profile data, data from inventorying research)
- extrinsic environmental characteristics
- data from monitoring of research fields
- soil exploitation, production, degradation, contamination etc.
- attributes of heterogeneity of the soil cover
- criteria of data evaluation
- pedotransfer functions
- models of transformation and transport, and pollutant transfer processes, between the soil and hydrosphere, the biosphere, the atmosphere and the food chain
- information about natural and anthropogenic factors, environmental loads

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For the establishment of our own Czech pedon database we used the procedure described in the contribution.

The design of PUGIS

The project of data acquisition and its organisation was based on the assumption the data collected will be both historical and recent (actual), their structure will be very heterogeneous, some will be in a time-sequence of data is expected and there will be hundreds thousand of individual soil parameter values.

Commercially available databases could not be used for developing PUGIS. The special software for capturing digital data was developed, based on user-defined hypertext, and this makes it possible for the user to have a dynamic and flexible access to the digital data. The operator can thus dynamically display on the screen only the data in which he/she is interested. The data are introduced into the system by a combination of different methods.

For the input of actual data the Transform and Form software modules are used. They are suitable for the repeated input of data measured on a geographical grid. Both the analytical and topological data are imported into the GIS system (ARCINFO) by means of specially developed software. The software associated with PUGIS is show in the Figure 1.

The core of PUGIS is represented by the pedon database. The structure of this database is given in Figure 2.

Figure 1: The scheme of software supporting PUGIS

Figure 2: Scheme of PUGIS database structure
The complete structure of the database of PUGIS is described below. W stands for text (words), C for alphabetic codes and N for numeric values. The size of data sets, available in Czech Republic are also given.

**Classification - location - extrinsic factors**

**Soil classification**

- standardised CR great soil group (= genetic soil type) : W
- subgroup(= genetic subtype) : W
- variety : W
- parent material : W
- particle size class (profile) : W
- substratum stratification : W
- depth (to bedrock or stony layer) : C
- degree of erosion, accumulation : W

- horizon sequence : C
- agricultural production type : C
- soil -ecological unit (for soil rating) : C
  - productivity rating : C
  - principal limiting factors : C
- genetic soil unit (systematic soil survey 1967) : W
- dominant of map unit (soil map 1: 200,000) : C
- reference classification FAO : W
  - Soil Taxonomy (subgroup) : W
  - (family) : W
  - Référentiel pédologique : W

**Soil profile designation**

Location, Climate, Landscape surface, Parent material (substratum), Hydromorphy

Land use, vegetation

**Morphological features in soil horizons**
in 4 - 5 master horizons, standardised for each great soil group (+ horizon O in forest soils)

Principal identification data for soil horizons
Morphological features
Color (moist)
Structure (pedality)
Texture
Consistence
Neoformations

Analytical data for soil horizons

In 4 - 5 horizons, standardised for each great soil group (+ Oh + Of in forest soils)

a) soil profiles with elementary standardised analyses
c. 30,000 soil profiles (135,000 samples) in the ER,
selected profiles in district reports: 2,500 (12,000 samples)

b) soil profiles with complementary characteristics for basic soil diagnostics
c. 250 soil profiles (1,500 samples)
    Chemical, physico-chemical analyses
    - Mineralogical properties
    - Micromorphology
    - Biological characteristics

The data stored in HYPERTEXT can be exploited by transformation into formats compatible with those of commercially available database and statistical software packages.

The software was tested by digitising a large set of data collected from special soil pits, excavated during the systematic soil survey of the Czech Republic - historical data, and on data collected from selected recently excavated soil pits - actual data.

The system proved to be fully suitable for the capture of such data and for their importation into a GIS (ARC/INFO).

Application of PUGIS

The practical use of PUGIS can be demonstrated by using the BPS model - Behaviour of Pesticides in Soils. This model consists of three databases and four computational software modules. The three databases contain data necessary for the model, i.e. pesticide characteristics, soil type characteristics and climate data. The computational modules are for estimating input data (based on information available in databases), correcting input data, processing of data and producing geographical and numerical output, and amalgamating the data centrally. The central computing module (BPS) is based on the mathematical model CALF (CALculates Flow), described by Nicholls et al. (1982). It is very flexible and, as a central computing module, can be used in conjunction with other mathematical models available to the user. The structure of the BPS model is schematically shown in the Figure 3.
The database of soil characteristics includes data on 70 soil types and subtypes and soil families (parent materials) most common for the soil cover of the Czech Republic. The data in the database are of two types: the data for input to the BPS model and the data for identifying the soil classification unit under study. The data necessary to run the prediction model are: soil texture, list of diagnostic horizons and their thickness (cm), content of clay particles < 1µm, content of particles 1-10 µm, humus content, pH(KCl) and CEC. The soil characterisation data include information on parent material, number of analysed soil profiles (used for calculation of mean values), coefficient of variation for each data set, and the value of relative base saturation of soil sorption complex. Characterisation of the soils is based on the Morphogenetic classification system (Czech version) or the FAO soil classification system (English version), respectively. Data for an orthic Luvisol, used in this study, are shown as a ‘window’ (Figure 4) produced by the PUGIS software described above.

Figure 4: The data for an orthic Luvisol produced by the system
The module for estimation of input data exploits both the soil and pesticide characteristics databases for estimation of Kf value (adsorption coefficient of Freundlich adsorption isotherm). The estimation is based on the multidimensional linear regression and correlation analysis.

The following equation was used:

\[ K_f^{\text{estim.}} = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \]

where:
- \( B_0 \) = absolute member,
- \( B_1 \) = regression coefficient for clay particles (<0.002 µm),
- \( B_2 \) = regression coefficient for CEC (cation exchange capacity, mmol. 100g\(^{-1}\)),
- \( B_3 \) = regression coefficient for pH(KCl),
- \( B_4 \) = regression coefficient for Cox (organic carbon).

The coefficients \( X_1, X_2, X_3, X_4 \) represent values of the above mentioned data, extracted from the soil characteristics databases. Details of the estimation procedure are given in Kozák et al. (1992), Kozak and Vacek (1996).

The problems to be solved

The up-to-date soil surveys and information needs involve the following steps:

1. The mapping of soil cover patterns at large scale 1:10,000 - 25,000 should include the total biologically used territory (croplands, grasslands, woodlands), and the urban and other anthropogenic areas. The soil surveys should make use of modern techniques and concepts of soil heterogeneity, a unified classification and nomenclature, which should be correlated with international systems (FAO 1990, FAO/ISSS 1994, Soil Taxonomy 1990, Référentiel 1995). In the Czech Republic, attention should be paid to the compilation of comprehensive soil maps at a scale of 1:25,000. Such a programme will include...
the synthesis of the maps of systematic soil survey and ecopedologic surveys of agriculturally used soils and also the soil cover content of the forest-typological maps, completed by soil surveys of urban and other anthropogenic soils. United classification and nomenclature will be used. It will be based on the unification of the morphogenetic classification of soils of the former Czechoslovakia (1987, 1991), the new system for forest soils (1993) and the legend of the soil map of the Czech Republic at scale 1:200,000, correlated with the above mentioned international reference systems at the lowest taxonomic levels (3rd level in FAO/ISSS system).

2. The principal problem of the contemporary pedological activities concerns the completing of soil characteristics, soil characteristics, soil qualities and soil regimes parameters from the point of view of the evaluation of soil functions, soil degradation and soil contamination assessment.

3. The monitoring of temporal changes in soils should be subdivided into obligatory monitoring of severely endangered or restored soils; systematic monitoring of seasonally dynamics characteristics, important for modelling of processes (water, temperature, N, biota); and of properties with medium-term dynamics. Long-term dynamics should be studied by means of retrospective monitoring when the archived samples are available. The results concerning the dehumification and pollution processes in Czech soils have been published (Niméeek, Podlešáková 1992), the repeating of inventories on fixed sampling sites (for properties non analysed when the samples were archive = retrospective monitoring).

4. The up-to-date soil survey interpretation systems involve the assessments of soil limitations, suitability and potential for different kinds of soil uses and managements.

5. The main goal of the Soil Geographic Information System (Soil GIS), from the standpoint of the future evaluation of the soil data, is the optimum possible interconnection of areal and point information, concerning soils, their use, management and protection. The GIS will have strata of areal information about all other site factors, including the anthropogenic inputs. One of the most important files will be a sophisticated geomorphological stratum, making possible the modelling of land surface transport processes. The semantic database will consist of soil profiles data and topsoil characteristics. It will comprise also critical limits of soils and soil-plant and soil-landscape transfer and transport models.

6. The international co-operation is now focused on the compilation of soil maps at small scales (1:1,000,000, 1: 500,000) concerning the European Soil Map and the SOTER projects, interconnected with soil mapping units attributes and soil profile database. Future programmes are aimed at comparative soil productivity assessments of European soils, soil degradation evaluations, soil vulnerability assessments and soil contamination and pollution criteria.

Acknowledgement

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References


Second-generation soil maps of Denmark – a case study from Western Zealand

Summary
Since the end of the Second World War, the expansion of urban settlements, road construction and the demand for recreation areas in Denmark has made it necessary to protect the most valuable farmland from further loss. For this purpose, a nation-wide soil survey was carried out between 1975-80. This was the start of the compilation of a nation-wide soil and land database. During the last decade, the need for soil maps for environmental protection has increased and demand for more detailed soil maps has been obvious. Thus for the county of Western Zealand new soil maps, with more detailed information, have been produced, based on the principles of the Danish Soil Classification.

Introduction
At the beginning of the 1990s, the county of Western Zealand (Figure1) made a new plan for agriculture in the region. This highlighted the need for more detailed soil information than that already provided by the Danish Soil Classification, e.g. for calculation of the demand for water for irrigation and for delineation of sensitive areas according to drinking water quality (ground water protection). Thus a project was initiated to develop the existing soil maps to give more detailed information on texture (Frandsen 1991). This paper describes the methodology used for the construction of these second-generation soil maps and how they have been implemented in the water and irrigation planning of the county.

The Danish soil classification
In 1975, the Ministry of Agriculture initiated a nation-wide soil classification based mainly on soil texture in the plough layer (Mathiessen and Nørn, 1976, Madsen et al., 1992). By 1980, approximately 400 soil maps (at 1:50,000 scale) were available, covering almost the whole country. The soil maps are based on texture analyses of soil samples from approximately 35,000 sites, slope classes from topographic maps, and the geological origin of the soil at 1m depth. The geological information is available for about 75% of the country.

Samples for texture analyses were taken at all sites from a depth of 0-20cm and at selected sites from a depth of 35-55cm. The samples were taken by local agronomists to take advantage of local knowledge. In the laboratory, texture, organic matter and calcium carbonate were determined in all samples, and the results stored in a computer system (Mathiessen, 1980).

Based on texture, the soils were classified into 12 soil classes, JB 1-12, and merged into 8 map colour codes, MCC 1-8 (Table 1). The agricultural land was classified into these 8 MCCs according to the texture at 0-20cm depth. The remaining areas were divided into urban areas and forest areas. The 8 MCCs were delineated by the local agronomists in co-operation with the soil surveying staff.

The agricultural land was also divided into three slope classes 0-6°, 6-12° and >12°. Experimental data show that in the first class mechanized tillage is carried out without any problems, in class two minor difficulties may arise, whereas in class 3 mechanized tillage is almost impossible.

The maps have been published in colour with the MCC in brown or yellow colours, the forests in green and the urban areas in white. The slope classes are indicated by hatching. The dominant geology is given for every 25 ha as a notation in the upper right corner in a grid.
The construction of the new soil map

The principle for the construction of the second-generation soil maps at 1:50,000 scale was to combine already existing topographical, geological and landscape maps to delineate specific geographical units having the same soil type. Based on analytical data from different sites within the county, the map units are given a soil texture in three depths according to the JB-system shown in Table 1. The three depths are 0-30cm, 30-60cm and 60-120cm.

Data

The data used can be divided into two types; area data and point data.

Area data

The primary area data are the MCCs on the soil maps from the Danish soil classification described previously in this paper. Western Zealand is covered by 33 maps sheets.

The Danish Geological Survey has elaborated geological maps at 1:50,000 scale covering the entire county (DGU 1978). These maps show the geological origin of the sediment at the depth of about 1m with the texture in the following classes: gravel, clay, silt, sand, peat. For example, units oth these maps are described as clayey till, silty ice lake deposits, sandy Aeolian deposits or gravelly meltwater deposits.

The wetlands were outlined from old topographic maps (1:20,000 scale) showing the extent of wetlands 60-80 years ago. The old topographic maps were preferred to later ones because of the recent decrease in wetlands due to drainage. The wetlands in the county consist of bogs, river valleys and marine forelands. Geomorphological maps at 1:100,000 scale divide the county into different landforms such as Weichsel moraine, outwash plains, marine forelands and dunes (Humlum 1983).

Point data

In Western Zealand, the Danish Soil Classification has collected 2720 samples from the plough layer and 402 samples at a depth of 35-55 cm. These samples have been analyzed for clay (<2µm), fine silt (2-20µm), coarse silt (20-63µm), fine sand (63-200µm) and (200-2000µm), organic carbon and calcium carbonate.

Several soil profile investigations have been carried out during the last decade. Among these, two large investigations will be described briefly.

In relation to the establishment of the main gas pipeline system from the North Sea gasfield across Denmark in 1981-84, pedological investigations along the lines were carried out (Madsen and Jensen, 1985). About 800 detailed profile descriptions and about 8000 soil profile classifications were made. In Western Zealand data from 65 soil profiles exist (Figure 2).

In order to improve the use of nitrogen fertilizers in Danish farming, the Danish Agricultural Advisory Centre established in 1986 a nation-wide 7 km grid, in which the inorganic nitrogen content should be determined periodically (Østergård and Namsen, 1990). The grid contains approximately 850 intersections, and at these, 50m x 50m test plots were established, in which pedological soil profile investigations have been carried out. In Western Zealand, data from 49 soil profiles exist (Figure 2).

All the profiles were described in detail according to a system very similar to FAO Guidelines for Soil Profile Description. From each profile, samples were taken according to the horizon sequence and texture, organic matter, pH and calcium carbonate were determined. From selected profiles, dithionite-citrate and pyrophosphate soluble iron and aluminium, CEC, exchangeable bases, total N and P, clay mineralogy, soil water retention and root densities were also measured.

Construction of texture in three depths

The new soil map consists of texture in three sections: I: 0-30cm, II: 30-60cm and III: 60-120cm. The texture classification system used is the JB-system given in Table 1. In none of the three sections has the JB system been used for delineation of map units. This means that for each section a JB map has to be constructed. The data available for this construction is not identical for the three sections which explains why different methodologies have to be used. Figure 3 is a flow diagram showing the methodology used for the elaboration of the JB soil map in the three sections, and the final construction of the second-generation soil map. Table 2 shows the number of texture analyses available in the three sections, the source and the density.

In Section I, 2834 texture analyses (96% from the Danish Soil Classification) are available. These are used in combination with the location of the MCCs from the Danish Soil Classification, the geomorphological map and the wetland map to delineate the JB-
soil types on agriculture land. Forest, urban zones and lakes are taken from the Danish Soil Classification.

In Section II, 516 texture analyses are available; of these, 80% are from the Danish Soil Classification. They are used in combination with the Danish Geological Survey maps, the Danish Soil Classification maps, and the wetland map to construct the JB-soil type for this depth.

In section III, 114 texture analyses are available, all from the soil profile investigations. These are used only in combination with the Danish Geological Survey maps for delineation of the JB-soil types.

The reliability of the various sections from the map differs because of the different data input. Section I is mainly based on the Danish Soil Classification Map which has been subdivided according to the texture analyses. Section III is in one way more precise than Section I, as the geological survey is based on an augering for every 200 metres. Therefore, the observation density is much higher than that of the Danish Soil Classification. On the other hand, the conversion of the geological classification system to the JB system is not straightforward. This is due to the fact that some geological types like clayey till or diluvial sand might cover two or more JB-soil types. Section II is not as reliable as sections I and III because no previous investigation has made a specific delineation at that depth and the number of texture analyses is limited. Therefore it was necessary to transfer the delineation of soil types at the depth of 0-30 cm to section II, and also to take the geological map from the depth of 1 m into account.

Results

The JB-soil layer from the three sections is combined into one soil map, the second generation soil map (Figure 4). Each map unit is identified by three figures, e.g. 4,6,7. The figures indicate the JB-soil type in the three sections; in this case the plough layer is fine clayey sand (4), section II is fine sandy clay (6) and the subsoil is clay (7).

Figure 4 shows the island of Omø located in the southern part of the Great Belt of Denmark. Geomorphologically the island consists of two moraine hills divided by a former narrow sound, which has turned into a sandy marine foreland with peat cover, due to isostatic uplift of the landscape. The second-generation soil map reflects this: the two moraine hills are dominated by fine clayey sand (4) to clay (7), while the marine foreland is dominated by soil types like coarse sand (1) to fine sand (2).

For the county of Western Zealand, an area of 3,000 km², 14 second-generation soil map sheets at 1:50,000 scale have been elaborated.

Uses

A major part of the county of Western Zealand is situated in the driest area of Denmark, where less than 350 mm of rain falls in the growing season (Madsen et al., 1992). Therefore, groundwater is a limited resource. Households, industry and agriculture have a need for continuous water supplies, which are almost exclusively taken from the ground, and careful planning is needed. The second-generation soil map makes it possible to calculate the maximum amount of water needed for irrigation of farmland more precisely than the first-generation soil map.

The water needed for farmland irrigation strongly depends on several parameters such as soil type, crop, precipitation, evapotranspiration, etc. The second-generation soil map shows the map units in three figures. It allows the root zone capacity, classically defined as the difference between the quantity of water in the soil at field capacity and the quantity of water unavailable to plants (at wilting point) multiplied by the effective root depth, to be precisely calculated (Madsen et al., 1992).

Figure 5 shows the calculation of the maximum amount of water needed for farmland irrigation of 100,000 m² (10 ha) fields with grass and a map unit of 1.1.4. in the area of Tystofte in Western Zealand.

Western Zealand still has enough drinking water of good quality for the majority of users, but one of the major problems in the future will be to avoid pollution of the groundwater with nitrate and pesticides from farmland, or to avoid intrusion of sodium chloride into the wells near the coast by the lowering of the groundwater table. In the future, we must expect that a large number of wells near the sea will need to be closed because of pollution. Therefore the county has started to elaborate a water plan for the next 25 years (1996-2020) to secure the water supply for households, industry and agriculture. The basic idea is to keep areas free of activities which threaten to pollute the ground water. To locate areas where groundwater needs to be protected and to identify new groundwater resources, the county administration is using second-generation soil maps in combination with the Geological Basisdata Map.
References


Figure 1: Denmark – location of Western Zealand and the island of Omø

Table 1: Definition of soil types for soil mapping in Denmark

<table>
<thead>
<tr>
<th>Map Colour Code</th>
<th>SOIL TYPE</th>
<th>JB nr.</th>
<th>Clay &lt; 2 µm</th>
<th>Silt 2-20 µm</th>
<th>Fine Sand 20-200 µm</th>
<th>Total Sand 20-2000 µm</th>
<th>Humus 58.7 % C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coarse Sand</td>
<td>1</td>
<td>0-5</td>
<td>0-20</td>
<td>0-50</td>
<td>50-100</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Fine Sand</td>
<td>2</td>
<td>5-10</td>
<td>0-25</td>
<td>0-40</td>
<td>40-95</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Clayey Sand</td>
<td>3, 4</td>
<td>5-10</td>
<td>0-25</td>
<td>0-40</td>
<td>40-95</td>
<td>65-95</td>
</tr>
<tr>
<td>4</td>
<td>Sandy Clay</td>
<td>5, 6</td>
<td>10-15</td>
<td>0-30</td>
<td>0-40</td>
<td>40-90</td>
<td>55-90</td>
</tr>
<tr>
<td>5</td>
<td>Clay</td>
<td>7</td>
<td>15-25</td>
<td>0-35</td>
<td>0-40</td>
<td>40-90</td>
<td>55-90</td>
</tr>
<tr>
<td>6</td>
<td>Heavy Clay or Silt</td>
<td>8, 9, 10</td>
<td>25-45</td>
<td>0-45</td>
<td>0-50</td>
<td>20-100</td>
<td>10-75</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Organic Soils</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Atypical Soils</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2: Western Zealand – location of soil profile from the main gas pipeline (\(\ell\)) and from the 7 km grid (+)
Figure 3: Western Zealand: Flow diagram showing the methodology used in construction of the second-generation soil map.
Figure 4: Showing the combination of the JB-soil layer from the three sections to form the second-generation soil map for the island of Omø
Table 2: Western Zealand: Number of texture analyses, sources and sample density in the three sections

<table>
<thead>
<tr>
<th></th>
<th>Danish Soil Classification</th>
<th>Main pipeline</th>
<th>7 - km grid</th>
<th>Total</th>
<th>Sample Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section I</td>
<td>2720</td>
<td>65</td>
<td>49</td>
<td>2834</td>
<td>85 ha</td>
</tr>
<tr>
<td>Section II</td>
<td>402</td>
<td>65</td>
<td>49</td>
<td>516</td>
<td>467 ha</td>
</tr>
<tr>
<td>Section III</td>
<td>0</td>
<td>65</td>
<td>49</td>
<td>114</td>
<td>2116 ha</td>
</tr>
</tbody>
</table>

Map unit: 1.1.4  
Crop: grass  
Effective root depth: 50 cm

Plant available water:

section I: 15.5 vol % water  
section II: 11.3 vol % water  
section III: 15.5 vol % water

RZC: 69 mm  
Irrigation need: 170 mm

The irrigation need is high and for the 10 ha it gives a need of 17,000 m³ water per year.

Figure 5: Showing the calculation of irrigation need of grass in the growing season
Development of soil information systems in the Federal Republic of Germany – Status Report

Introduction

The systematic development of soil information systems in the Federal Republic of Germany began in 1979 with a joint project by the German Research Association (DFG) entitled “New Communication Paths in the Geosciences with the help of ADV”. The title demonstrates that the need had been recognised for a change in the way spatial data were processed. In addition to some state geological surveys, the project also involved several university departments representing a range of disciplines from geosciences, agriculture, forestry, landscape ecology, mathematics and informatics to geodetics/geodesy (Vinken, 1983, 1988, 1991).

This joint project generated a large amount of information and laid the foundation for the conception and development of geoinformation systems. The main results were:

• the integration of all relevant geoscientific specialisations;
• the use of standardised database management systems (DBMS);
• recognition of the need to set up method bases;
• further development of specific systems to acquire and evaluate all existing data at different spatial resolutions;
• an intensive discussion on the structure and content of geoscientific maps.

With respect to the definition of “geoinformation systems”, it showed that a very comprehensive approach was the most workable. In addition to the general treatment of data and their spatial analysis, this approach also encompasses system components which, with the help of additional (meta) information on data and evaluation methods, facilitate the answering of user queries by the generation of suitable technical methods (Bartsch and Stbresny, 1994).

Co-ordination between state geological surveys

These developments were accompanied by substantive work by political committees in 1985. The federal government promulgated its soil protection policy on 7 March 1985. The subsequent implementation of this policy has involved several working groups combining federal and state resources, in particular the Special Working Group on Soil Protection Information Bases.
(SAG) initiated by the Conference of Environment Ministers. One of the aspects on which this working group is engaged is the formulation of a concept agreed by the federal government and the states to develop and describe a suitable database specifically for soil protection. This assignment led to the SAG conceiving the idea of creating a soil information system (SAG 1987). Moreover, a “Soil Information Systems Sub Working Group (UAG BIS) was put into place to formulate a concrete proposal for the development, content and organisational integration of a soil information system based on existing guidelines. This led to the following outline:

- definition of the data, methods and model specifications,
- presentation of the research required and
- proposal of specific steps to be taken (Soil Information Systems Sub Working Group, 1989).

The 33rd Conference of Environment Ministers in 1989 recommended that states follow this outline in building up soil information systems.

An important point in the development of soil information systems in the Federal Republic of Germany is the definition of the term “soil” in connection with soil protection. In pedological terms, soil is generally defined as an intrinsic natural body whose creation involves rock, relief, climate, weathering, groundwater, flora, fauna, and mankind, and which reflects its own sphere — the pedosphere. According to this definition, the soil is a three dimensional part of the geosphere, generally extending down from the surface of the earth to the rootless or lifeless zone of unconsolidated or consolidated rock.

The definition of soil laid down by the Conference of Environment Ministers goes far beyond the pure pedological definition, encompassing all areas of the earth’s upper crust affected by man’s activities. A similar wide-ranging definition is proposed at a European level.

In order to make this definition workable, it was agreed to consider soil from three different viewpoints:

**Geoscientific principles**
- nature conservation
- landscape protection
- anthropogenic effects such as contamination, surface utilisation.

It was also recommended that the geoscientific section of this tripartite division be built up of technical information systems (TIS) dealing with the following classic fields:

- soil
- geology
- hydrogeology
- resources
- geochemistry, etc.

These technical information systems should then be amalgamated step by step to form a soil information system. This procedure was considered to be an adequate basis for efficiently and effectively carrying out the tasks involved in soil protection.

A classification of this type touches on many of the areas of responsibility of the geological surveys and institutes in the Federal Republic of Germany. In 1989, therefore, the Conference of the Directors of State Geological Surveys and the Federal Institute for Geosciences and Resources set up special working groups for the technical areas falling within their sphere of responsibility. The aim was to co-ordinate the setting up of each technical information system throughout the country to ensure system compatibility.

Specifically, the following technical information systems are to be set up the states and at a federal level:

- TIS soil;
- TIS geology;
- TIS resources;
- TIS hydrogeology;
- TIS geochemistry;
- TIS geophysics;
- TIS engineering geology.

The following aspects must be incorporated within all of the technical information systems:

- standardization of data nomenclature;
- recommendations for the formation of databases;
- standardisation of methods;
- recommendations for the formation of method bases.

The associated objectives are:

- laying down the data nomenclature;
- using uniform working standards e.g. mapping instructions (Pedology Working Group, 1996), sampling instructions (Ad-Hoc Soil Working Group, 1996) etc.;
- formulating recommendations on the specific architecture of a technical information system (design of core systems, data and method bases).

The soil technical information system is the best developed with respect to these targets; the structures for the profile, area description and laboratory analysis databases, as well as the method
Soil information system structure

Overall, the conditions which soil information systems have to meet are as follows:

- the stipulations laid down for soil protection in the soil protection concepts of each state
- the responsibilities of the state geological survey.

The most important responsibilities derived from the soil protection policies of the federal government and states are as follows:

I. Mapping and monitoring soil
- country-wide mapping of the extent, composition, and properties of the soil (spatial, and laboratory databases) and the changes to the soil (long-term observation areas, sample banks) and rocks
- evaluation and use of geo-scientific data (method bases).

II. Reducing the amount of land needed
Documenting the actual status and changes to the:
- natural areas;
- agricultural and forestry land;
- resource production areas;
- built-up areas;
- traffic infrastructure areas;
- areas for waste disposal;
- areas for leisure, relaxation, sport;
- areas used by the armed forces.

III. Limiting contamination of the soil by pollutants from:
- the air
- agriculture and forestry practices
- domestic and industrial wastes
- contaminated sites.

IV. Maintaining soil structure and its productivity
- protection from negative influences such as erosion and compaction
- remediation, recultivation, rehabilitation, etc.

During the development of the information system, it became apparent that the standards that had been set, particularly those concerning the databases, required further specification and revision. In addition to a structured data stock forming the basis of the system, a high priority also has to be set on the evaluation of data – without which the development of a soil information system and its application for soil protection purposes would make little sense.

A particularly complicating factor here is the evaluation of data from different disciplines. This involves the integration of data systems for each discipline, and ensuring that a proper technical evaluation takes place by incorporating suitable methods and models. In order to meet this challenge, the following system modules needed to be discussed and their principles uniformly defined:

- evaluation methods;
- system method base;
- documentation (properties, qualities, areas of application) of evaluation methods.

To meet these demands, a working group defined additional specifications for the most important methodological components of the soil information system, and in particular for the method base. These are briefly outlined in “Ad-Hoc-AG core systems and method bases” (1994a and b). A more detailed discussion of the development and classification of methods is presented by BARTSCH (Architecture of the soil information system of Niedersachsen, 1998, in this volume).

As defined by SAG 1987, soil information systems are not self-contained units but rather an amalgamation of different technical information systems which can be operated by different organizations. Such a joint system requires formal agreements on the content and terminology (languages) of the systems involved.

A core system and the tools for its implementation were agreed upon (Ad-Hoc-AG core systems and method bases, 1994a).

Core systems can be considered as a meta-language on the basis of their structures, and contain the descriptions of the contents of
the systems involved in the sense of a database.

In addition, control elements within the system are required for requesting information and for providing the actual data behind the information. This demand is met by the development and application of the so-called method bases (Ad-Hoc-AG Core Systems And Method Bases, 1994b).

Method bases contain tools for requesting and providing information.

At the 42nd Conference of Environment Ministers in 1994 it was proposed that recommendations submitted by the Ad-Hoc-AG (core systems and method bases for the development of soil information systems) should become the standard.

The amalgamation of databases, core systems, method bases and integrated communications components make the proper processing of all relevant data possible for the user of the soil information system, and thus also for the pedological TIS.

Figure 2 shows the developed structures in diagrammatic form.

**Implementation status**

The federal and states governments agreed that the Ad-Hoc-AG recommendations should be followed when setting up and operating soil information systems. In addition, the division of responsibility between the federal government and the states on one hand, and between the state and federal ministries involved on the other (Eckelmann 1996), must also be considered. The following outlines the current development and application status.

On behalf of the federal government, the Federal Institute for Geosciences and Resources is responsible for:

- advising the federal government on all geoscientific matters,
- providing a database suitable for federal requirements in collaboration with the state geological surveys,
- ensuring information transfer and collaboration at a European and international level.

To meet these demands, the Federal Institute for Geosciences and Resources is developing a soil information system which is structured according to the framework agreements. It contains, amongst other things, the following data and standards depicted using the pedological technical information system as an example (Eckelmann and Adler, 1994; Eckelmann, 1996):

- soil survey map of the Federal Republic of Germany at 1:1,000,000 scale (Hartwich et al., 1995),
- soil survey map of the Federal Republic of Germany at 1:2,000,000 scale for EU and international collaboration
- soil survey map at 1:200,000 scale in collaboration with geological surveys (first edition 1996),
- profile and laboratory data matching these scales,
- standards jointly formulated with the geological surveys for the processing of maps and laboratory analyses (e.g. sampling instructions, mapping instructions, instructions for the production of a soil survey map at scale 1:200,000).

For evaluation purposes, the Federal Institute for Geosciences and Resources uses a method base which in all significant aspects matches the prototype developed by the Geological Survey of Niedersachsen. However, the evaluations derived from its use are oriented to the special requirements of the federal government and its international collaboration partners.

The state geological surveys are mainly responsible for researching and documenting the distribution and properties of the soil's geology/pedology, and making this information available to third parties, amongst other things, for soil protection matters. In detail these are:

- advising state governments on all geoscientific matters,
- providing a database suitable for state purposes,
- evaluating the data required for planning purposes at scales of 1:5,000 to 1:200,000.

In order to meet these demands, all state geological surveys are developing soil information systems, and most adhere to the recommended structures.

It could be shown that considerable stocks of the most important available data have already been established. However, the stocks of available data vary widely from state to state – which considerably complicates the uniform country-wide analysis by the Federal Institute of Geosciences and Resources. This therefore gives a
rather differentiated picture with respect to the use of soil information systems for soil protection matters.

Further action is required by the federal government and the states because, although the methods to evaluate various questions are already available, there is not yet a country-wide method base in place. The reason for this is that although the technical methods have been developed and are ready for application, (Müller 1992; Hennings, 1994), the software tools for the method base concept have not yet been fully developed (Bartsch, 1996). The most important modules for such a method base are currently in development, and in some cases already in use, only at the Geological Survey of Niedersachsen. Completion is scheduled for 1997. It is then planned to make it available to other geological surveys.

**Conclusions**

In the last 10 years, considerable efforts have been undertaken in the Federal Republic of Germany to create the necessary framework for effective soil protection. This involves the use of soil information systems which are currently being developed in all states and at a federal level. Although the systems have not yet been fully completed in any of the states, they are already being used as a basic source of information for advising farmers, local authorities and associations, and federal and state bureaucracies, as well as at an international level. In many cases, the development of soil information systems has reached such an advanced stage that they can now already be used directly in land use planning (farmers, associations) as well as for promulgating relevant regulations and codes of practice. Because of the very high spatial resolution of its data, the state geological surveys and the Federal Institute of Geosciences and Resources can also make effective contributions to support European committees and institutes. This has laid the foundations for collaboration in the creation of spatially highly-resolved information sources for EU committees (e.g. soil database on the basis of EU soil map 1:250,000). Furthermore, the development of method bases can make an additional important contribution to ensuring sustainable land use.

**References**


129


Development of the Soil Information System in the Federal Republic of Germany
(coordination of work)

Figure 1: Organization structure for the co-ordination of work
Figure 2: Structure of the system
The FISBo BGR Soil Information System: State of the Art

Summary

The German Federal Institute for Geosciences and Natural Resources has started to establish a soil information system (FISBo BGR). This system is intended to contain all information relevant to soil protection. It will then be possible to recall and interpret the data according to scientific or regional criteria. Additionally, methods and criteria will be developed for the recognition and assessment of soil contamination. FISBo BGR consists of three main components: The areal database, containing all small-scale soil maps for nationwide needs will be used as an extensive data set to create thematic maps.

The laboratory and profile database contains the results of soil analysis, i.e. basic chemical and physical data (soil properties), as well as inorganic and organic contaminants. The method base is intended to document and select standardized methods, e.g. for the derivation of the filtering capacity, groundwater recharge or soil productivity from soil maps and the relevant basic pedological data.

The FISBo BGR Soil Information System – general outline

The ongoing discussion on soil protection has caused the demand for pedological data and information to increase abruptly. As a result data availability and access have become priorities at EU and national levels as well as for the individual state geological surveys in Germany. To meet this need, the Federal Institute for Geosciences and Natural Resources (BGR) has initiated a soil information system for Germany, called "FISBo BGR" (Eckelmann and Adler 1994; Eckelmann et al. 1995).

The FISBo BGR System is one of a number of linked geo-information systems, e.g. geology, soils, geomorphology, hydrology etc. Together they form a geo-information network which enables broad interdisciplinary evaluation of different topics. The structure of such an information system has been described by Vinken (1992). This and other papers in the same volume give an overview of current work on information systems in Germany.

Objectives and aims of the BGR Soil Information System

In Germany, sixteen federal states are responsible for soil survey and soil protection at regional level. The federal government is responsible for all nationwide aspects of soil and for issues at EU and international levels. Once fully developed, BGR’s Soil Information System will be a specialized addition to the individual states’ information systems, fulfilling today’s technical demands. It is intended to contain all data relevant to soil use and soil protection for nationwide requirements. It helps to make extensive data available to handle all kinds of questions and to process these data for use throughout Germany.

FISBo BGR’s detailed objectives and aims are:

- To elaborate and provide a database of soil information in cooperation with the German federal states according to the needs of the federal government,
- to analyze this database answering requests for
information from the federal government (e.g. for preparing presentations of the current situation,

- for compiling basic and thematic maps, for prognosis, and for drafting guidelines as required by law,

- to provide a basis for answering questions submitted by EU agencies or international bodies,

- to provide a basis for cooperation with other research institutions (e.g. for nationwide analyses).

Structure of the BGR Soil Information System (FISBo BGR)

The above mentioned aims and objectives of the BGR Soil Information System require close co-operation between the federal government and the individual state geological surveys. This means, for example, that the structures of the individual state information systems and that of the BGR's must be similar in order to guarantee the most effective information transfer. Structural patterns suitable for a nation-wide information system were proposed by a special working group representing the federal states (SAG Informationsgrundlagen Bodenschutz 1989). They have been completed by a number of pieces of advice and agreements, e.g. "Mindestdatensatz Bodenuntersuchungen" by the same working group (SAG Informationsgrundlagen Bodenschutz 1991).

The following main structural components are being built up at BGR at the moment analogous to those information systems of the individual German states:

- a spatial database that maintains a number of already existing soil and related maps including the geometric-topographical data
- a soil profile and laboratory database that contains both the observations of soil surveys as well as the results of all soil chemical and physical analyses,
- a method base that defines the data processing techniques (for determining groundwater recharge, water retention and filter functions, soil productivity, etc.) from soil maps and the relevant principal and supplementary data.

With respect to future cooperation with EU organizations, these structure components have to be adjusted to those of the EU level. This indicates above all the need of compatible data field registers, data sets and methods.

Contents of the FISBo BGR spatial Database

The spatial database established at the FISBo BGR has to meet the special requirements to produce soil maps in order to fulfil its duty for the federal government. For the national and international need these maps are

- the Digital Cartographical Database of Europe (EURODB) to serve as the basic map,
- the 1:200,000 soil map as the common base map to be compiled jointly with the federal state soil surveys,
- the 1:1,000,000 soil map as the most important graphical database for the national requirements,
- different soil maps at scales 1:2,000,000 to 1:5,000,000 to show landscape relations or to give an overall view on soil information.

The 1:200,000 Soil Map

In order to co-ordinate the production of a 1:200,000 soil map for Germany, BGR and the sixteen state soil surveys have started to set up guidelines, rules and a legend for the standardized soil map as follows:

- Guidelines for soil map unit and soil profile descriptions including flow charts showing all steps to be taken by the state geological surveys of Germany as well as those, taken by BGR,
- data sheets with 42 data fields for data collection related to the soil units of the 1:200,000 soil maps,
- rules for amalgamating soil survey maps to other scales,
- a general legend for the standardized 1:200,000 soil map.

To ensure that the soil surveys describe similar soil units for the 1:200,000 soil map in a comparable way, a system of landscape relations has been defined for Germany. This hierarchical system classifies landscapes based on geology, morphology, climate, and vegetation as well.

Areas with mostly similar geology and morphology are defined, and within those areas climate, water regime and relief show only limited variations. It follows that parent material and soil genesis in such an area only vary little, and this in turn permits dominant soil types to be defined for each area. Such an area is
called “Bodenlandschaft” or “soil landscape”.

On a higher hierarchical level, several soil landscapes are united to form a “Bodengroßlandschaft” or “Soilscape” (after Dudal, 1993), and several of these form a “Bodengroßregion” or “Soil Region”, of which there are twelve in Germany.

When drafting the 1:200,000 soil map, soil scientists must pay attention to ensure that similar soil landscapes have similar soil inventories or the soil landscape boundaries should be changed. Using this procedure, it will be possible to work out 1:200,000 soil maps in co-operation with the state geological surveys of Germany. This procedure would also be suitable for compiling 1:250,000 EU soil maps, as has already been proposed by Dudal (1993).

The 1:1,000,000 Soil Map

Up to reunification in 1990, there was no national German soil survey in the FRG to co-operate with the state soil surveys in order to summarize soil mapping activities on a national level to work out national soil maps. The only soil map which was compiled in consultation with the state soil surveys is the 1:1,000,000 Soil Map of the Federal Republic of Germany, worked out by Roeschmann (1986).

For the area of the GDR Haase and Schmidt (1979/85) produced the 1:500,000 soil map, which was well suitable to be used for the preparation of a 1:1,000,000 soil map.

Ultimately, after reunification, the first nation-wide soil map at a scale of 1:1,000,000 was worked out on the basis of these two soil maps by Hartwich et al., (1995). Therefore, it became necessary to use a common soil classification for both parts of Germany and to define standardized descriptions for all soil units. As a result, a relatively homogeneous map has been produced which represents balanced assessment of soil patterns in Germany.

The 1:1,000,000 soil map shows 72 soil map units described on the basis of the German and the FAO soil taxonomies. Each unit has been assigned a characteristic soil profile (“Leitprofil”) to make detailed map interpretations on various themes possible. The map also shows the twelve soil regions boundaries mentioned above (see 1:200,000 Soil Map), in order to demonstrate the connection between these hierarchical soil map levels and the 1:1,000,000 soil map units.

The German 1:1,000,000 soil map has been established digitally. It is an important part of the spatial database integrated in the FISBo BGR Soil Information System being set up at the Federal Institute for Geosciences and Natural Resources. In addition to the characteristic soil profiles (“Leitprofile”) thematic maps dealing with region-wide problems of soil protection can be derived. The 1:1,000,000 scale makes the soil map suitable especially for evaluating problems at both national and the EU level (Jamagne et al., 1995).

Contents of the FISBo BGR Soil Profile and Laboratory Database

The soil profile and laboratory database stores all soil attribute data extracted from point observation of fully described and analysed reference profiles in sets of digital files for later retrieval. Links between the files, that is tables, are maintained through primary keys. Depending on regional or national requirements, the soil database may be set up according to various nomenclatures. In addition to the German soil taxonomy, the FAO soil classification system has been realised so far. The latter has been done in order to specifically cater for international co-operation. Similarly, a soil database is presently being developed according to the U.S. Soil Taxonomy (widely used in Asia and the Americas).

In a further step towards harmonisation of global soil information (Van Engelen and Wen 1995), BGR recently also adopted the terminology and components of the Multilingual Soil Database (FAO, ISRIC and CSIC, 1995) for their FAO soil database version. Unlike the FAO-ISRIC-CSIS Soil Database (SDBm), the “FISBo BGR” soil database allows, however, to be easily tailored according the customer needs and wishes. Based on the standard software (i.e. MS Access), soil and other components (e.g. vegetation) can readily be added to or removed from the database by individual users or customers.

One essential purpose of the harmonised, site-specific soil data is to estimate representative soil profiles for small scale soil maps in order to make areal
interpretations on various themes (Hennings, 1994). Additionally, this soil profile and laboratory database can be used to create pedotransfer functions, which relate different soil properties to one another or to soil texture (Bouma and Van Lanen, 1987). The pedotransfer functions are essential for creating standardized data sets from inhomogeneous data. At least, these data can be used to analyze the spatial structure of specific soil properties using geostatistics or to determine the background values of soils for selected inorganic or organic pollutants (Utermann, et al., 1996).

Contents of the FISBo BGR Method Base

The processing of pedological data e.g. to make interpretations of soil maps on various themes or to analyze specific topics requires not only the availability of the data necessary within an efficient information system, but also well defined methods to be applied out of a digital method base. This method base contains methods to derive land qualities from pedological base data (e.g. maps). The methods themselves consist of pedotransfer functions (in modular form). These pedotransfer functions, once they are established as reliable and accurate, permit key parameters (relationships) to be calculated, thus, greatly simplifying the data as required in modelling (Wagenet et al., 1991). Moreover, the methods collected in such a method base must be programmed according to a single scheme so that they can be used by both BGR and the German federal state soil surveys.

The principles behind these methods are described by Eckelmann and Müller (1989). An up to date documentation of a large number of methods has been published (Hennings, 1994). This method collection was prepared by a joint working group of the geological surveys of the German federal states and the Federal Institute for Geosciences and Natural Resources (BGR) set up to study various methods for processing basic pedological data, to assess these methods, and to compile a documentation.

The methods are restricted to calculating specific soil properties, parameters or functions and determining the vulnerability of the soil to specific hazards:

- potential susceptibility to compaction,
- retention capacity for heavy metals,
- vulnerability to erosion by water,
- groundwater recharge,
- nitrate retention capacity,
- potential agricultural yield,
- vulnerability to erosion by wind,
- vulnerability of forest soils to acidification.

All of the methods in the method base represent deterministic models based on simple empirical relationships. These models sometimes considerably simplify the physical and chemical processes concerned and provide only an approximate estimate of the parameter of interest. So that the different methods, available in the method base for the same desired parameters, can be compared, information is given for each method about the kind of input data needed, the appropriate scale, and whether the result is qualitative or quantitative.

This documentation describes methods whose applicability is restricted to certain areas or to maps of a certain scale. Therefore, all of the methods must be checked and developed further according to the results of further research (Hennings, 1994).

Substantial importance will be given to the optimization of algorithms for the pedotransfer functions. Several pedotransfer functions for estimating soil hydraulic properties were published in the 1980s. To prevent repetition and to identify the approaches best suited for a target-oriented selection of methods for the method base of a soil information system, existing algorithms should be tested on the basis of an existing soil profile database. The main objectives of such an investigation are

- to quantify the validity of pedotransfer functions for estimating hydraulic properties in general,
- to compare existing approaches on a common database, and
- to obtain a ranking according to the accuracy of the predicted values.

An important approach is being prepared within the EU scientific co-operation network project “Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning”, co-ordinated by the Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen (NL).

At present, it is being examined whether numerical simulation models can be included in a method base like that one to be built up in the BGR Soil Information System. In addition to the above-mentioned method
documentation, some more methods, guidelines and instructions have to be standardized in the future, e.g.

- for collecting data
  - generalization procedures for maps at different scales (e.g. amalgamating of soil information)
- for analysis
  - geostatistical classification of individual characteristics,
  - adjustment of classification diagrams,
  - supplement for DIN norms, ISO standards, complete standardized research programs.

Recently, a first printout of “Guidelines for Taking Soil Samples” (Eckelmann et al., 1996) has been published jointly by the individual state soil surveys of Germany and BGR. Some other of these topics are being dealt with jointly by the same group.

**Use of the Soil Information System**

The various soil information systems will be employed first to advise the German state government and the individual federal governments respectively. Moreover, they will be employed to develop pedotransfer functions and more or less complex methods for evaluating soil data. When the individual state geological surveys as well as BGR use the same standardized methods, comparable results are guaranteed. At least it will be a basis for co-operation with other institutes at the EU and the global levels.

For another application, the structures of the FISBo BGR will be developed further for the special needs of developing countries. It will then be possible for data from technical co-operation projects to be processed in the project area as well as in BGR and to be used in a global soil information database.

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Introduction

About two-thirds of Greece is mountainous country; only about 4 million out of a total of 13.2 million hectares of its land is arable. In mountainous areas, animal husbandry and forestry are the major sources of income and large tracts are rocky outcrops completely devoid of vegetation or covered with brush and shrubs. Greece’s 13.2 million ha are classified into four major categories as follows: 30% arable, 44% pastures, 19% forest and 7% other uses.

Among soil scientists, the concept of "land" is not to be confused with "soil", because land is wider than soil and soil is a part of the land. The concept of land involves its physiography, hydrology, climate, soil, etc. To describe land, one refers to its land characteristics (single or compound). Examples of land characteristics are: slope, total rainfall, soil depth, soil moisture holding capacity etc. Complex clusters of land characteristics are land qualities.

For the study of a Land Use System, we must describe the Land Utilization Type (LUT) with its key attributes that reflect the biological, socio-economic, technical and other aspects of the production environment that are relevant to the land’s production capacity. We are aware of the single land use systems that is LU-LUT in combination; multiple systems that have more than one crop on the same field at the same time, and compound systems that are treated as concatenations of single and/or multiple systems.

Also, it is known that a farming system (FS) is made up from different land use systems (LUS), practiced in the context of one farming enterprise. To advance the above, the presence of a soil information system is a prerequisite for land system analysis. We are dealing here with the Soil Information System.

Seeking improved environmental quality and the conservation of our land resources, two nationwide surveys of land are currently being undertaken in Greece. The first survey is designed to further agricultural planning by identifying the detailed soil units of each area and provide some additional laboratory results related to these map units. The second survey determines the suitability of terrain for forestry. While the measures and classification scheme used to date by the two surveys are different, the end product is a similar mosaic of polygons, each containing a classification symbol.

The main mission of the forestry survey is an inventory of those areas which are not suited to agriculture, but would support timber or range production. The polygon mosaic is produced by a combination of aerial and ground surveys and by reference to 1:50,000 contour maps. Currently only one thematic map and one interpretive map are produced. The result is a complete polygon mosaic with each area labelled as to its suitability for timber growth. The label is well suited to computerization, having a standard format with clearly defined and consistent meanings of each field in the label. The boundaries at the polygons in the mosaic are produced from topographic features and follow the natural curves of these features.
In the case of the agricultural maps, the labels imply different interpretations of the symbols.

Also, on the agricultural maps, the boundaries are produced by manual interpolation of curves between the sample points. Once the two surveys have reached the most detailed category, they have far more in common, computationally. Each detailed map consists of a polygon mosaic with areas labelled with a particular classification scheme.

The survey for agricultural land makes more detailed soil surveys (1:5,000-1:20,000) and uses the Soil Taxonomy system. The second study (on the suitability of land for forestry) works on semi-detailed soil surveys in mountainous forest land and uses photo-interpretation in combination with the FAO Unesco soil classification (maps at the scale of 1:50,000).

The soil survey method in Greece

Field work

Field teams of experienced surveyors examine a dense network of soil profiles and draw the boundaries of each mapping unit on either aerial photographs or, more commonly, on local maps at a scale of 1:5,000, 1:10,000 or 1:20,000. The morphological characteristics of each profile are examined for classification purposes according to a system described below. The soils are further examined by borings to 1.50 m depth, made with a hard soil auger. The distance between the borings ranges from 50 to 200 m, depending on the uniformity of the soils. For most soil types, water infiltration rates are measured using the method of two concentric cylinders or a single cylinder with a shallow ditch around it.

Survey legend symbol systems

A system of classification symbols was developed by Yassoglou and Henrard. This system was ameliorated and completed by Professor Yassoglou in order to cover the soil conditions met in Greece (Yassoglou et al, 1971). This system is based on the texture and drainage classes of the whole profile, the degree and trend of soil genesis, the topography and erosion of the soil surface, the presence of organic matter layers and gravels throughout the profile, the presence of carbonate salts, the presence of a calcic or a petrocalcic horizon, of soluble salts (salinity-alkalinity) and the depth of salinity. All these attributes are indicated with letters or numbers in the mapping unit symbol (Figure 1.). The set of symbols corresponds to the soil Phase. If the symbols of slope, erosion and textural class 0-25cm are dropped, then the combination of symbols corresponds to the soil series.

Figure 1. Mapping unit symbol

<table>
<thead>
<tr>
<th>textural class</th>
<th>order</th>
</tr>
</thead>
<tbody>
<tr>
<td>75-150 cm</td>
<td>suborder</td>
</tr>
<tr>
<td>25-75 cm</td>
<td>great group</td>
</tr>
<tr>
<td>0-25 cm</td>
<td>subgroup</td>
</tr>
<tr>
<td>4</td>
<td>↓</td>
</tr>
<tr>
<td>3</td>
<td>↓</td>
</tr>
<tr>
<td>5</td>
<td>↓</td>
</tr>
<tr>
<td>Drainage class</td>
<td>I o x v*</td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>slope</td>
<td>←</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>k</td>
<td>f</td>
</tr>
<tr>
<td>s</td>
<td>b</td>
</tr>
<tr>
<td>erosion</td>
<td>↑</td>
</tr>
<tr>
<td>CaCO3</td>
<td>↑</td>
</tr>
<tr>
<td>calcic hor. presence</td>
<td>↑</td>
</tr>
<tr>
<td>alkalinity</td>
<td>↑</td>
</tr>
<tr>
<td>salinity</td>
<td></td>
</tr>
</tbody>
</table>

*Ioxv : Inceptisol-ochrept-xerochrept-vertic*
After finishing the field work observations and measurements, and with all additional laboratory results, the standardization of the attributes is a desk exercise.

The field work map units are matched with the final chemical analytical data, making the proportional corrections, to construct the source map.

The traditional method is based on manual production of thematic maps. The thematic maps are: soil map, soil series map, irrigability map, infiltration map, slope maps, calcium carbonate map, etc.

The transition from tradition to computer

The transition from traditional databases into GIS systems is a major change. The introduction of RDBMSs in connection with the GIS have facilitated the whole procedure of delineation and evaluation of graphic and attribute data.

Land Information System (LIS)

The Land Information System described is a sophisticated GIS, a configuration of computer hardware and software specifically designed for the acquisition, maintenance and use of cartographic data. Cartographic modeling is one approach to the use of this technology. It involves models expressed in cartographic form or as maps. Geographic data are organized and manipulated in the form of single factor maps called overlays or levels.

A database includes levels of factors such as topographic conditions, soil types, urban structures and so on. These levels are derived either from direct observation or from sources such as published maps or aerial photographs, and they are registered with respect to a common cartographic base. Existing levels can thus be selectively retrieved and graphically transformed to generate new levels of site characteristics. The process is known as overlay mapping.

Geographic data processing is a field that has grown from roots in geography and computing, and from application areas ranging from the natural and social sciences to urban planning and environmental management. It is a field that has grown steadily since the 1960s and continues to grow in terms of the number of practitioners involved, the range of applications addressed and the sophistication of tasks performed.

Data

Data are simply recorded facts. In the case of geographic data, these are facts pertaining to locations on or near the surface of the earth. There are a number of ways in which such geographic data can be stored for digital processing. The data construct is intended to provide a common frame of reference that can be easily translated both to and from a variety of storage formats. Among the major components organized as a hierarchy are included the following: cartographic models, map levels, titles, zones, values, labels, co-ordinates, etc.

The ORACLE RDBMS

The ORACLE RDBMS is a high-performance, fault-tolerant database management system, especially designed for outline transaction processing and large database applications. At the heart of the ORACLE RDBMS is the SQL data language. SQL was developed and defined by IBM Research and has been refined by the American National Standards Institute (ANSI) as the standard language for relational database management systems. SQL offers a complete set of data definition and manipulation functions.

With SQL we can:

- create tables in the database
- store information in tables
- select exactly the information we need from our database.
- make changes to our data and the structure of underlying tables
- combine and calculate data to generate the information we need.

We can use all SQL facilities interactively, embedded in standard programming languages such as COBOL, FORTRAN, PASCAL, C, and ADA as well as through a variety of ORACLE tools, including report writers, application generators, spreadsheets and graphics packages.

In the current method, we digitised the hard copy map, inputting graphic data into the computer memory. This was done after defining the Coordinate System. We selected the UTM (Universal Transverse Mercator) System, the user-defined (non-standard) Geodetic Datum, and the Bessel 1841 Ellipsoid, with Zones 34 and 35 of the Northern Hemisphere in the system parameters. Kilometres were defined as the master working units and metres as the sub-units.

The geographic data for cartographic modelling are organised and
manipulated in the level forms. The database includes levels of factors such as topographic conditions (contours), polygon mosaics of soil types, urban structures, road networks, railroad networks, drainage patterns and so on.

These levels derived from direct observation or from existing maps or aerial photographs.

The digitised maps, at a detailed scale of 1:5,000, are merged with each other. After correcting the errors in 2-D digitised linework (line cleaner) and creating the centroids of mosaic polygons (cartographic units), we construct the database. We use the Intergraph Corporation Modular GIS Environmental System Nucleus (MGE/SX computerized database management system) for capturing, storing, retrieving, analysing, and displaying spatial data that supports the ORACLE relational database and uses Intergraph's Relational Interface System (RIS) to access non-spatial data (attributes) for use within our GIS environment. RIS allows us to retrieve and review related information by establishing a direct link to remote databases. This capability speeds inter-departmental access and allows departments to share current information. RIS supports a number of popular relational databases including DB2, Informix, Sybase, Ingres.

The database is a relational database containing feature, category, maps, and user-defined attribute tables of information for the project. Twelve database tables are generated by MGE/SX (attribute_catalog, domain_catalog, join_catalog, list_domain, range_domain, view_catalog, view_content, view_join, feature, category, label, and maps) and one table is required by Microstation (mscatalog).

Climatic data

Generally the climatic conditions are Mediterranean; i.e dry and hot in summer and rainy and cold in winter. According to the Koppen classification these are climatic types Csa and Cfb.

Textural classes

According to the system used, the soil profile is divided into three sections:
(A) surface, 0-25 cm,
(B) subsoil, 25-75 cm
(C) substratum, 75-150 cm.

Numerals from 0 to 5 are assigned to each section according to texture, as indicated in Table 1. The textural classes are grouped in five, four and three groups for the sections A, B and C respectively.

<table>
<thead>
<tr>
<th>Table 1: Textural classes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section A</strong></td>
</tr>
<tr>
<td>symbol:</td>
</tr>
<tr>
<td>*</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>M</td>
</tr>
</tbody>
</table>

S= Sand, L= Loam, Si= Silt, C= Clay

Degree and direction of soil genesis

For classification purposes the USDA Soil Taxonomy System is used. Soils are classified down to the subgroup level and sometimes to the family level. Taxa are
symbolized with the initial letters i.e. Axhm means: Alfisol-Xeralf-Haploxeralf-Mollic

**Drainage classes**

The drainage class is determined on the basis of the colour throughout the soil profile, the presence of iron and manganese mottling as well as gleying, according to the following scheme:

According to the Soil Taxonomy (Soil Survey Staff, 1975) the soil series is defined as the detailed taxonomic unit. The family contains soils within the subgroup with common physical and chemical properties which affect their reaction to management practices and land use. The various phases within the family are similar enough for the interpretation of such reaction to be possible.

The series within a subgroup is defined on the basis of the drainage class and the texture of the subsurface and the subsoil. Thus it is possible that a series includes more than one family as the textural classes are different from those used for the families in Soil Taxonomy. It should be noted that all technical aspects and differentiating criteria for the establishment of a taxonomic unit at the level of the "family" for use in Greek conditions are already being considered in the Greek system. In detailed mapping (scale 1:5,000), the soil series and its phases form the basis of soil interpretation. The phase of the soil series is the most homogenous taxonomic unit.

<table>
<thead>
<tr>
<th>Drainage class</th>
<th>Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Very well drained, soil profile dry, no mottling</td>
</tr>
<tr>
<td>B</td>
<td>Well drained, limited mottling below 100 cm</td>
</tr>
<tr>
<td>C</td>
<td>Moderately drained, obvious mottling below 50 cm</td>
</tr>
<tr>
<td>D</td>
<td>Imperfectly drained, mottling starts at 25 cm below the surface</td>
</tr>
<tr>
<td>E</td>
<td>Poorly drained, mottling starts in depths shallower than 25 cm</td>
</tr>
</tbody>
</table>

When a permanent water table exists throughout the years in depths shallower than 150 cm, the following symbols are employed

| F              | Permanent water table between 50 and 150 cm depth. |
| G              | Soil with permanent water table in a depth shallower than 50 cm. |

The combination D/E or E/F etc means that up to the water table depth the drainage class is indicated by the numerator.
SOIL PHASES

1. **Slope**

<table>
<thead>
<tr>
<th>Symbol/class</th>
<th>Slope</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-2</td>
<td>Flat</td>
</tr>
<tr>
<td>B</td>
<td>2-6</td>
<td>Slightly sloping</td>
</tr>
<tr>
<td>C</td>
<td>6-12</td>
<td>Moderately sloping</td>
</tr>
<tr>
<td>D</td>
<td>2-18</td>
<td>Strongly sloping</td>
</tr>
<tr>
<td>E</td>
<td>18-25</td>
<td>Extremely sloping</td>
</tr>
<tr>
<td>F</td>
<td>25-35</td>
<td>Slightly steep</td>
</tr>
<tr>
<td>G</td>
<td>35-50</td>
<td>Moderately steep</td>
</tr>
<tr>
<td>H</td>
<td>&gt;50</td>
<td>Strongly steep</td>
</tr>
</tbody>
</table>

2. **Erosion**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No erosion, no subsurface horizon or layer is present on the surface of the soil</td>
<td>Not eroded</td>
</tr>
<tr>
<td>1</td>
<td>Slight erosion, subsurface horizon on layer is present in less than 30% of the surface</td>
<td>Slightly eroded</td>
</tr>
<tr>
<td>2</td>
<td>Moderate erosion, subsurface horizons is present in more than 30% of the surface</td>
<td>Moderately eroded</td>
</tr>
<tr>
<td>3</td>
<td>Strong erosion, deep lying subsurface horizons or layers are present on the surface</td>
<td>Strongly eroded</td>
</tr>
</tbody>
</table>

3. **Carbonates (CaCO₃)**

Symbols are employed according to the reaction of the soil material upon addition of an HCl solution, as follows:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No reaction to HCl</td>
</tr>
<tr>
<td>1</td>
<td>No reaction in the surface (A) but reaction evident in the subsurface (B) and/or substratum (C)</td>
</tr>
<tr>
<td>2</td>
<td>Weak reaction in section A, regardless of the reaction in B and C sections</td>
</tr>
<tr>
<td>3</td>
<td>Strong reaction in section A regardless of the reaction in B and C sections</td>
</tr>
</tbody>
</table>

If a calcic horizon exists, it takes symbols according to its depth as follows:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>k2</td>
<td>40 - 60 cm</td>
</tr>
<tr>
<td>k1</td>
<td>60 - 100 cm</td>
</tr>
<tr>
<td>k0</td>
<td>100 - 150 cm</td>
</tr>
</tbody>
</table>
4. **Alkalinity**

For Alkalinity, symbols are used as follows:

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>f1</td>
<td>Degree of Alkalinity 15-25</td>
</tr>
<tr>
<td>f2</td>
<td>Degree of Alkalinity 25-50</td>
</tr>
<tr>
<td>f3</td>
<td>Degree of Alkalinity &gt;50</td>
</tr>
</tbody>
</table>

5. **Salinity**

Symbols for salinity description are used as follows:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Electrical conductivity 4-8 mhmhos/cm</td>
</tr>
<tr>
<td>S2</td>
<td>Electrical conductivity 8-15 mhmhos/cm</td>
</tr>
<tr>
<td>S3</td>
<td>Electrical conductivity &gt; 15</td>
</tr>
</tbody>
</table>

Symbols for the depth of Salinity - Alkalinity

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Depth cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>b1</td>
<td>0-25 cm</td>
</tr>
<tr>
<td>b2</td>
<td>25-75 cm</td>
</tr>
<tr>
<td>b3</td>
<td>75-150 cm</td>
</tr>
<tr>
<td>b4</td>
<td>in all the depth</td>
</tr>
</tbody>
</table>

The presence of less than 60% stones in the three depth sections is indicated as follows:

A star symbol above the corresponding symbol of textural class is used, e.g.:

* * *

334 225 111
C----- I  B----- E  A---- I
A01  B12  A01

**Codification of profile characteristics**

In the Greek Soil Survey System, symbols are used for profile description according to the "Soil Survey Manual, Agriculture Handbook No. 18" and the FAO-UNESCO Guidelines for Soil Profile Description (Rome, 1977). For computing purposes, we correspond numbers and symbols in the following manner. A mapping unit that has drainage class B, textural classes in section B=4 and where the presence of stoniness is less than 60%, namely *, R in section C, 5 in section A and slope C(6-12%), erosion 2 and the reaction of the soil material upon addition of a HCl solution 0, the order = Inceptisol, suborder = Ochrept, great group = Xerochrept and subgroup = Typic; then, when we want to retrieve the information about this unit, we use the SQL command as follows: select mapping_unit from table ' where mapping_unit = 'B 4*R5/C20 Iox';.

In the same way we retrieve the codes of other soil characteristics – mottles, structure, etc.

Generally, properties such as the shape of structural aggregates are described in qualitative terms: granular, blocky, prismatic, platy, and so on. When there are more than two states they are said to constitute multi-state characters.

For computing purposes we identify each state by the codex symbol. Other multistate morphological characters describe the moisture state of the soil and the degree of structural development.

Properties are recorded in a fully quantitative way when they are measured and assigned values on a continuous scale. Examples include the thickness of horizons, organic carbon content (proportion). The Munsell colour scales are regarded as alphanumeric form (character column types) since the Hue is recorded as character and the value and chroma as numeric e.g 10YR 7/1. The information are retrieved through SQL commands (e.g : select colour munsell from
Integrating soil data with satellite imagery and GIS

The traditional methods of cartography and inventory are rather long and expensive as they need ground surveys at large scales. Over the last twenty years, major developments in data processing entailed great changes in all areas of the classical chain of information, from the setting up of geographical information to the cartographic realisation and its recording and later exploitation. The revolution was brought about by two complementary techniques: remote sensing and geographical information systems.

Remote sensing includes all the techniques developed to obtain information about the earth's surface. For twenty years the satellites of Earth observation (the Landsat and SPOT series, etc.) have allowed us to obtain more and more precise images all over the Earth for land use and agricultural planning. Data obtained by satellite remote sensing are multispectral (recording the radiation emitted by objects in precise and significant radiometric bands as visible, near infra-red, middle infra-red and microwave) and numerical (they are composed from all numeric values recorded on the different points or pixels of the image).

According to the studied themes and to the regional contexts, the use of remote sensing should be optimized through the choice of the satellite, the choice of the dates of image acquisition, the methods used to define and manage the data and the form of the final data.

Schematically, remote sensing and GIS are the two ends of an operating chain. These techniques employ rather different modes of work: remote sensing processes raw data in "raster" mode and GIS processes elaborated data in "vector" mode. But a strong synergy exists between them: remote sensing is one of the best means of creating GIS data (inventory, standardisation and actualisation of data), and GIS data are mandatory for the regular and rational use of remote sensing.

In the past, ground data collection was the pre-eminant source of information for land resource surveys, but remote sensing imagery has reduced its importance for many types of survey including soil survey. Ground data collection nevertheless remains an essential element even in surveys heavily dependent on remote sensing.

Scientists involved in the geographical distribution of soil especially in medium and small-scale surveys, can gain much from remote sensing techniques because they offer an overview of large areas and facilitate the study of various landscape elements as individual items as well as in their interrelationships.

Several studies have reported positive results in the use of satellite data to delineate and map important soil differences, and to determine important soil properties and characteristics. The conclusions reported in the literature during recent years suggest that the aspects and possibilities with satellite-acquired reflectance data which provide a significant new tool to aid in soil survey are: a synoptic view of the survey area and surroundings; a quantitative assessment of the homogeneity of the map unit; repetitive coverage; digital format; computer-implemented image processing possibilities; and possibilities for registering, overlaying and combining multiple data sets.

In operational surveys, the ground data collected are primarily for extrapolations over the whole target area, and may include some of the

Maps

The following soil and soil interpretation maps are made:

Detailed soil maps, at 1:5,000 or 1:20,000 scale

A map of soil series and soil types based on the detailed soil map with the same scale and indications of the soil types (textural class of section A, 0-25 cm). In the Greek classification system, the textural class of sections B and C and the drainage class define the soil series.

Maps of cultivation groups or soil management maps. These show the areas with similar soil and water properties for land management practices.

Map of irrigability classes. Six classes are used on the basis of soil, topography and drainage limitations.

Non-graphic data

The non-graphic data are retrieved with the SQL data language of the ORACLE RDBMS, saved in ASCII form. Afterwards we transform the data list from UNIX into DOS status for further statistical processing.
main physical properties affecting radiation recorded for different parts of the spectrum. The properties are usually those needed to describe the final classes or properties in the terrain analysis. Some sets of characteristics have a direct effect on the appearance of remotely sensed data, namely those of surface forms (as slope, angle and aspect) surface materials (texture, organic matter, soil colour, soil moisture, iron oxides, the presence of secondary accumulations as carbonates and salts, the degree of compaction, soil structure as represented by the size and shape of surface aggregates) and land cover.

Particularly in terms of spatial extent, satellite imagery may in a sense be more accurate than ground data. However, this necessitates an integration of ground level and remotely sensed data, using the strengths of both. An expansion of research work on all aspects of ground data collection is necessary for a more productive use of remote sensing imagery in soil survey.

References


YASSOGLOU et al, (1971) (A system of soil classification symbols for the soils of Greece.)
A database for sustainable agriculture and environmental protection in Hungary

Summary

Soils represent a considerable part of Hungary’s natural resources. Consequently, sustainable land use and proper soil management ensuring normal soil functions are particularly important elements of both the natural economy and of environmental protection. All soil-related actions require adequate information on soils and its environment (terrain, land-site, ecosystem). The main objective of the present work is to give examples on the multipurpose applicability of the SOTER concept and SOTER database in the decision support systems of various soil-related activities for land users, planners and policy-makers at various levels.

Introduction

The International Society of Soil Science (ISSS) officially endorsed a proposal on the establishment of a uniform World Soil and Terrain Digital Database at a scale of 1:1,000,000 during its 13th Congress (Hamburg, 1986). The main function of this database is to provide the necessary data for improved mapping, modelling and monitoring of changes of world soil and terrain resources (ISRIC, 1993) and presenting a wide range of accurate, timely interpretative analyses for decision- and policy-makers for their development concepts, decision-making, planning and implementation activities (Batjes, 1994a, 1994b).

The methodology of SOTER was elaborated by ISRIC (Wageningen, The Netherlands) within the frame of a UNEP-funded Project, with the co-operation of an international expert group. After several modifications it was published by ISRIC (UNEP-ISSS-ISRIC-FAO) in 1993, as: "Global and National Soils and Terrain Digital Databases (SOTER). Procedures Manual".

Basic Elements of the SOTER Methodology

The two main, simultaneous task groups of the SOTER system are:

- the delineation of areas with a homogenous set of terrain and soil characteristics (mapping of SOTER units);
- the development of an attribute database related to the mapping units and based on well-defined differentiating criteria.

In SOTER three hierarchic levels are distinguished:

1. SOTER unit: an area (map unit) that can be identified, characterized and quantified by similar physiography. These areas can be subdivided according to lithology or parent material.
2. Terrain component: an area within each terrain, with a particular pattern of surface form, slope, mesorelief, and texture of parent material.
3. Soil component: an area within a terrain or terrain component covered by a particular pattern of soils.

Only the SOTER units are delineated on the map, because territorial separation of the distinguished terrain components and soil components is not always possible at the applied SOTER scale, due to the complexity of their occurrence.

HUNSOTER

In 1993, a project proposal was elaborated by the Hungarian Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences, Budapest, under the title "Multipurpose applicability of
soil and terrain digital database (SOTER) for sustainable land use and soil management (HunSOTER)"). The proposal was submitted to and accepted by the United Nations Environment Programme (UNEP) as "Establishment of soils and terrain database for sustainable agriculture and environmental protection in Hungary (HunSOTER)" (Project No. FP/6101-93). It was the first "SOTER-window" in Europe (Pásztor et al., 1995a, b; Szabó et al., 1995; Várallyay et al., 1994).

Arguments (Why in Hungary?)

The proposal to select Hungary as a "SOTER window" was based on the following features of the country:

a) Highly variable physiographical conditions.

b) Occurrence of a large range of soils in the various phases of their development as well as a large range of soil deterioration due to natural factors and/or human activities (Várallyay, 1989a).

c) Various types of farming units (small private farms, cooperatives, state farms, etc.), land use and cropping pattern, agrotechnics and amelioration (Láng et al., 1983).

d) Various environmental problems and hazards ("hot spots") (Várallyay, 1991).


f) Traditionally good institutional and personal scientific contacts and long-term experiences in (soil) scientific co-operation (Várallyay, 1994c).

Main objectives

The large amount of available information and the long-term experiences in their practical utilization in Hungary give rational opportunity for the development of a comprehensive, scientifically-based computerized land resource development and environmental management system in Hungary using the SOTER concept and SOTER methodology, proving its multi-purpose applicability in the regional and national decision-making process concerning:

- the sustainable use of land and water resources for agricultural production and for other purposes;
- the conservation of these resources ensuring their renewal and normal functions;
- the prevention of natural environmental hazards and human-induced side-effects, such as soil or land degradation processes and landscape deterioration (SOTER, 1994a, b; Várallyay et al., 1994).

The HunSOTER database

The system is a well-structured, simple and easily applicable soil and terrain digital database prepared at the scale of 1:500,000 for the whole country (93,000 km²) following the SOTER methodology (ISRIC, 1993).

The database – according to the internationally accepted SOTER Guidelines – contains the necessary information on the differentiated SOTER units, terrain components and soil components.

The 1:500,000 scale map of SOTER units (1210 altogether) was prepared for the whole country, in co-operation with the
The database contains point data for about 550 representative soil profiles and for their horizons (Table 1). The three main sources of these data are:

- The 1:100,000 scale agro-topographical map of Hungary distinguishing more than 5000 delineated polygons according to 9 main soil attributes (Várallyay, 1989b; Várallyay et al., 1993);
- GIS database of the Hungarian Soil Information System (HunSIS = TIR) developed in RISSAC for Pest county (including data for about 10000 profiles!);
- The database of the newly established "National Soil Conservation Information and Monitoring System" (TIM) operated by the Ministry of Agriculture (Tim, 1995; Várallyay, 1994b).

The multipurpose applicability of the SOTER database on national level was demonstrated on a "window area" at the 15th ISSS Congress (Acapulco, Mexico, 10-16 July 1994) (SOTER, 1994a, b). The selected area was about 25,000 km². Within this area 355 SOTER units were indicated in the 1:500,000 scale map, consisting of 470 terrain components and 1089 soil components. For the characterization of their soils 337 representative soil profiles have been selected and their profile and horizon attributes were included in the database of the "window area" (Várallyay et al., 1994).

The SOTER units are far from being homogeneous in the 1:1,000,000 or 1:500,000 scale. The main limitation of the present system is that this lack of homogeneity sometimes makes the spatial (territorial) interpretation risky (in spite of the fact that the percentage of the various soil components are given in the database), because the location of the various soil "inclusions" are not indicated on the map. For the demonstration of the various spatial variabilities of the SOTER units the percentage of the dominant soil type within a SOTER unit is presented in Figure 1 for the selected Hungarian SOTER window.

Benefits and Applicability of HunSOTER Database

The HunSOTER database with its "windows" represents a scientific basis of the various "Plans of Action" for sustainable land use and soil management.

It offers a wide range of opportunities for spatial quantification and comprehensive analysis-modelling-evaluation of soil properties and pedotransfer functions.

On this basis the SOTER database can be used for:

- rational use and management of natural resources (surface and subsurface waters, soils; vegetation, biota, etc.);
- protection and conservation of land, soil, water and biological resources;
- evaluation of land productivity; maintenance or increase of soil fertility;
- optimization, rationalization and regionalization of land use, cropping patterns;
- national planning (concepts, main directives, general guidelines) of activities on soil fertility and soil moisture control, such as amelioration, agricultural water management, irrigation, drainage, agrotechnics;
- evaluation, modelling, monitoring and forecast of environmental hazards for their prevention or control;
- provision of data for retrospective or predictive models and early warning systems;
- prevention, elimination or moderation of soil degradation processes (water and wind erosion; acidification; salinization-alkalization; soil structure destruction, compaction; biological degradation; unfavourable changes in moisture and nutrient regimes);
- inventorying environmental "hot spots" (environmentally sensitive, valuable, protected ecosystems and their land-sites; highly polluted areas with susceptible soils; etc.);
- evaluation of the buffer capacity of soil; level, form and sources of soil pollution and toxicity (possibilities and criteria of liquid manure, sewage sludge, waste and waste-water disposal, etc.);
- evaluation, mapping and monitoring of critical loads for various ecosystems;
- rational territorial planning of non-agricultural land use (industry, surface mining, infrastructure, urban and rural development, recreation, etc.).

HunSOTER can serve as an indispensable soil and terrain digital database for many international programmes for environment control (e.g. "Chemical Time Bombs" (non-linear, time-delayed impact of potentially harmful chemicals); "Long-term Environmental Risks for Soils, Sediments and Groundwaters in
The database can be used for the transfer and exchange of technologies for sustainable land use and soil management, as well as for ecosystem redevelopment.

The general SOTER concept and methodology can be improved on the basis of HunSOTER experiences.

Case Studies

From this wide spectrum of potential practical applications, five practical possibilities are demonstrated by case studies.

1. Land (soil and terrain, "land-site") evaluation

In Figure 2 a map is presented for Pest county (one of the nineteen administrative regions of Hungary) indicating the "soil bonitation value" (potential productivity level) categories for the distinguished HunSOTER units according to the Hungarian land evaluation system (Stefanovits, Máté and Fórizs in Várallyay, 1988). In this system the soil bonitation value (land productivity) 0 expresses the lowest and 100 the highest soil fertility in the country.

The "soil bonitation value", B, is calculated as follows:

\[ B = A - (a+b+c+\ldots+n) - R \]

where:
- \( B \) = soil bonitation value,
- \( A \) = starting point, depending on the soil type according to the Hungarian soil classification system,
- \( a,b,c,\ldots,n \) = limiting factors of soil fertility evaluated by a special, experimentally validated point system,
- \( R \) = relief factor (depending on slope gradient and exposure)

All the required input parameters of this land evaluation system are stored in the HunSOTER database as terrain, terrain component or soil component data, or as profile or horizon attributes (for the representative soil profiles). The preparation of such a thematic map is therefore a routine output of the System.

Having – preferably experimentally – validated land-site requirement criteria of a given crop, or even its selected/bred varieties, the land suitability map for that crop can be prepared with the application of the SOTER database. A similar approach was successfully tested within the National Programme for the "Assessment of the Agro-ecological Potential of Hungary" (Láng et al., 1983). Such an evaluation can be the scientific basis for a better territorial co-ordination of the agro-ecological conditions of the country and the agro-ecological requirements of cultivated crops (and their varieties or even ecotypes): rational land use and cropping pattern, regionalization of biomass production, crop rotation, etc., favourable for crop production, soil and water conservation and environment protection.

2. Vulnerability of land and susceptibility of soils to various degradation processes

(State Of The Hungarian Environment, 1991; Szabóks and Várallyay, 1978; Várallyay, 1989a, 1991)

These case studies are illustrated (as potential possibilities) on the four "sub-windows" of the map, shown in Figure 3:

a) Vulnerability of soils to water erosion (Stefanovits, 1964; Stefanovits and Várallyay, 1992).

In this system the following land characteristics are taken into consideration for the water erosion risk assessment (either as causative or influencing factors):

- climate – weather characteristics (rainfall distribution, frequency and intensity of heavy rains);
- relief characteristics (slope gradient and slope morphology);
- erodability of soil (texture, compactness, porosity, state of soil structure; infiltration rate, permeability; depth of the soil and water storage capacity);
- density, type and duration of vegetation (land use, cropping pattern, natural vegetation).

The vulnerability of soils to water erosion is demonstrated for a representative part of the country in Figure 4.

b) Vulnerability of soils to wind erosion (Stefanovits, 1964).

In this system the influencing factors are the wind characteristics; stability and morphology of soil surface; soil texture, structure, compactness and organic matter content; and type of vegetation cover.

The vulnerability of soils to wind erosion is demonstrated for a representative part of the country in Figure 5.

c) Susceptibility of soils to acidification (Várallyay et al., 1993b).
In this system the different susceptibility categories depend on the parent material, present soil reaction and carbonate status, texture, organic matter content and soil depth (determining the buffer capacity of the soil). The susceptibility of soils to acidification in Hungary is indicated on the map in Figure 6.

d) Hazard of secondary (human-induced) salinization/alkalization (Szabolcs, 1974).

In this system – in addition to climate characteristics (especially aridity: the ratio between potential evapotranspiration and atmospheric rainfall) and the character of field water balance – soil properties (present pH, salinity profile, salt composition and ESP; texture, structure, rate of swelling-shrinkage phenomena, infiltration rate, saturated and unsaturated hydraulic conductivity) and groundwater characteristics (average and temporal variability of the depth of the water table; salt content, salt composition, pH, and SAR of the groundwater) were taken into consideration.

On the basis of this concept the vulnerability of soils to salinization/alkalization in Hungary is presented for a salt-affected region in Figure 7.

The definition, dimension and criteria of the various susceptibility/vulnerability classes and the methods of their determination are described in detail in the relevant publications of the above-mentioned authors.

Most of these required input data can be found in the HunSOTER database or in the attached climate and hydrology data files; or they can be derived from these data. Similar sensitivity analyses can therefore be extended to the whole country and to other soil degradation processes and soil pollution risk assessments. (Várallyay, 1991).

Conclusions

The HunSOTER case study presented here and our SOTER application experiences can be directly used or adapted (with minor modifications) in many countries of the world existing under similar natural conditions and socio-economic circumstances. The Project might be extended in the future to establish a regional SOTER Centre at RISSAC (Budapest, Hungary) for the elaboration of a series of GIS-based "SOTER expert systems" for various practical applications. It could also be used to train scientists from Central and Eastern Europe in the SOTER concept and in the compilation, interpretation and multi-purpose utilization of the SOTER database, as well as to co-ordinate and harmonize SOTER activities in the region.

The first step within this plan was a Regional Training Workshop for the Central and Eastern European countries on the concept, establishment and multi-purpose applicability of SOTER database (RISSAC, Budapest, 14-16 June, 1995).

References


Figure 1:

PERCENTAGE OF THE DOMINANT SOIL TYPE WITHIN THE SOTER UNITS
Figure 2:

SOIL EVALUATION IN PEST COUNTY
ACCORDING TO THE HUNGARIAN LAND EVALUATION SYSTEM
Figure 3:

VULNERABILITY OF SOILS
TO VARIOUS SOIL DEGRADATION PROCESSES

LEGEND:
- Water erosion
  - non to slight
  - moderate
  - severe
- Soil erosion
  - non to slight
  - moderate
  - severe
- Acidification
  - strongly acidic
  - severe
  - moderate
  - slight
  - non
- Soil erosion
  - non to slight
  - moderate
  - severe

Uniform National Projection

COMPILRED IN RISSAC GIS LAB IN 1995
BASED ON HUNSOFTER DATABASE

160
Figure 4:

VULNERABILITY OF SOILS TO WATER EROSION IN HUNGARY

1:750,000

- MAJOR RIVERS
- DEGREE OF HAZARD:
  - NON TO SLIGHT
  - MODERATE
  - SEVERE
- MAJOR LAKES

COMPiled in RISSAG GIS lab based on MUNISOTER DATABASE
VULNERABILITY OF SOILS TO WIND EROSION IN HUNGARY

LEGEND:
- MAJOR RIVERS
- DEGREE OF HAZARD
  - NON TO SLIGHT
  - MODERATE
  - SEVERE

Uniform National Projection

0  10  20 Kilometers
Figure 6:

SUSCEPTIBILITY OF SOILS TO ACIDIFICATION IN HUNGARY

LEGEND:
- Major rivers

DEGREE OF HAZARD:
- Strongly acidic soils
- Highly susceptible soils
- Medium susceptible soils
- Moderately susceptible soils
- Slightly susceptible soils
- Non susceptible soils
- Major lakes

Compiled in RISSAC GIS Lab in 1998
Based on Hunsoter database

0 50 100 Kilometers
VULNERABILITY OF SOILS TO SALINIZATION-ALKALIZATION IN HUNGARY
Introduzione

Il sistema di informazione del suolo è il natural development e updating tool per il programma di indagine del suolo della Lombardia. È collegato con gli altri tre settori del programma (classificazione e mappatura, interpretazione, disseminazione) e favorisce l'integrazione dinamica di tutti i settori.

Il sistema di informazione del suolo della Lombardia (LOSIS) dovrebbe aiutare a migliorare le procedure del personale tecnico coinvolto nel progetto, e aumentare l'infiltrazione e l'efficacia dei dati pedologici forniti ai ricercatori.

Alcuni esempi concreti di applicazioni di LOSIS sono:

- Gestione di archivi prodotti dalle indagini sul suolo;
- Manutenzione e aggiornamento dei modelli interpretativi e delle proprietà del suolo visti in questi modelli;
- Produzione di mappe tematiche e distribuzione su supporti digitali e di rete.

Il struttura LOSIS è utilizzata in ogni area di indagine del suolo e costruita su basi semantiche e geometriche (Jamagne et al., 1993) che sono connesse attraverso di essa. Il metaphorbase del LOSIS registra i contenuti di dati immagazzinati e le regole che supportano la loro implementazione.

Il base semantiche

La base semantiche o, in certi documenti, l'elemento alfanumerico è parte del LOSIS che descrive e archivia gli oggetti che processano e documentano i risultati dell'indagine del suolo:

1. Unità di campionamento: queste sono osservazioni punto-per-punto – profili del suolo che sono descritti e campionati – e controllo dei controlli perforato. Un foglio di campionamento è riempito con vari gradi di accuratezza a seconda del tipo di osservazione. Il manuale di compilazione è stato recentemente distribuito per quello che è attualmente definito Version 2 del modulo. L'analisi e l'ingegneria del sistema hanno portato alla riduzione dell'ambiguità di alcune definizioni, e quindi è pianificato un Version 3 del modulo e del manuale, presumibilmente a coincidere con l'indagine dell'area successiva.

Più di 1500 profili del suolo sono già stati archiviati in LOSIS. Circa il doppio di questo numero sarà utilizzato come fonte di dati alla fine del primo ciclo di indagine del suolo semi-detaillato delle pianure.

Controlle osservazioni non sono state inserite nel computer. Questa operazione dovrebbe essere preceduta da un'analisi per determinare se tale procedura è utile per aumentare la qualità e la consistenza dei dati di input.

2. Unità taxonomiche (TU): queste unità sono l'application of the Soil Taxonomy (Soil Survey Staff, 1975) a copertura del suolo regionale. In ogni area la definizione o l'identificazione di una TU significa riconoscere un particolare tipo di suolo all'interno di una famiglia fornita dal sistema taxonomico di riferimento. Specifici lineamenti e procedure normali limitano la naturale proliferazione di TU, la cui identificazione è meno rigorosa di quanto previsto per il livello taxonomico di serie (Soil
Survey Staff, 1975), as was illustrated in an AIP (Italian Pedologists Association) workshop discussing the problem (AIP, 1995). At present there are 667 TU identified within the framework of 402 Soil Taxonomy families. A TU is formally described with a special form in each area in which it is discovered or established. These forms, which are entered in LOSIS, make up the TU database.

3. **Mapping Units (MU):** these units are the result of the modelling and mapping of regional soil cover, of which there are high, medium, and low-resolution examples. The most consistent database is the medium-resolution one, meaning the units connected to the semi-detailed survey. All MU identified in a survey area constitute a legend for the soil map of the area. On a semi-detailed scale, MU are commonly identified and named using phases of the Taxonomic Units referred to in paragraph 2). Mapping Units that are identified and approved for the published legend are formally described according to a manual, which is in its third version, and a database is compiled. The manual lists different procedures for describing the MU according to the scale. At present more than 1,100 MU have already been stored on a semi-detailed scale. Several MU may have the same name and be found in more than one area. The group of databases compiled for each area constitutes the general database for the semi-detailed mapping units.

There are 168 MU recorded in the reconnaissance scale that have been identified through associations of Soil Taxonomy subgroups. The data describing the units is inserted, according to the manual mentioned above, in the parts that specifically concern this survey scale.

The schematic scale identifies 16 mapping units (Previtali and Rasio, 1993) constituted by phases of Soil Taxonomy suborders. The relative data available for consultation and manipulation concern classification and a brief evaluation, in tabular form, of the productive, protective, and ecological value of the dominant soils in each unit.

4. **Regional Soil Catalogue:** this is a brief repertoire that may be arranged according to user preferences. It contains all the taxonomic and mapping units found in the semi-detailed mapping program. Created and designed as a catalogue (Rasio, 1988), it has gradually turned into an integral collection of taxonomic units and relative soil profiles (taxonomic section); of mapping units and documented inclusions recorded in various areas (mapping section); and of variations that the types have undergone over time (historical section). The system administrator directly updates this database.

These four databases are linked with each other. Precise procedures, which are listed in the reference manual for each database, describe the relations between each archive and explain how modified data affects the other archives. The regional soil catalogue, which was described last, was the first to be designed and managed by computer. It may be used to manage and monitor the other three databases.

The engineering and standardizing procedure phases were preceded by an analysis of semantic data, which permitted configuration of the conceptual scheme used to link the various entities in the archives. The entities are described with entries and code numbers contained in data dictionaries, which are an integral part of the reference manuals.

### The geometric element

This base is managed through ARC-Info, which is widely used and adopted as a standard for Regional Official GIS (ROGIS). The geometric base permits geo-referencing of objects in the semantic base through the following databases:

1. **Soil Polygons:** all soil polygons are digitized in each surveyed area. The content of these polygons is identified by a precise mapping unit described in the area and listed in the legend. Using a technical language, the mapping units may be defined as instances and the polygons (in soil mapping the delineations) as occurrences. An order number is given to each polygon related to its specific location.

The digitized polygons on the database number 6,186 at the reconnaissance scale, more than 4,500 at the schematic scale, and 98 at the semi-detailed scale.
2. **Miscellaneous Area Polygons**: these are also called non-soil areas and correspond to bodies of water, rock outcrops, quarries, dumps, etc. These polygons are treated separately from soil polygons in the geometric base.

On a schematic scale (Version 2) and on a reconnaissance scale, the topographic base, which is perfectly consistent with a base on a scale of 1:300,000 that was prepared for ROGIS, is able to completely identify these miscellaneous areas without having to connect them to a specific database. On a semi-detailed scale, these polygons are consistent and complementary to soil polygons, within the so-called “soil layer”. Consistency between soil cover and non-soil areas, as treated in the geographical base taken from the Regional Topographic Map at scale 1:10,000, must still be set up and engineered.

3. **Soil Survey Areas**: each survey area has an ID number and a boundary that distinguishes it from the others in the regional frame (Bornand et al. 1994). Thirty-eight soil survey areas have been established on a semi-detailed scale, while there are two on a reconnaissance scale. The entire region is covered on a schematic scale.

The conceptual scheme was prepared after an analysis of geometric base data and a survey taken of possible LOSIS users. This scheme, which is based on the Geo-Er model (Pelagatti, 1993), portrays the relations of this element on a semi-detailed scale with the other elements in ROGIS. As mentioned in paragraph 2, this analysis has still not been engineered. Soil polygons on a semi-detailed scale, although georeferenced according to ROGIS, are consulted and manipulated as an autonomous layer.

### Integration between the two bases and system output

Computer applications link the semantic base with the geometrical base, thereby making it possible to consult and use LOSIS products for practical purposes. Given the present application needs, this link is currently limited to the mapping units database. It works according to two separate procedures:

- through software that links the mapping units and the soil polygons databases
- when pedological polygons are digitized, through compilation of relational tables for legend units, polygons, and the latest properties describing and interpreting soil cover.

Here are some examples of application opportunities provided by LOSIS that may be viewed on the screen or plotted on paper:

- Creation of thematic maps and, more specifically, of interpretative maps. Examples of these maps, in a reduced scale and with graphic simplifications, are published in the soil survey reports (SSR Series);
- Selection of soil polygons of particular interest to the user;
- Application of models and simulations to the soil database, with the production of various scenarios (Strada et al., 1993);
- Overlay mapping of several data layers consistent with LOSIS, generating scenarios useful for planners and decision-makers.

Basically, the two bases may also be linked using sampling units, at least for the units that have been stored in the database. All observation points of the survey program have not been inserted, in fact. Geo-referencing of soil profiles may be obtained through a query to sample forms by geographical co-ordinates.

### LOSIS metadata

Metadata is information about a database, or a portion of it, such a layer, an attribute, or specific features. Metadata tells what the database contains, how accurate the data is, and even how to use it. Any description of where data came from, who worked on it, and what was done to it, is a recording of “metadata”: this is the definition of metadata proposed by Barton (1995).

The LOSIS structure is strongly tied to various soil survey areas and to the different levels of detail used to collect and process the data. The relation between data collected and the status of the survey, when certain methodological standards were operative, is very important. These relations are recorded in a table: the lines represent the survey areas and the columns provide information on methods, rules, and manuals used for data collection, and their updating in each area. The columns list the relative code numbers for each
version of the methodological standards. Many of these codes are coherent with data dictionaries, which are an integral part of the reference manuals for the semantic base.

A LOSIS metadatabase may be operative for just the semantic base (a geometric one must necessarily be structured in coherence with that of ROGIS).

Fundamental elements of this metadatabase are:

- ID numbers for each soil survey area;
- pedolandscape categories and classes in various versions;
- taxonomic classes deriving from the various editions of the Keys to Soil Taxonomy;
- rules for identifying soil moisture regimes;
- survey manuals;
- manuals for filling out mapping unit forms (that include various versions of the interpretative models, rules, and pedo-transfer functions);
- laboratory methods and their significance over time, in relation to the various sampling units;
- mapping generalization rules, that provide a geographical database consistent at the different scales.

**Sustainable land management applications**

LOSIS applications are mainly designed for agriculture, which is required to become more active in environmental protection and to improve production quality. The sector is also faced with the general objective of sustainable production.

LOSIS is applied to zoning the agronomic use of liquid manure on a regional scale. It was combined with the layer that describes the community perimeters of the region. Consequently, several scenarios have been created that may guide and support decisions. At present, zoning subdivides the region into two major classes, with more restrictions for communities that have soils which provide little protection for groundwater. The elements of choice are transparent, and many options were quickly submitted to decision-makers. This is one of the advantages of LOSIS and of a geographical information system in general.

The use of pesticides is controlled in the Regional Plan for the Prevention of Pesticide Risks. Soil data is required for various models that were adopted, at least in the preliminary phase of the plan. LOSIS may be initially used to evaluate the feasibility of various models according to prevailing pedological conditions. Furthermore, the geometric element of LOSIS facilitates geographical representation of output, while mapping unit attributes are directly implemented in pre-selected models. This permits linkage of the models and geographical information systems (Burrough, 1989).

The protection of water resources is a sustainable management objective that is implemented in Lombardy not only for qualitative aspects (see previous examples) but is also implemented with quantitative measures. After a recent deliberation of the regional government, the Area (sub-regional administrative unit) comprised in the land reclamation and irrigation scheme must revise its plans for the use of water resources for agricultural production and for environmental stability. LOSIS is an instrument used for this planning, as established by the agreement between the interested parties. The geometric element of LOSIS and all mapping unit attributes useful for describing the hydro-pedological situation (permeability, drainage, available water capacity, etc.) are transmitted to the Areas for reclassification of their managed and administered territories.

A last example concerns the quality of farming production and, more specifically, the cultivation guidelines for Protected Geographical Indication (IGP) areas. There was a request to improve production in an area primarily used for the production of fresh pears. A procedure for IGP identification has been presented in this area, but producers want to know in advance the restrictions and opportunities for various soil types in the area. Thanks to LOSIS, various options were prepared according to factors that most affect the quantity and especially the quality of production. Areas most suitable for the production of pears according to desired standards of pear farmers were identified, and a precise evaluation of these areas has permitted a rational planning of possible developments for this type of cultivation.

**References**

168


The Lithuanian Soil Database for sustainable Land Use: developments and planning

Summary

The proper study of the terrestrial environment, of which the soil is the principal component, requires the ability to integrate and manipulate a large amount of data from various points of landscape, i.e. spatial data. The Republic of Lithuania is a country situated in the central part of Europe, with an area of 65,305 km\(^2\), 58,794 km\(^2\) of which is covered by soils. The population of Lithuania is 3,751,400. Soils are the main national resource, and because of this, the development of the Lithuanian Soil Database (LTsDB-LTdDB) for sustainable land use is urgently needed.

In view of the very large initial costs of collecting the soil information needed for the Lithuanian Land Resources Information System (LTlrIS-LTzrIS) interactive with a Geographical Information System (GIS) and operating suitable databases, it is highly desirable that all relevant soil data already collected in the country should be stored in a computerized database:

- providing a scientific basis for the most suitable and sustainable use of land in future;
- helping to establish an objective basis for the management of soil pollution by administrators, policy makers, and those responsible for agricultural development;
- helping to set up monitoring and research projects into agro-ecosystems in all parts of Lithuania;
- bridging the gap between scientists, agricultural managers, farmers, and policy makers, and supplying necessary information to assist decision makers.

State of soil survey

The VZI, LZI, LMI and LZUU hold very large soil research, investigation and land use data sets, covering more than 3 million ha and experimental data on plant nutrition and fertiliser application on different arable soils, collected during 35 years of soil survey and research activities. However, none of these institutions has a database to store and manage this valuable information, and a comprehensive computerized soil information system is now needed. This would enable the proper inventory of data quality and timely application of quantitative soil data to the pressing environmental and land use problems which Lithuania confronts today.

Institutional Framework

The State Land Survey Institute (VZI) is one of the national centres of land survey in Lithuania. Its Department of Soil Science is responsible for field soil survey, soil mapping on various scales and land evaluation for the Land Reform now going on in the country. VZI holds soil research by the Lithuanian Institute of Agriculture (LZI), Lithuanian Forest Research Institute (LMI) and Lithuanian University of Agriculture (LZUU).
survey and land use data sets in its archive.

The Agrochemical Research Centre (ATC) of the Lithuanian Institute of Agriculture (LZI) has data and general maps of pH, liming requirements, contents of available P, K (4 phases of investigations), Mg, trace elements, and organic matter.

ATC and other branches of LZI, as well as the Department of Soil Science and Agrochemistry (DAK) of the Lithuanian University of Agriculture (LZUU) have crop yield data from experimental plots of plant nutrition with different levels of fertiliser application.

The Lithuanian Forest Research Institute (LMI) has data sets of research and investigations on forest soils.

Soil is an ever-changing system. The need for new methods of soil research, for new information to be integrated, for socially responsible sustainable development have not only theoretical but also practical sense. In Lithuania there are areas where local soil conditions of drainage, erosion and parent material vary greatly.

In such areas it is not enough to use geographic methods of soil cartography. There is a need to adopt updated soil cartographic methods and terrain modelling. Such a perspective allows a systematic appraisal of soil cover and division of the land surface into integral territorial units (systems) for investigation.

Data type and volume

The VZI, LZI, LMI and LZUU hold soil data collected during the scientific research and survey activities over the last 35 years. This information is stored in the form of maps, tables, diagrams and published papers in archives. VZI had only land use data (in ha) which was stored in the Ministry of Agriculture of Lithuania. The agro-climatic data for the whole area of Lithuania have been collected and stored in the Lithuanian Survey of Meteorology. This information can be used for the application of LTsDB-LTdB by special agreement.

Existing soil data sets

Soil data for Lithuania under the control of VZI, LZI, LMI and LZUU are:

- soil (type and variety) maps at various scales (1:10,000 – about 10,000 sheets for each former farm up to 1991; 1:50,000 – 44 sheets, for each region, 1:300,000 – 1 sheet for the whole country);
- the relief at 1:300,000 scale – 1 sheet for whole country;
- maps of the content of organic matter (1:300,000 – 1 sheet for the whole country and some areas at a scale of 1:10,000);
- soil-agricultural (soil texture, wetness and stoniness) maps at 1:10,000 scale – about 10,000 sheets;
- the Geomorphic map of the land surface of Lithuania at the scale of 1:300,000 – 1 sheet for the whole country;
- general maps of pH and lime requirements, and contents of available P, K, at the scale of 1:10,000 for each former farm until 1991 and (for some areas) Mg and trace elements.

Point analytical data for 7,000 standard soil profiles, and detailed but not standardised soil profile descriptions represent the major agricultural and forest soils covering about 4 million ha of arable land and land under forest in Lithuania. These data describe the main soil properties: particle size distribution (PSD), soil texture (method of N. Kachinsky), pHKCl, organic matter content (OM), exchangeable and potential acidity, content of mobile Al, base content, content of available P, K, and Mg (major plant nutrients), calcium carbonate content.

Also:
- point data of bulk density of soils at 100 points;
- point data of total chemical composition of soils at 200 points;
- point data of chemical composition of clay fraction at 100 points;
- some point data for trace elements – As, Cd, Cr, Ni, Pb, Se, V, Co, Cu, Mn, B, Mo and Zn, also S content in soils.

These data come from over 1 million points located throughout Lithuania (the higher sampling densities were in experimental stations and vegetable and fruit growing farms).

There are also point data of the yield of different agricultural crops and plants from 2,000 experimental sites with different fertiliser application rates on representative soils throughout Lithuania.

Soil and plant nutrition databases

In 1992-1995 an active scientific research programme on Soil Cover Systems of Lithuania to Adopt FAO-Unesco Soil Classification was set up at LZUU. The Scientific Support Group for this programme included soil scientists of VZI, LZI and also LMI. In 1993 the attribute and analytical Database
Lithuanian soil scientists have begun to create a soil profile analytical database. In 1995, using the documents on preparation of EU Soil DB version 3.1, preparation of the main part of Lithuanian Soil Profile Analytical Database (LTspaADB-LTdpaDB) was started. But first there is a need to update it and develop the Lithuanian Soil Database (LTsDB-LTdDB) based on a Geographic Information System (GIS) and at the same time to adopt the legend of FAO-Unesco World Soil Map (1990).

In Lithuania there is ongoing emphasis on rural development and environmental pollution. However, none of the above-mentioned institutions have a DBMS/GIS to store and manage developed PNDB-TBDB version 1.0 and LTspaADB-LTdpaDB databases, land use and environmental information. A soil information system accessed through a user-friendly menu-driven query and retrieval system is needed which would be operated as an on-line service to officers of the Ministry of Environmental Protection and the Ministry of Agriculture and Forestry. Scientists and technical specialists would be able to query the database for information about specific points and areas as well as other soil attribute data.

Future Developments

The strategy of soil scientists in Lithuania is devoted to developing future projects and defining the terms of development of the LTsD-LTdDB, and providing an inventory of soil research and investigations. Our responsibilities are to extend all this through the necessary stages of development:

- logical design and physical design;
- implementation;
- training.

The logical design must be for the overall LTsD-LTdDB attributes and analyses. The main consideration in hardware options of this database is the desirability of the connection directly to Lithuanian Land Recourses Information System (LTrIS-LTzrIS) and GIS, thus avoiding duplication of data and offering output from updated, standardised and coded information.

Pilot Study

Development of the Lithuanian Soil Database (LTsDB-LTdDB) must be introduced in stages. This is in recognition of the fact that many of the relevant data require capturing in computer-compatible format, a task which will take a long time. There is also a need to update soil maps and to do the missing standard soil analyses.

The main objectives of the Pilot Study in Phase 1 are to:

- review available data;
- develop a methodology for geo-referencing data;
- develop routines for database development and data validation;
- test the data capture and the preliminary modelling capabilities;
- test the range and validity of the suitability and risk assessment models;
- test the operation and quality of the system outputs.

Objectives in Phase 2 include:

- undertaking reclamation around the Iganlina Atomic Power Station and areas affected by karst processes in Pasvalys and Birzai regions;
- testing the design of the (LTsDB-LTdDB) with a view to the development of Phase 2;
- training VZI, LZI, LMI and LZUU staff to operate the system.

Modelling capability of the pilot system

The advanced application of the LTsDB-LTdDB/DBM system would be the production of an integrated impacts model. This would embrace interactions of soil properties, climate, crops, and pollutants. The model would address both the long-term impact of pollution and land use strategy – sustainable land use – as well as shorter event-based soil pollution problems. It would be used by experts to interpret and quantify pollution impacts and will form, through scenario assessment, a basis for management strategy formulation and policy discussion.

GIS will enable regionalisation of models to provide the basis for comparing and integrating data at different spatial scales. The integrated impacts model will have modules for suitability and risk assessment and be capable of being linked to larger decision support systems incorporating work in other programmes, e.g. human health.

Future projects will link strongly with VZI, LZI, LMI and LZUU’s corporate policy, which includes the following components:
• to be the national organisations responsible for surveying, documenting, and research for the agricultural and soil resources of Lithuania;

• to contribute to State Environmental Monitoring, being responsible for monitoring of soils and agricultural products;

• to seek to establish a reference base for the assessment of land quality that will provide a scientific base for soil protection and contribute to identifying and solving existing problems of land degradation in Lithuania;

• to contribute a scientific base to ensure adequate food, timber and other land-based needs while maintaining sustainable land use in harmony with, and causing minimum damage to, the environment;

• to strengthen links with policy makers and legislators in Lithuania, the European Union and elsewhere, to assist in policy development in our country and to ensure that policies and legislation are supported by the best available scientific information.

Financial support and consultation

There is a need for financial support and consultation with soil scientists from a country which has a soil research centre, has been mapping soils and is experienced in the systematic collecting and storage of information on soil and site data (including descriptive and analytical information), and which also uses spatial climatic and land use data, has the major national responsibility for soil databases and related geographic information systems. The organization should also be active in research and consultancy, particularly in the fields of soil, hydrological and environmental interpretative techniques and thematic mapping, using a medium-sized land information system of considerable capability.

Assistance would be needed with the pilot studies and successful implementation of the pilot system, as would further involvement with Phases 2 and 3. There is an urgent need to consult with soil scientists and specialists of a country experienced in developing relational database management systems and GIS systems for soil and land data in Europe based on the Users Guide for the Elaboration of a Soils Geographical Database of Europe, version 3.1 (Daroussin et al., 1995) and Soil Profile Analytical Database for the European Union (Madsen and Jones, 1995).

Training

Training of VZI, LzI, LMI and LZUU staff in the operation and application of the DBMS and (LTsDB-LTdDB) would be a major element in the work of the soil scientists. GIS and DBMS/computer specialists from the consulting country would provide practical in-service training as a forerunner to formal training, so that within the life of the co-operation, VZI, LzI, LMI and LZUU would become proficient in the expertise needed to operate LTsDB-LTdDB DBMS and GIS in the Lithuanian Land Resources Information System (LTlrIS-LTzrIS) for long term.

The main components of the training programme would be:

• soil classification problems;

• data collection, storage, retrieval and manipulation within the framework of a computerised database;

• map digitization or scanning and vectorization;

• design, operation and updating/improvement of the LTsDB-LTdDB.

Use of the Lithuanian soil database

The establishment of the Lithuanian Soil Database (LTsDB-LTdDB) as a part of Lithuanian Land Resources Information System (LTlrIS-LTzrIS) will provide decision support for planners, policy makers and specialists, guiding them towards the best strategy for use and proper management of arable land and better protection of the environment in Lithuania. It will help to:

• develop a code of good management practice leading to the establishment of sustainable and improved land use systems;

• show the regions of high environmental risk and to develop an action plan for reclamation of degraded agro-ecosystems in Lithuania.

Specific needs include the adoption of the FAO-Unesco World Soil Map (1990) legend, and other purposes are:

• soil consolidation, protection of land from degradation, while maintaining productivity and minimising pollution.
Conclusion

It is highly desirable that all relevant soil data already collected in the Lithuania should be stored in a computerised database. The Lithuanian Soil Database (LTsDB-LTdDB) would comprise a national database management system, the Lithuanian Land Resources Information System (LTlrIS-LTZrIS) interactive with a Geographical Information System (GIS) and operating suitable databases.

All the data in the LTsDB-LTdDB need to be geo-referenced and the system fully relational. Then the soil data would be accessible through the geo-reference or any other attribute held within the system. The output of such data is very often required in geographic format, especially by those concerned with planning and policy-making.

References


Using a soil information system to combat soil erosion from agricultural lands in Norway.

Introduction

The Norwegian Institute of Land Inventory (NIJOS) started its soil mapping activities in the early 1980s. The mapping technique used was based on stereoscopic aerial photo interpretations and augerings in the field. The first soil mapping projects included small test areas and agricultural research stations. The development of a Soil Information System with digital map production was initiated in 1988, as a result of a political decision to reduce soil erosion and runoff from agricultural land.

The agricultural areas in southeastern Norway were given the highest priority for soil mapping. The soils in these areas are mainly developed in marine deposits, usually with a high silt content, and are therefore vulnerable to soil erosion. The dominating crops in the area are grains.

From 1988 to the present day, NIJOS has been mapping 30,000 to 40,000 hectares of agricultural land each year. The mapping scale is 1:15,000. The map unit delineations, map unit signatures and soil data, is stored in a ARC/INFO and ORACLE-based information system. Today this system covers close to 3,00 km² agricultural land, which is about 30% of the total agricultural area in Norway.

The Soil Information System at NIJOS consists of a geographical database (map polygons) and a soil data base, which contains a map unit table, a soil type table, and a soil profile table (Figure 1). The map unit table includes map unit signatures with attributes (suitability classes etc.). The soil type table includes soil classification, physical, chemical, and morphological properties, and other parameters derived through pedotransfer functions and models. The soil profile table contains soil profile descriptions and analytical soil data.

One important use of the Soil Information System is to produce tools for the agricultural authorities to use in their task of reducing soil erosion and runoff of soil particles to water from agricultural land. This tool consists of three thematic soil maps derived from the basic soil data. The first, a potential soil erosion risk map (assuming conventional autumn ploughing as the only soil tillage method), shows potential soil erosion risk in four classes (low, medium, high, and very high). This map is based on an adjusted version of the Universal Soil Loss Equation (Hole, 1988). The second map, of soil tillage methods, gives a choice of feasible soil tillage methods as alternatives to conventional autumn ploughing. The model used to derive this map gives a recommendation of soil tillage methods on the basis of soil texture and drainage class (Børresen et al., 1990). The third map, of recommended measures for reducing soil erosion, is derived from the first two maps by combining potential soil erosion with the possibility of reducing soil erosion by changing tillage practice.

Measures against soil erosion in Norway are based on voluntary regulations which are given by “The regulation of government grants for changed tillage practice” (Ministry of Agriculture, 1996a):
The following measures qualify for grants (where the erosion risks are moderate, high and very high):

- Grain and oil seed fields left as stubble during the winter (until 1 March)
- Grass-covered drainage ways
- Use of catch crops.

Grants applications from the farmers are processed by local agricultural offices, with the help of the thematic soil maps received from NIJOS. The grants are differentiated according to the erosion risk classes of the actual fields.

The results from 1989-1996 show a marked increase in stubble-covered areas. The stubble field area left as a result of grants increased from 3,000 ha in 1989 (1% of the total grain area) to about 110,000 ha (31%) in 1996. In addition, stubble areas that are not the result of grants are estimated to comprise about 10%, which brings the stubble-covered area to about 40% of the total grain area. The goal for 1997 was to reach 50% (Ministry of Agriculture, 1996b). The effect of government grants on reducing soil erosion is secured by prioritizing the high erosion risk areas.

Fig.1. A simplified overview of the contents of NIJOS’ Soil Information System.
Figure 2. The use of the Soil Information System in the measures against soil erosion in Norway

References


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MINISTRY OF AGRICULTURE, 1996b: Jordbruksoppgjøret 1996: Endringer i statsbudsjettet for 1996 m.m. Stortingsproposisjon nr 72, 1996.
Creating an FAO-compatible soil map of Poland

Summary

Four versions of the soil map of Poland according with the FAO legend were elaborated during the period 1971-1994. These maps differ in scales and the number of soil mapping units (SMU). The number of SMUs depends on the number of soil typological units (STU), the level of generalisation during presentation of texture and on parent material of soils, as well as on the method of map editing. In general, the smaller the number of SMUs, the poorer the representation of the soil cover characteristics. In order to determine such relations, the four versions of the soil map of Poland were analysed for three test areas with significantly different landscape characteristics.

The analysis was completed with the following conclusions

1. for areas where landscape units are clearly diversified (mountains), the decrease in the number of SMUs has the smallest influence on the quality of soil cover representation;
2. for flat areas with a high degree of heterogeneity of texture and soil moisture, the decrease of the number of SMUs results in considerable deterioration of the quality of soil cover representation;
3. for areas of diversified landscapes, the quality of soil cover representation of the young glacial period depends on the type of terrain morphogenesis.

In general, it turns out that the minimum number of SMUs for Poland should be approximately 60-65.

Introduction

Two terms have been specified for the European Geographical Soils Database: Soil Mapping Units (SMU) and Soil Typological Units (STU). The term ‘Soil Mapping Units’ refers to previous FAO activities which have been related to the Soil Map of the World (FAO-UNESCO, 1975) and corresponds to ‘Associations’, which were specified in the course of these activities. The term ‘Soil Typological Unit’ corresponds to the term ‘Soil Unit’ in the FAO classification.

These terms are described in the User’s Guide for the elaboration of the Soil Geographical Database of Europe (User Guide, 1995) in the following way:

a) SMUs are areas that can be identified and delineated on a map at the scale 1:1,000,000. They are geometrically defined by at least one polygon and are composed of at least one STU.
b) STUs are soil types that can be identified but not delineated within the SMUs due to insufficient resolution. An STU corresponds to a soil type homogeneous for all its characteristics (attributes).

The delineation of SMUs on the map is strongly related to landscape units.

During meetings of national co-ordinators of the European Geographical Soils Database, the number of SMUs for particular countries has been discussed in detail. All participants agreed that it is impossible to specify a number which would be suitable for every country (Varallyay, 1996). This number depends on the size of the country, heterogeneity of the soil cover and the associated number of STUs, the level of knowledge of the soil cover (details of the existing maps), applied methods of map editing, in particular the level of generalisation of contours.
of soil types, parent materials and texture.

For the recent version of the Soil Map of Poland at the scale of 1:1,000,000, which has been produced for the European Geographical Soil Database, the number of SMUs for Poland equals 51, and the average area of a SMU is 6040 km².

Soil maps of Germany (70 SMUs and 5100 km² per SMU) and Spain (24 SMUs and 6527 km² per SMU) have been produced with a similar level of details.

More detailed elaborations have been produced, for example, for Belgium (31 SMUs and 977 km² per SMU), the Netherlands (24 SMUs and 1415 km² per SMU) and Luxembourg (12 SMU and 216 km² per SMU).

After eliminating the factors which are related to the map editing process (as generalisation), a question arises, related to the logical relation between the homogeneity or diversification of the landscape and the number of SMUs. Such a relationship definitely exists. The measure of landscape inhomogeneity should be specified at first. Attempts to apply a logarithmic scale for the needs of evaluation of the level of diversification have been undertaken (Ibanez et al., 1995).

If a relationship between the level of landscape diversification and the number of SMUs exists, the optimum number of SMUs can be specified.

However, the question remains: what is the optimum number of SMUs for a map at the scale of 1:1,000,000? The optimum should provide an appropriate representation of the soil cover characteristics, with due consideration of the state of the art of the cartography.

In order to determine the optimum number of SMUs, four soil maps of Poland, produced in accordance with the FAO legend during the period 1971-1994, have been analysed.

They were the following maps:

<table>
<thead>
<tr>
<th>Created</th>
<th>At scale</th>
<th>SMUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>1 : 1M</td>
<td>85</td>
</tr>
<tr>
<td>1972</td>
<td>1 : 1M</td>
<td>38</td>
</tr>
<tr>
<td>1984</td>
<td>1 : 2M</td>
<td>19</td>
</tr>
<tr>
<td>1994</td>
<td>1 : 1M</td>
<td>51</td>
</tr>
</tbody>
</table>

**Map characteristics**

The first version of the Soil Map of Poland for the future Soil Map of the World was produced in 1971. The Soil Map of Poland at the scale of 1:500,000 was the source material for this map. A Systematic Soils of Poland, in Polish and English, as well as comments on the FAO list of soil units to the Soil Map of the World at the scale of 1:5,000,000, was published in 1970. Soil units, newly introduced by the Systematic Soils of Poland, and corresponding units included in the FAO list, were of great interest.

These circumstances resulted in specification of numerous new units in the legend of the Soil Map of Poland, according to the FAO classification (the idea of SMUs did not exist at that time); the total number of units equalled 85; thus the number of specified units exceeded by 34 the number of units specified for the existing 1:500,000 map.

Co-ordinators of the Soil Map of Europe pointed out that this number was too large with respect to neighbouring countries and they recommended a decrease in the number of units. As a result, some similar units were merged.

Unfortunately, the merging of units was of too large an order to reach the number of 38 units (although this number of 38 units was rather arbitrary).

Generalisation of the soil boundaries required for the new map with 38 units was also too radical. It did not consider characteristic features of landscape within various regions. As a result a map was produced which was too general, and the quality of representation of the soil cover in Poland was inadequate.

When it turned out that the Soil Map of Europe would not be published because of financial constraints, the authors published an extensive commentary to the FAO list of soil units and the map of scale 1:2,000,000 (Dobranski, 1984) which covered the territory of Poland. Only typological units were specified in the legend of this map, since parent materials, texture and typography could not be considered at this scale.

In 1992, when the decision to include Central and Eastern European countries in the European Geographical Soils Database was made, the Polish co-ordinator initiated works which aimed at amending the materials prepared in 1972 for the Soil Map of Europe. It became clear in the course of these works that, in practice, a new map should be produced that would meet the requirement of unification of attributes within STUs and that would better relate the SMUs to landscape characteristics. These new requirements could not be met using the map produced in 1972, because only 38 different soil map units are specified in it.

Thus a new map was produced in 1994 which identified 51 units. The Polish version of this map was produced at the same time for the National Atlas (Bialousz, et al., 1995).
After this map was completed, critical consideration of this map and its utilisation for the MARS and CORINE projects, as well as for the harmonisation of border regions with neighbouring countries, was critically appraised.

It turned out that in selected areas of Poland, the level of detail of physical characteristics of soil and landscape attributes should be greater.

The question still remained: how many SMUs should be specified for Poland in order to represent the soil cover characteristics accurately?

**Analysis of maps**

Portions of the four previous maps of Poland cover three distinctly different landscape types. These are:

- mountainous landscape and old sedimentation basins in the south of the country;
- areas of old glaciation, flattened as a result of periglacial processes and Holocene accumulation;
- areas of young glaciation, with hills and the system of tunnel-valley lakes and fields of fluvioglacial accumulation.

Within the areas of mountainous landscape, Lithosols, Rankers, Dystric Cambisols, Calcaric Cambisols and Fluvisols SMUs are found. Within the old sedimentation basins, the dominant soils are Rendzinas and Haplic Phaeozems.

The area is almost lithologically uniform in the mountainous part (Flysch and granites). The number of SMUs is determined by the slope patterns and the density of river valleys.

The smaller number of SMUs employed on maps produced in 1972 and 1984 did not therefore result in any considerable loss of detail in the representation of soil cover for these areas. The main differences in the 1994 representation are the result of generalisation in river valleys. This also resulted in a decrease in the number of areas of Fluvisols on the maps which were produced in 1972 and 1984.

In the case of old sedimentation basins, the main factors which influenced the soil cover are the geological formation of calcareous rocks and the level of loess cover. As in the mountainous areas, differences in the representation of loess cover results mainly from the generalisation of boundaries.

Thus, for the areas located within this part of Poland, which are characterised by clear landscape

<table>
<thead>
<tr>
<th>SMU</th>
<th>Number of SMUs on analysed maps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1971 (85 SMUs)</td>
</tr>
<tr>
<td>Lithosols</td>
<td>3</td>
</tr>
<tr>
<td>Rankers</td>
<td>1</td>
</tr>
<tr>
<td>Dystric Cambisols</td>
<td>3</td>
</tr>
<tr>
<td>Calcaric Cambisols</td>
<td>2</td>
</tr>
<tr>
<td>Fluvisols</td>
<td>2</td>
</tr>
<tr>
<td>Rendzinas</td>
<td>3</td>
</tr>
<tr>
<td>Haplic Phaeozems</td>
<td>1</td>
</tr>
</tbody>
</table>

The number of units, distinguished in particular maps, was as follows:

Within the areas of old glaciation the landscape characteristics are mainly influenced by glacial, proglacial and contemporary river valleys, wide fluvioglacial and glacial terraces and flat areas located between river valleys with dense and random drainage systems.

Parent materials of the soils are sands, sands over loams, sandy loams and thin layers of silts over sands or loams. The parent materials and texture of soils show considerable variation within these areas.

Cartographic units which influence the soil cover characteristics are:

1. Fluvisols, Fluvic Gleysols, Gleysols and Histosols in proglacial and contemporary river valleys,
2. Stagnogleyic Luvisols, Podzoluvisols and Leptic Podzols within areas located between river valleys,
3. Leptic Podzols and Orthic Podzols, within areas of fluvioglacial accumulation.
The number of SMUs, distinguished in particular maps, is as follows:

<table>
<thead>
<tr>
<th>SMU</th>
<th>Number of SMUs on analysed maps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1971 (85 SMUs)</td>
</tr>
<tr>
<td>Fluvisols</td>
<td>2</td>
</tr>
<tr>
<td>Fluvic Gleysols</td>
<td>2</td>
</tr>
<tr>
<td>Gleysols</td>
<td>4</td>
</tr>
<tr>
<td>Histosols</td>
<td>2</td>
</tr>
<tr>
<td>Stagnogleyic Luvisols</td>
<td>8</td>
</tr>
<tr>
<td>Podzoluvisolis</td>
<td>14</td>
</tr>
<tr>
<td>Leptic Podzols</td>
<td>8</td>
</tr>
<tr>
<td>Orthic Podzols</td>
<td>3</td>
</tr>
</tbody>
</table>

For these areas, five SMUs for Stagnogleyic Luvisols, five SMUs for Podzoluvisolis and three SMUs for Gleysols are considered as almost sufficient for a 1:1,000,000 scale map.

However, it is necessary to increase the number of SMUs for Fluvisols, Fluvic Gleysols and Leptic Podzols, since, for the current number of SMUs, it is impossible properly to represent per-cent changes of STU within corresponding SMU.

Fourteen SMUs for Podzoluvisolis, which were distinguished in 1971, seems too large a number.

Diversification of cartographic representation of the soil cover for this area is not only the result of varying numbers of SMUs, but also of changes in interpretation of criteria for particular STUs and, to a considerably smaller degree, of generalisation of units.

In general, the representation of SMU groups of the same prevailing STUs is appropriate on maps produced in 1994, and the soil cover characteristics are represented properly by these maps, but in order to achieve better representation of the diversification of the various STUs, parent materials and texture, several new SMUs should be distinguished.

For areas of young glaciation (Vistulian), the main elements of the landscape are latitudinal belts of terminal moraines, hilly areas of ground moraines with random outflow and cavings without outflows. These remained after the outflow of waters from dead ice filled longitudinal gullies with water and glacial sands, as did the large fields of fluvioglacial sands located in the south around terminal moraines.

High horizontal and vertical diversification of parent materials, soils and texture occurs. The main characteristic typological units for this area of Poland are Cambic Arenosols, Eutric Cambisols, Stagnogleyic Luvisols, Leptic Podzols and Histosols. The Orthic Podzols unit occurs at the Southern edge of the area, in uniform and poor fluvioglacial sands, in the final stage of deposition. River valleys are not clearly formed, so there are few Fluvisols.
The numbers of prevailing SMUs, distinguished in particular maps are as follows:

<table>
<thead>
<tr>
<th>SMU</th>
<th>Number of SMUs on analysed maps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambic Arenosols</td>
<td>2</td>
</tr>
<tr>
<td>Eutric Cambisols</td>
<td>3</td>
</tr>
<tr>
<td>Stagnogleyic Luvisols</td>
<td>6</td>
</tr>
<tr>
<td>Leptic Podzols</td>
<td>6</td>
</tr>
<tr>
<td>Orthic Podzols</td>
<td>3</td>
</tr>
<tr>
<td>Histosols</td>
<td>2</td>
</tr>
</tbody>
</table>

Cambic Arenosols 2 2 2 2  
Eutric Cambisols 3 2 1 2  
Stagnogleyic Luvisols 6 3 1 3  
Leptic Podzols 6 2 1 4  
Orthic Podzols 3 1 1 2  
Histosols 2 1 1 2

Spatial diversification of glacial sands, from which Cambic Arenosols and accompanying Calcaric Cambisols have formed, is relatively high. However, the two SMUs for the 1:1,000,000 scale is sufficient for this group, since these soils are associated with distinct geomorphological units.

On the map of 1994, the number of units representing the combination Be and Lgs is too low, since the three factors which results in variations – Be and Lgs percentage, class of slopes a and b, and textural classes 1,2,3 and 4 – accumulate.

Four SMUs within Leptic Podzols are sufficient, but two units within Orthic Podzols (one for flat areas and one for dune areas) do not allow consistent differentiation of other STUs.

Similarly, the two units within Histosols do not cover all variations.

For this landscape type, it is also very important that STUs of different morphogenetic features – and with various trophic characteristics and water relations – are not merged during generalisation. Otherwise, the belt system of landscape units will disappear, as happened on the map of 1972.

**Conclusions**

The number of 38 SMUs used on the map of Polish soils produced in 1972 is definitely too small for the proper representation of soil characteristics of Poland at the scale of 1:1,000,000. The generalisation of contours on this map is too generalised.

The number of 19 SMUs on the map of 1984 is almost optimum for the scale of 1:2,000,000. The number of 85 SMUs on the map of 1971 is close to the optimum for the majority of soil types, but it is too large for the following types: Luvisols, Stagnogleyic Luvisols and Podzoluvisols. The number of 51 SMUs on the map of 1994 allows proper representation of the soil cover for areas of distinct landscape diversification such as mountains and old sedimentation basins, but it is too small for areas of large vertical and horizontal diversification of soil parent materials and texture.

The results of this analysis and the efforts made to harmonize SMUs for border areas with those of surrounding countries indicate that the optimum number of SMUs for a soil map at 1:1,000,000 scale is 60-65.

**References**


Romanian Soil and Land Information System – an overview

Introduction
The Romanian Research Institute for Soil Science and Agrochemistry has developed a soil/land information system which is used in research activity, and for studies on Romanian land at national, district/zone and local levels for: land evaluation, land use planning, formulating recommendations for soil/land improvement/reclamation, pollution control, assessing technological cropping methods, etc. The development of this system has passed through different stages (Vlad et al., 1986, 1988, 1992) and took into consideration other earlier works concerning data processing on soil profiles and land units (Canarache et al., 1981; Teaci, 1980).

The present system operates on three levels (Figure 1):
- national level (implemented at the Research Institute for Soil Science and Agrochemistry) for research purposes, national-level decision support and special studies;
- district level (to be implemented at the district agricultural departments) – for district-level decision support;
- sub-district level (to be implemented at sub-district agricultural centres) for local-level decision support and advising farmers.

All system levels are built with a common structure, having common modules and specific modules, as required. The structure of the national level (the most complete) is presented in Figure 2. Each of its subsystems is presented in the following. The different components (which are or will be more or less interconnected) are implemented on personal computers or, some of them, on a Coral 4021/4030 minicomputer (DEC PDP-11 compatible) under an RSX-11M operating system.

Soil Analysis Subsystem

Primary processing of analytical data.
(Basic and F77 programs on PC or minicomputer.)

The main functions are: calculating parameters from measured data and reports printing. Data acquisition may be manual and automatic (analytical instruments with incorporated computer). The analysis reports provided are: particle-size distribution, physical parameters “in cylinders”, chemical parameters, etc.

Soil Micromorphology Image Analysis

The image processing software used is IDRISI on PC. The applications are:
- image classification (identification of micromorphology elements): void shapes (irregular, circular, elongated), soil aggregates, soil pedofeatures (nodules, coprolites);
- image quantification (distribution of micromorphology elements) on shape and size.

Experimental Data Subsystem

The main interest has been on Management and Statistical Processing of Experimental Data. A software package – STATIS (Basic programs on PC) has been elaborated for this purpose (Motelică et al., 1994). It is oriented towards soil/agricultural
experiments and provides the following functions:

- data management (experiment-oriented): data entry, updating, display, conversion and printing;
- descriptive statistics;
- regression analysis (24 regression equations using the least squares method);
- analysis of variance (9 ANOVA models): one/two/three way, randomised block design, split plot design, Latin square; field/greenhouse experiments may all be taken into consideration.

Point Databases

Database of Soil Profiles (PROFISOL).

(F77 programs on minicomputer and Paradox 3.5 application on PC.)

The provided functions are (Canarache et al., 1997a; Vlad et al., 1997b):

- Data entry/updating/retrieval: for each profile: 31 general data (identification, location, etc.), 64 land data, 12 profile morphology data, analysis method for each analytical parameter; for each horizon (of 10 possible): 135 data on profile horizons and morphology, 41 physical data, 34 chemical data; for groundwater: 13 chemical data;
- Data validation (type, codes, coherence, etc.);
- Calculation of input data (if missing): for each horizon: 12 physical data;
- Calculation of new data (not input data): for each profile: 12 profile morphology data (stored data); 4 land data (stored data); for each horizon: 20 physical data and 8 chemical data;
- Calculation of data for pre-defined depths (various combinations of layers of 10, 20, 50 cm depths): for each horizon: 48 physical data;
- Statistical processing on groups of profiles: for each pre-defined depth – for each of 26 physical properties: 8 statistical parameters;
- Transformation of measuring units: for each horizon: 8 physical data;
- User reports printing: directory of database; data dictionary of database; for each profile: 8 reports; for each group of profiles: 4 reports;
- Management of codes dictionaries.

Stored data: over 4,200 soil profiles, of which: all profiles have general and physical data (ca. 200), over 450 profiles have also chemical data (ca. 125) and over 170 profiles have all types of data (ca. 1000); acquisition period: 1965-1996.

Database of the National Integrated Soil Monitoring System

This database contains soil profile data as defined in the PROFISOL database and an extension with geochemical data: for each horizon 8 geochemical data (total forms of heavy metals). Data on about 1200 profiles (ca. 200 data/profile) have been stored. Data processing (Quattro-Pro, Excel) on groups of profiles provide 7 statistical parameters, abundance classes based on frequency histogram, geochemical threshold, abundance index (local, zone), loading/pollution index, etc. (Lácástus, 1997).

Pedo-GeoChemical Database

(Paradox 3.5 application on PC)

This database (Lácástus and Lungu, 1997) contains soil profile data as defined in the PROFISOL database and an extension with geochemical data: for each horizon 8 geochemical data (total forms of heavy metals). Data on about 1200 profiles (ca. 200 data/profile) have been stored. Data processing (Quatro-Pro, Excel) on groups of profiles provide 7 statistical parameters, abundance classes based on frequency histogram, geochemical threshold, abundance index (local, zone), loading/pollution index, etc. (Lácástus, 1997).

Micro-organisms Database

(Paradox 3.5 application on PC).

This database is MINE (Microbial Information Network Europe) compatible and is used as a specialised extension of the PROFISOL database. The provided functions are (Tapalană et al., 1997c):

- Data entry/updating: 19 data on nomenclature, 12 data on
Land units databases

Database of land units at 1:50,000 scale

(Paradox 3.5 application on PC.)

This database (Tapalagă et al., 1997a) contains the following main data:

- Homogenous land units characteristics: 2 land unit identification data, 4 relief data, 8 climatic data, 4 groundwater data, 2 parental rocks/material data, 4 soil taxonomy data, 24 soil data, 12 technological characterization data, 25 current land suitability indices (for 25 crops and land uses), 25 potential land suitability indices (for 25 crops and land uses);
- Land units (sub-units) areas, referring to: district, sub-district (commune), owners’ group, 7 land uses, homogenous land unit, main river basin;
- Synthetic data at sub-district (commune) level: for each of 4 land uses and total agricultural: land area, mean current land suitability index, mean current land suitability class.

Stored data: the whole agricultural land of the country (over 125,000 homogenous land units); acquisition period: 1953-1975.

Pre-defined functions (menu driven) provide data retrieval/selection (various criteria) and reports printing.

Database of land units at 1:10,000 scale

(F77 programs on minicomputer.)

This database (Marian et al., 1997) contains the following main data:

- Homogenous land units characteristics: 3 land unit identification data, 4 relief data, 4 climatic data, 3 hydrology data, 4 soil taxonomy data, 22 soil data, 2 anthropogenetic parameters;
- Land units (sub-parcel) areas, referring to: district, sub-district, farm/production unit, 6 land uses, cadastral parcel, homogenous land unit, planned land reclamation works;

Stored data: over 35% of the agricultural land of the country (over 40% of the arable land); acquisition period: 1980-1996.

The functions provided are:

- Data entry/validation;
- Data retrieval/updating;
- Calculation of land suitability (parametric-multiplicative method): for each of 25 crops and land uses: current suitability index, current potential suitability index, ideal potential suitability index;
- Calculation of 8 parameters for technological characterisation;
- Data aggregation (areas, averages of land suitability);
- 15 reports printing.

Database for monitoring main soil agrochemical qualities

(Paradox 3.5 application on PC.)

This database (Tapalagă et al., 1997b) contains the following data: for each district: areas of 5 land uses for 5 quality classes of 5 parameters (pH, N, P, K, humus). Stored data: whole country; Acquisition period: 1987-1995. Provided functions: data entry/validation, data retrieval, reports printing.

Geographical Information Subsystem

(ArcInfo application on Sun Sparc-20 station and on PC; GRASS application on PC.)

Different studies have defined the approach to build a geographical information system for Romanian soil/land resources (Vlad et al., 1989-1990; Vintila et al., 1991; Munteanu et al., 1992-1993; Munteanu and Zota, 1994; Vlad, 1994; Vintila et al., 1994-1996). Up to now, the following layers have been stored (using digitizers and scanners for spatial data entry):

a) Scale 1:1,000,000:
- Districts;
- Subdistricts (attributes: for each of 4 land uses and total agricultural: land area, mean current land suitability index, mean current land suitability class);
- Localities (partially entered);
- Roads (partially entered);
- Railways (partially entered);
- Main rivers and lakes (partially entered);
- Main relief units;
• Eco-regions (attributes: identification, areas on land uses, current land suitability classes);
• Pedoclimatic microzones (attributes: identification, area, climate, relief, soil);
• Soil units.

b) Scale 1:500,000:
• Vegetation (partially entered).

c) Scale 1:200,000:
• Soil units: (25% of the area of the country entered; attributes: erosion, gleyzation, salinization, texture, etc.; different thematic maps and areas on soil types and characteristics classes have been obtained);
• Soil-terrain, according to ROMSOTER-200 (Munteanu et al., 1997), an adapted SOTER methodology (attributes: 16 general data, 32 soil mapping unit data and soil typological unit data and 78 soil profiles data; different pilot areas have been used for applications to obtain thematic maps).

d) Scales 1:10,000 and 1:25,000:
• Land Units (different land characteristics have been taken into consideration; different pilot areas have been tested; some pilot tests have been carried on concerning classification and integration of remote sensing images in GIS).

Applications

Modelling/Simulation

(Soil water dynamics and crop yield formation)

Land evaluation expert system ExET:

This application implements on PC (Vlad et al., 1997a) the Romanian land evaluation methodology for natural conditions (parametric-multiplicative method) using the ALES expert system shell (Rossiter, 1990) and, for some extended functions, C++ programs. The application can use the data from the database of land units at 1:10,000 scale. The evaluation of land units (homogenous or compound) is performed for 24 crops or land uses – taken into account 23 primary land characteristics. Physical suitability subclasses (FAO), physical suitability indices (Romanian methodology) and economic suitability (based on gross margin and a reference technology of medium-current level in Romania) are provided.

Computer-aided diagnosis of nutritional disorders in crops.

(Paradox 3.5 application on PC.)

This application implements (Vintila et al., 1994) an empirical (expert type) model concerning about 50 mineral nutrition disorders (deficiencies, excesses and syndromes) for the main annual/perennial crops in Romania. It takes into account 130 visual symptoms, 50 soil conditions, 46 crop management conditions and 18 climate conditions and provides 23 correcting recommendations and 40 preventing recommendations.

SIBIL, SIBQUICK, SOS and other simulation models (EPIC, NLEAP, DSSAT3, CERES, etc.) are used for different predictions and studies.
**Computer-aided technological recommendations:**

a) *Technological recommendations for soil tillage.*
(C++ and Actor programs on PC.)

This application (Canarache *et al.*, 1997b; Vlad *et al.*, 1997c) provides different recommendations based on soil physical properties: equipment type, workability, ploughing type/depth, trafficability, necessity for special tillage works, etc.

b) *Recommendations for fertiliser and liming material use.*
(Basic and Actor programs on PC.)

This application (Budoi *et al.*, 1992; Vlad *et al.*, 1997c), based on empirical/statistical models, provides:

- Economic-optimal rates of fertilisers (N, P, K, manure) to obtain a given yield of a crop (based on soil agrochemical properties, crop/manure in preceding year and input/output prices ratio);
- Rates of micro-elements;
- Rates of liming materials;

c) *Soil Agrochemical Properties Evolution.*
(C++ programs on PC.)

This application (Gavrilita *et al.*, 1997) assesses the evolution of main agrochemical properties of soil (Humus, pH, available P and K), over a time period, with/without fertilisers use.

**Concluding remarks**

For designing a nation-wide soil/land information system, a systematic approach is necessary to avoid having to re-design because of interfacing needs or the necessity of complex conversion programs. Consequently, a design team at system level is necessary to co-ordinate subsystems and software component designing. For development of complex systems/subsystems/applications, an interdisciplinary approach is necessary in most cases.

Good modular structuring of a system/subsystem/application can facilitate the development process, to solve such problems as: utilization requirement changes, development distribution among different people, development team changes (especially during the long period of software development).

Future development of the Romanian Soil/Land Information System will comprise (among others):

- GIS development: soil map and ROMSOTER-200 at 1:200,000 scale; DEM and spatial analysis applications, etc.;
- Modelling/simulation;
- Decision support system for land evaluation and sustainable land use planning (Vlad, 1996);
- Integration of models and decision support systems with GIS.
Figure 1. Levels of the Romanian Soil/Land Informational System

Figure 2. Structure of the Romanian Soil/Land Informational System
References


ROMSOTER-200: a Digital Soils and Terrain Database for Romania

Abstract

ROMSOTER-200 is a digital, nation-wide geo-referenced database of the soils and terrain resources of Romania, built up on the basis of the soil map at a scale of 1:200,000 using ARC/INFO software. It combines the physiographic and taxonomic approaches, and has a hierarchical, integrative structure. The basic area unit is the Soil Mapping Unit (SMU), the second level is the Pedo-landscape Unit (PU), and the third and highest level is represented by the Physiographic Unit, which corresponds to the main Geomorphological Unit for Romania. For the sake of accuracy, each delineation on the map bears a unique identification number in the database.

ROMSOTER-200 is composed of four distinctive compartments:

i. Soils and Terrain Database (area data, attributes);
ii. Points (profiles and horizons) Database;
iii. Methods and Models Database,
v. General Database (e.g. road and hydrographic network, administrative limits, etc.).

ROMSOTER is able to generate new interpretative and thematic maps, for the purpose of deriving some missing soil characteristics. It is also able to supply private and public landowners with cartographic, tabular and statistical data about soils and terrain resources for agriculture and forestry, as well as for the protection of the environment and biodiversity.

As a result of about half a century of continuous and sustained soil survey work carried out in changing circumstances, Romania has built up a valuable pedological information base and a wide range of soil maps at different scales:

• 1:10,000 for about half of farmland (~4.5m ha)
• 1:50,000 for the whole agricultural area (15m ha)
• nation-wide, at scales of 1:200,000, 1:500,000 and 1:1,000,000.

Several small scale (1:500,000-1:1,000,000) thematic or interpretative maps (e.g. soil erosion, excess of moisture, soil salinity, pedological microzones) have been added (Figure 1).

In recent years a Soil Geographical Information System (GIS) at a scale of 1:1,000,000 has been set up (Munteanu and Zota, 1994), and a partly-computerised soil database for agricultural land evaluation at scales of 1:10,000 and 1:50,000, and the soil profile database (Profisol) have been added.
Figure 1: System of pedological maps of Romania

Proper pedological (genetical) maps
- 1:10,000: about 1/2 of arable land (19%) of the country
- 1:50,000: all agricultural land (61% of the country)
- 1:200,000: Danube Delta Biosphere Reserve

Thematic/pedological maps
- 1:100,000: Nation-wide cover
  - Soil erosion, excess of moisture (1:500,000)
  - Soil salinity (1:1,000,000)

Pedoclimatic microzones (1:500,000)

Interpretative pedological maps
- 1:100,000: Nation-wide cover
  - Pedotechnical maps (soil permeability, water storage, resistance to ploughing)

Locally
- Suitability for different soil improvement works, irrigation and drainage, etc. (scales between 1:10,000 and 1:50,000)
Objectives

The main aim of this work was to build up a national digital geo-referenced database of the soils and terrain resources of Romania, taking as a basis the soil map at 1:200,000 scale, using the ARC/INFO GIS package. The database was named ROMSOTER-200 after the Global Soils and Terrain Digital Database SOTER; (UNEP/ISSS/ISRIC/FAO 1995). Because the FAO soil map contains only a limited number of soil characteristics – its units being defined in taxonomic genetical terms – another important aim was to overcome this disadvantage by improving it with relevant data concerning the physical environment, (relief, lithology) and complementing the legend units with soils data, important both for agricultural land use and ecological purposes.

ROMSOTER-200 is intended to meet the needs of land use planning and the management of soils and terrain resources, at national, district (județ) and even communal level. It is well-suited to support the development of a sustainable agriculture as a basis for sound environmental protection. On the other hand, ROMSOTER will provide the necessary data in a digital compatible form for the future European Soil Map at a scale of 1:1,000,000 (Le Bas and Daroussin, 1995) as well as for the Digital Global and National Soils and Terrain Database.

Concepts

ROMSOTER-200 is based on the Romanian experience, (Florea 1994, Teaci 1980, Munteanu 1996) and uses principles and criteria from SOTER and European Soil Data Base at a scale of 1:1,000,000 (Le Bas and Daroussin, 1995). Like SOTER it is based on the unanimously accepted concept that soil and terrain represent a single entity that incorporates processes and systems of interrelated physical, chemical, biological, geomorphological and even social phenomena. These
phenomena influence both the use and evolution of the soils and terrain, as well as of the ecosystems to which they belong. Under the name of “landscape science” this idea has been largely developed in Russia and Germany and subsequently used in the land systems approach developed in Australia (Christian and Stewart, 1953; Cochrane et al., 1981, 1985; Gunn et al., 1990).

In accordance with the approach outlined above, the ROMSOTER-200 database operates with three main spatial concepts, as follows:

**Physiographic unit.**

This is a concept taken from physical geography and represents a large area (usually of several thousands of sq. km) characterised by the predominance of a major type of relief (e.g. mountains, hills, plains, tablelands) that has a relatively unitary geological and geomorphological evolution. Within ROMSOTER-200 the physiographic unit is used as a basis for the regional organization of the database and helps to put in context the regional peculiarities of the soils and terrain resources, in relation to the basic characteristics of relief, climate, lithology, land cover and use, and socio-economic features. This kind of unit corresponds roughly to the “Grosslandschaft” concept used in German literature. 49 physiographic units have been distinguished over the whole of Romania (Figure 2).

In the ROMSOTER database the physiographic units have been taken with minor modification from the physiographic maps and given the names commonly used by geographers.

**Pedolandscape unit (Soil and Terrain Community Unit).**

This represents an area that has a relatively uniform or repetitive pattern of landforms and soils, slope gradient, relief intensity, surface lithology, altitude, atmospheric temperature and rainfall. The soil components form a system (pedosystem) with complex interrelationships that reacts in a unitary mode to external (anthropic or natural) impacts. The Pedolandscape units often correspond to simple landform systems – e.g. terraces, alluvial fans, piedmontane plains, low mountains, etc. It correlates partly with the “pediterritory” and “pedosocion” concepts from the Romanian literature (Florea, 1994) and with the “soil community” concept as defined by the Soil Survey Manual (1993).

The reason for identification of the Pedolandscape unit is a result of its usefulness in embracing the interrelationships between soil cover characteristics (properties) and environmental-pedogenic factors. It also facilitates the regional planning of soils and terrain use, and soil and environmental protection that operates within areas larger than those of cartographic mapping units represented on the soil map of Romania at a scale of 1:200,000. The Pedolandscape unit is used for the second level of organization of the ROMSOTER database and is identified and delineated on the soil map by the soil scientist through interpretation of soil cover components and their relationships with the physical environment, mainly terrain conditions.

**Soil Mapping Unit**

This represents the former mapping unit described in the soil map legend 1:200,000 (defined in taxonomic terms), of which the soil components have been complemented with data about environmental factors, and soil characteristics that do not result from the soil name and now called “Soil Typological Unit”. Following this operation, a mapping unit from the original map may now be divided into several soil mapping units. A soil mapping unit may consist either of a single soil typological unit or of a group of similar soils (soil consociation) or of two or many dissimilar soils (soil association). On the map, a soil mapping unit is represented by one or many map delineations (polygons) that are the basic spatial units of the ROMSOTER-200 database.

Both “Soil Mapping Unit” and “Soil Typological Unit” are used with the same meaning as in the European Soil Database.

**Structure**

The ROMSOTER-200 Database is composed of four distinct components:

1. Soil/Terrain Database (area data, attributes) Points (profiles/horizons) Database
2. Methods and Models Database
3. General Database (i.e. road and hydrographic networks, river basins, administrative limits: (communes, judete), agricultural zones, etc.)
I. Soils and terrain Database

This is the core of the ROMSOTER-200 database. Its organization is hierarchical (Figure 3). The basic area unit is the Soil Mapping Unit (SMU). The second level is the Pedolandscape Unit (PLU) and the third and highest level is represented by the Physiographic Unit (PGU). Each delineation (polygon) is given a unique identification number both on the map and in the computer file. The mode of aggregation of the different levels of spatial units (Figure 4) allows either working with all units simultaneously or with each of them independently. At the country level, the spatial, soil and terrain database is organized in both formats: on each soil map sheet 1:200,000 (50 sheets) and on each physiographic subdivision of Romania (Figure 2). The attributes of the spatial units and their components are given in Annex I.

1. The Physiographic Unit (PGU)
   1.1... The Pedolandscape Unit (PLU) (Soil and Terrain Community)
      1.1.1... Soil Mapping Unit (SMU)

Figure 3: Organization of Area and Point (profiles) Database

II. Point Database (profiles and horizons).

This component of ROMSOTER-200 includes all soil profiles that have relevant descriptive and analytical data. There are two categories: soil profiles that belong to the national soil profile database (PROFISOL) which generally have physical data; and other soil profile data which have not been included in PROFISOL. The soil profiles do have descriptive, particle size and chemical data. The first category bears the identification number from the PROFISOL database and the second is identified by two numbers – the sampling number and that given within the soil map sheet 1:200,000. The information assigned to the soil
profile includes: identification number, ID, location, environmental conditions, horizons and morphological, physical and chemical properties.

For each soil profile, the number of horizons is limited to 7 and the depth to 150 cm. or bedrock, whichever is shallower. Each profile/horizon is characterized by two kinds of proformas: measured data belonging to the representative profile of the given taxonomic/typological soil unit, and estimated data, that contains minimum and maximum of each numerical attribute, derived from all existing representative profiles. Both kinds of proforma contain mandatory and optional data. The latter are filled up only if there are measured data. The attributes of profile and horizons data are shown in Annex II.

III. Methods and Models Database.

This database (Figure 5) is a collection of evaluation methods and models for generating thematic/interpretative maps (e.g. soil suitability) and for deriving new, simple or complex soil characteristics (e.g. bulk density, field capacity) from existing data. Each method contains a list of required parameters, models/pedotransfer functions used, and the connection between these data, the pedotransfer functions and the intended results. At this stage the methods database includes the expert systems and methodologies used in Romania for making thematic interpretative maps (e.g. suitability for different crops) and a set of simple models/pedotransfer functions for obtaining missing soil characteristics. Numerical simulation models have not yet been considered.

Methods for generating thematic/interpretative maps

These methods are generally empirical, and are based on selected soil and terrain characteristics, quantified and included in a system of classification related to the given purpose. The most important in use are those that refers to:

- soil suitability for different crops
- soil suitability for irrigation
- soil suitability for drainage
- soil vulnerability to chemical contaminants and to acidification

Besides the above-mentioned methods, an expert system of land evaluation and land suitability for agricultural crops has been developed (Vlad et al., 1996)

Models for deriving additional soil characteristics from existing data.

- Statistical models (of regression type) with value limited by the amount of experimental data used to calculate the coefficient, used for:
  - assessing the field capacity from: texture, bulk density and soil organic matter content
  - assessing hygroscopic coefficient from: clay content, bulk density
  - computing saturated hydraulic conductivity from: texture and bulk density (for mineral soils).

- Semi-empirical models that include both deterministic algorithms and regression equations, used for:
  - computing the resistance to penetration in relation to soil moisture content from bulk density and clay content
  - assessing the range of soil workability (Atterberg plastic limits) using the water retention curve.
  - computing the soil water-retention curve using the Arya-Paris model based on particle size and bulk density

- Analytical models used to
  - describe pedotransfer function (including statistical methods for calculation of analytical equations coefficients) used for:
    - assessing soil water retention curve by the Van Genuchten equation, with parameters estimated on the basis of clay, silt and sand content, bulk density and organic matter content.
    - estimation of unsaturated hydraulic conductivity on the basis of the Van Genuchten equation coefficients for calculation of the water retention curve.
Figure 4: Documentation of methods – meta-information –

For generating thematic/interpretative maps
- expert systems
  e.g. land evaluation & suitability for different crops
- empirical methods
  e.g. suitability for irrigation
  - risk of soil erosion
  - vulnerability to contamination with heavy metals
  - risk of acidification

For deriving additional soil characteristics
- Statistical models of regression type
  e.g. estimation of bulk density
- Semiempirical models
  e.g. assessing range of soil workability
- Analytical models
  e.g. estimation of water retention curve using Van Genuchten equation

Area data (Soil Mapping Unit)

Figure 5: ROMSOTER-200 – Methods and Models Database.
General Database (Supplementary layers)

These represent the spatial reference data necessary to provide an efficient territorial use of information offered by ROMSOTER-200. They are as follows:

- Limits of administrative subdivisions, communes and districts (județe)
- First order hydrographic network and main hydrographic basins
  - Limits of agricultural zones
  - Land cover / land use
  - Limits of ecoregions
  - Main road network
  - Network of meteorological stations
  - Agricultural research stations network

Possible uses of ROMSOTER-200

This is a flexible and easily handled nation-wide digital soils and terrain database. As far as its content and structure are concerned, although somewhat different, these are compatible both with SOTER and the European Soil Database at a scale of 1:1,000,000. Some possible uses for this database are as follows:

- nation-wide and local planning of the use and protection of soil and terrain resources; planning of non-agricultural land use (industry, surface mining, infrastructure, urban and rural development, recreation etc.);
- regional evaluation of land suitability for different crops and uses; estimation of land productivity;
- fundamental programmes and strategies for development of a sustainable agriculture;
- support for national policy on restructuring agricultural land use; set-aside; afforestation;
- assessment of risks to the environment from: erosion, nitrate leaching, pollution with agrochemicals, salinity, compaction, water quality, waste disposal;
- development of regional projects for soil conservation and erosion control; degraded land rehabilitation;
- assessment of soil vulnerability to chemical contaminants; resilience and soil buffering capacity with regard to acidification, desiccation, acceptance of sludge, pesticide toxicity, heavy metal storage capacity;
- estimation of soil water regimes in connection with drainage and irrigation requirements;
- fundamental future strategies with regard to global climate change and competition for land from different sectors of the economy;
- fundamental redevelopment of landscape and wild ecosystems;
- assessment of suitability of lands for ecological habitats, recreation and conservation of biodiversity;
- Romanian contribution for the planned European Soil Map at a scale of 1:250,000;

Case studies

ROMSOTER-200 methodology has been experimentally applied in two areas: Sheet 1:200,000 Arad and the Subcarpathian Hills of Buzau.

The Arad sheet comprises a wide variety of landforms (plains, hills and low mountains) and soils (Chernozems, Phaeozems, Luvisols, Solonetzes, Vertisols, Fluvisols, etc.). The original soil map legend consists of 89 units, defined in taxonomic genetical terms. By converting this map into a soil-terrain format using ROMSOTER-200 rules, 5 Physiographic units and 64 Pedolandscape units were identified.

The final soil mapping units are represented by 1167 polygons (delineations). At the first and second aggregation level new thematic maps, e.g. terrain type, landforms, parent material, etc. are easily issued (Figures 6, 7, 8).
At the third level (soil mapping units), besides soil maps complying with FAO and Soil Taxonomy systems (Figures 8, 9) thematic maps of practical importance, such as slope, topsoil texture and topsoil depth on an impermeable layer, are relevant examples (Figures 10,11,12). As far as derivation of maps with new soil characteristics, obtained using pedotransfer functions at this stage, are concerned, the checking (Figures 13, 14, 15) has been carried out only for the Chernozems and Phaeozems for which analytical soil profile data were available.

References


Fig. 6. ROMSOTER 200
Highis Area - Main Landforms Map
Scale 1: 200,000

Fig. 7. ROMSOTER 200
Highis Area - Parent Materials Map
Scale 1: 200,000
Fig. 8. ROMSOTER - 200
Highis Area - Soil Map
scale 1: 200,000

Fig. 9. ROMSOTER 200
Highis Area - Soil Map
Scale 1: 200,000
Fig. 10. ROMSOTER 200
Highis Area - Slope Map
Scale 1: 200,000

Legend
- 0 - 2 (3) %
- 2(3) - 5 %
- 5 - 8 (10) %
- 8 (10) - 15 %
- 15 - 25 (30) %
- 30 (25) - 60 (50) %

Fig. 11. ROMSOTER 200
Highis Area - Topsoil Texture Map
Scale 1: 200,000

Legend
- Sandy
- Loamy Sandy
- Sandy Loamy
- Loamy
- Clayey Loamy
- Clayey
Fig. 12. ROMSOTER 200
Highis Area - Depth to an impermeable layer - (cm)
Scale 1: 200,000

Legend
- > 150 cm
- 80 - 150 cm
- 40 - 30 cm
- < 40 cm

Fig. 13. ROMSOTER 200
Highis Area - Available water for Chernozems and Phaeozems
Scale 1: 200,000

Legend
- 0.11 w/w
- 0.16 w/w
- 0.17 w/w
Fig. 14. ROMSOTER 200
Highis Area - Field Capacity for Chernozems and Phaeozems
Scale 1: 200,000

Legend
- 0.2 w/w
- 0.24 w/w

Fig. 15. ROMSOTER 200
Highis Area - Saturated Conductivity for Chernozems and Phaeozems
Scale 1: 200,000

Legend
- 2.71 cm/d
- 8.75 cm/d
- 10.46 cm/d
ANNEX I

AREA DATA - ATTRIBUTES

1. PHYSIOGRAPHIC UNIT (PGU) - 49 units
   3 Attributes:
   - No
   - Code
   - Area - km²
     - PC country

2. PEDOLANDSCAPE UNIT (PLU) - (1000 - 1500 units (estimated))
   12 Attributes:
   - No
   - Area - Km²
     - PC/PGU
   - TR - Terrain type - 3 categories (SOTER, 1995)
     (17 categories, first level, 32 categories, second level)
     1 - dominant
     2 - secondary
     Each of landform type is semantic defined and characterised by:
     - general gradient (6 classes)
     - relief intensity (7 classes)
     - dissection (3 classes)
     (3 classes, first level, 21 classes, second level)
     1 - dominant
     2 - secondary
   - Z [min, max] - Absolute altitude (concrete data are recorded)
     min - minimum
     max - maximum
   - DS [12] - Main soils - (39 soil types of the present Romanian Soil Classification)
     1 - dominant
     2 - codominant
   - Tm - Average annual temperature (8 classes)
   - Pr - Average annual rainfall (10 classes)
     - Soil temperature regimes (tentatively)
     - Soil moisture regimes (tentatively)

3. SOIL MAPPING UNIT (SMU)
   The general Legend of the Soil Map 1: 200 000 comprises 471 units defined on taxonomic genetic base. (i.e. Chernozems, Luvisols, a. s. s.). At the country level one expect to have up to 6000 Soil Mapping Units (each legend unit is susceptible to be split in 5 - 15 SMU)
   5 Attributes
   - Number... (in the first phase within the map sheet in the final phase, within country)
   - Code - (i.e. Bd
     - Area - ha
     - PC/ local PGU
     - PC/ country
   For inventory reasons each polygon (delineation) of the soil map is kept in Data Base as an independent SMU, bearing an unique number of identification per sheet/ country.
4. SOIL TYPOLOGICAL UNIT (STU)
21 Attributes

- Soil Typological Unit (number)
- Soil name Romanian classification (symbol)
- Soil name FAO-1990 (symbol)
- Soil name Soil Taxonomy (code)
- Percent of the SMU
- TS\(_{(1,2)}\) - Topsoil texture (six classes)
  1- dominant surface textural class
  2 - secondary surface textural class
- P\(_{(1,2)}\) - Slope (8 classes)
  1 - dominant slope
  2 - secondary slope
- F\(_{(1,2)}\) - Phases (5 categories)
  1 - dominant phase
  2 - secondary phase
- M\(_{(1,2,3)}\) - Parent materials
  (9 categories, first level; 37 categories, second level; 33 categories, third level)
  1 - dominant parent material
  2 - secondary parent material
- E\(_{(1,2,3)}\) - Soil erosion
  1. kind (type) of erosion
  2. affected area (from STU)
  3. erosion intensity
- A - Landslide
  affected area from STU (%) - 5 levels
- AD\(_{(1,2,3)}\) - Anthropic degradations
  1 - strip mining, ballast
  2 - dumps
  3 - wastes, urban garbage
- W - Waterlogging
  \(W_f\) - from ground water (5 classes)
  \(W_s\) - from surface water (4 classes)
- U\(_{(1,2)}\) - Land - use (9 categories)
  1 - dominant landuse
  2 - secondary landuse
- DT - Depth to textural changes (5 classes)
- TD\(_{(1,2)}\) - Subsurface textural class (6 classes)
  1 - dominant
  2 - secondary
- RO - Depth to an obstacle to roots (4 classes)
- IL - Presence of an impermeable layer (4 classes)
- WR - Dominant annual average water soil regime (4 classes)
- LI\(_{(1,2,3)}\) - Land improvement works
  1 - endykment, drainage
  2 - irrigation
  3 - erosion control
- IN - Inundability (3 classes)
ANNEX II

POINT DATA - ATTRIBUTES
(SOIL PROFILE)

1. GENERAL DATA

1 - No. in Soil Data Base
2 - sampling date
3 - laboratory that made the analysis
4 - location
   - longitude
   - latitude
5 - absolute altitude
6 - slope
7 - parent material
8 - natural drainage class
9 - depth of ground water
   - minimum
   - maximum
10 - Land use / Vegetation
11 - Romanian classification
12 - FAO / UNESCO classification
13 - Soil Taxonomy Classification

2. HORIZON MORPHOLOGY DATA

14 - horizon number
15 - lithological layer
16 - horizon designation
17 - subhorizon designation
18 - associated horizon
19 - lower limit
20 - distinctness transition
21 - matrix colour, (moist)
22 - mottling
23 - grade of structure
24 - size of structure elements
25 - type of structure
26 - cracks, fissures
27 - supplementary characteristics

3. HORIZON ANALYTICAL DATA

28 - very coarse sand (2.0 - 1.0 mm) %
29 - coarse sand (1.0 - 0.5 mm) %
30 - medium sand (0.5 - 0.2 mm) %
31 - fine sand (0.2 - 0.1 mm) %
32 - very fine sand (0.1 - 0.05 mm) %
33 - very fine sand (0.05 - 0.02 mm) %
34 - Total sand (2.0 - 0.02 mm) %
35 - Silt (0.02 - 0.002 mm) %
36 - Clay (<0.002 mm) %
37 - abundance of coarse fragments
38 - Texture
39 - Bulk density, g/cm³
40 - Hygroscopic coefficient (g/g⁻¹)
41 - Hydraulic conductivity (cm/day)
42 - Resistance to penetration (Kgf/cm²)
43 - Moisture content at various tensions
44 - pH (H₂O)
45 - CaCO₃
46 - humus (organic carbon ) %
47 - total Nitrogen (%)  
48 - total Phosphorous (%)  
49 - available K (ppm)
50 - available P (ppm)
51 - exchangeable bases (cmol/kg soil)
  52 - Ca⁺⁺  
  53 - Mg⁺⁺  
  54 - K⁺  
  55 - Na⁺  
  56 - Al⁺⁺⁺  
57 - Exchangeable acidity  
58 - CEC  
59 - EC - dS/m (saturation extract)
60 - Total soluble salts (water extract 1:5) %
61 - Cl⁻ me/100 g soil
  62 - SO₄²⁻  
  63 - CO₃H⁻  
  64 - CO₃²⁻  
  65 - Ca²⁺  
  66 - Mg²⁺  
  67 - Na⁺  
  68 - K⁺  
69 - Phosphate retention (%)  
70 - Extractable Fe -Dithyonite (%)  
71 - Extractable Fe - Pyrophosphate at pH 10 (%)  
72 - Extractable Al - Dithyonite (%)  
73 - Extractable Al - Pyrophosphate at pH 10 (%)  

4. CLAY FRACTION MINERALOGY

  74 - Allophanic 
  75 - Chloritic 
  76 - Illitic 
  77 - Mixed 
  78 - Kaolinitic 
  79 - Montmorillonitic 
  80 - Vermiculitic

NB Underlined positions are compulsory
The Soil Information System of Slovakia and its utilization in land evaluation

Introduction

A soil information system for agricultural use has been developed and implemented in Slovakia for approximately 15 years. Its creation was established on internationally accepted principles, as applied to information systems theory. It may be defined as follows:

The significance of soil information system development resides in its utilization by management systems at various levels (governmental, regional, etc.). The information system must be developed with regard to the requirements and parameters of its users, especially from the point of view of hardware, software and systems structure, but above all from the aspect of data compatibility throughout the system and also in relation to the management systems of its various users.

Pedological data sources

The Slovakian soil information system is based on three main pedological data sources:

1. The survey of agricultural soils in Slovakia: soil maps at the scale of 1:10,000; 16,000 soil profiles analysed in detail; and 200,000 in semi-detail. The density of the soil profile network is 1/14 ha. The soil survey was carried out between 1961 and 1970. The soil classification system used was the national system of the former Czechoslovakia (Nimeeek, J. et al., 1967). In terms of taxonomy, definition of soil diagnostic horizons, definition of soil taxonomy units and analytical methods, this soil classification system is fully compatible with the FAO classification system.

2. Soil maps of new land evaluation:

3. Soil monitoring system.
Agricultural and forest soils are monitored together as part of the environment monitoring system. The monitoring network of 637 sites and 15,000 farm plots has been in existence since 1992. The monitoring cycle is 5 years. The following soil properties are monitored:

Soil contamination by risk trace elements and organic pollutants; content and quality of humus; soil reaction and active aluminium; physical properties; available P, K, Mg, Ca; soil erosion (at six sites with the help of 137Cs as a marker element).

Existing soil databases

The present soil information system in Slovakia consists of the following databases:

Database of 16,000 soil profiles.

The main data blocks are: identification data, co-ordinates in the national JTSK system with the possibility of transformation into geographical co-ordinates, classification data (soil classification according to both the Slovakian and the FAO system), code of polygons for soil ecological units (outlined in the following section), horizon properties (designation, colour according to Munsell, particle size distribution, pH/KCl, Cox, CaCO3, CEC, base saturation, available P and K). The database...
is managed by a user program based on MS-DOS.

**Database of soil mapping units**

This comprises the so-called evaluated soil ecological units. The database contains polygons, data of mapping units which were digitized on all the farming land (12,000 map sheets at 1:5,000 scale) of Slovakia and a 7-digit code number of an (evaluated) soil ecological unit.

**Database of soil mapping units**

The code explanation is as follows:

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xx xx x x x
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- agroclimatic region (10 categories)
- soil subtypes in combination with main types of parent material (99 categories)
- slope and exposition (9 categories)
- soil profile depth and skeleton content (9 categories)
- soil texture in A horizon (5 categories)

In Slovakia, there are 7000 soil ecological units (digit-code combinations) and each occur in many polygons (mapping units).

The databases are managed as a GIS by PC ARc/INFO under Windows 95 and also by a UNIX system.

The units of soil classification, soil depth and soil parent materials categories are comparable with the FAO system. It is also possible to transform the other categories.

**Database of national soil monitoring system**

The soil monitoring database consists of 637 monitoring sites. The main data blocks are identification data; co-ordinates in a JTSK system with the possibility of conversion into the geographical co-ordinates; classification data (classification according to the Slovakian system as well as the FAO system); code of soil ecological unit polygon.

See the following list:
- Territorial identification of monitoring sites
- Soil classification and horizon designation
- Physical properties
- Soil reaction and CaCO₃ content
- Macronutrients
- Micronutrients
- Humus content and quality
- Exchangeable cations and sorption complex
- Total content of trace risk elements
- Trace risk elements extracted in 2M HNO₃ (As in 2M HCl)
- Trace risk elements – available in forms (in 0.05 M EDTA)
- Trace risk elements in plants
- Organic pollutants and radioactive indicators (137Cs)

The monitoring data from separate cycles is archived in time series. The database is managed by a user program based on ACCESS/Windows 95.

The main data block consists of territorial and administrative identification data, co-ordinates in the national JTSK system (with the possibility of conversion to geographical co-ordinates), soil classification data (of the national system, the FAO system and the polygon code of the soil ecological unit), soil physical properties, soil acidity/alkalinity, CaCO₃ content, macro and micronutrients, humus content and quality, CEC, exchangeable cations, trace elements: total, mobile (0.05 M EDTA) and in extraction of 2M HNO₃ content, content of trace elements in plants, organic pollutants.

The database is managed by a user program based on ACCESS/Windows 95.
Other databases

There are a number of databases at the Soil Fertility Research Institute. Some of these are described below.

Database of land evaluation

This database contains the listing of soil ecological units code, their area and type of agricultural land utilization (arable land, grassland, etc.) and the list of soil ecological units is according to farms and municipalities. It also contains the prices of all units, the present average yield potential of 15 agricultural crops and the average cost of inputs in agricultural production. The database is continuously updated.

National cadastral soil database

This is the largest database and information system concerning the soils from a cadastral and geodetic viewpoint. The pedological characteristics, soil price and other land evaluation categories of each agricultural field (plot) are expressed by means of a soil ecological unit code in the cadastral GIS information system.

Database of national soil agrochemical testing

The oldest database of agrochemical soil properties has been in existence since 1961. The monitoring cycles are five years in duration. The results from this system have shown the development of nutrient status and the build up of soil acidity during the last 35 years.

The Slovakian soil information system

The present utilisation and future potential of the Slovakian soil information system are influenced by the following:

- new national socio-economic conditions (privatisation, relatively low subsidies, increasing costs of agricultural inputs, etc.)
- the strong impact of environmental legislation (a function of Environmental Impact Assessment (EIA), process monitoring and control systems of soil, food and forage products, drinking water sources, protected landscape areas, etc.)

Present utilisation (function)

The database is currently used as a soil (pedology) information and land evaluation system for:

- soil appraisal: by means of soil-ecological units; a soil appraisal system for assessing soil value has been set up for the purposes of taxation and agricultural soil subsidies; and renewing the national soil cadastre
- soil protection by means of soil ecological unit categories according to a special duty system. (The stamp duty system is based on multiplication of the soil value in a geometrical scale.)
- environmental protection for district administrations (soil maps, land evaluation maps, soil contamination maps, created by means of ARC/INFO GIS).
- urban planning on the strategic (national) level and regional and municipal levels. Used for soil appraisal maps, map of stamp duty categories for soil loss – permanent or temporary (interpretation of soil ecological unit maps) – and soil contamination map and database of soil monitoring system. Partly by means of ARC/INFO GIS, partly using traditional maps.
- information on soil nutrients, pH status and soil contamination for farmers. Data and interpretations from national agrochemical testing and from monitoring soil information system. Information is localised at individual field level.
- education, research and publicity. Data from the soil information system serve for education, environmental and agricultural research projects, and also for public information.

Future tasks of the soil information system

The data and interpretation of this system are expected to be used to achieve the following goals:

- Updating the soil cadastre: the soil ecological units and their appraisal will assist in grouping and simplifying the large number of existing records of individually-owned plots into larger, relatively homogenous plots, resulting in ecological reconstruction of the landscape.
- As a feedback in many control systems for planning and
managing sustainable land use and environmental development. The data and interpretations of soil degradation processes (and the steady state of soil properties) will be the most important. The present legislation and national institutions have asked for this information.

- The collection of scientific information about agricultural utilisation and profitable land management, rational fertilization and other technologies, especially anti-erosion measures.

Conclusion

The soil cover is the focal part of the environment and therefore soil data will become increasingly important in planning for sustainable land use. Scientists and others working with soil information in Slovakia would also like to take an active part in using soil information systems at national and international levels. The system described here already has many of the parameters necessary for compatibility with these other systems.
LandIS - a Land Information System for the UK

Summary

Soil information has been collected over the past 50 years in the UK and a major milestone has been the development of a computerized Land Information System (LandIS) to store, retrieve, manipulate and visualise the data. LandIS contains a number of key data sets: a National Soil Map at 1:250,000 scale, a National Soil Inventory (5km intervals), a National Catalogue of Soils, morphological and analytical data on nationally important soil types, an agroclimatic databank and other information, such as land use, collected during soil sampling. LandIS was fully operational over the wide area network (WAN) in Britain for more than 10 years.

Under a recent project, LandIS_2000, the existing databases have been re-engineered to conform with the latest hardware platforms and software engineering techniques in use today. LandIS has been widely used for the interpretation of soil information for the sustainable use of land in the UK. The interpretations are used for decision support in the utilities, engineering, finance, ecological and agricultural sectors. The LandIS_2000 project is also addressing ways of expanding the applications for which the information base can be used. This paper describes the history, overall design, physical implementation, source data and processing capabilities of LandIS. The system’s modelling capabilities are also briefly described.

Introduction

The Land Information System (LandIS) is a database system containing a wide range of soil and related land information. It has been developed and maintained by the Soil Survey and Land Research Centre (SSLRC) over the past 15 years and there has been a continuous improvement in the facilities for storage, retrieval and manipulation of soil and related land data for the UK.

The Soil Survey has had a national responsibility for collecting and storing information about soils for over 50 years. The results of the diverse surveys undertaken have produced a vast quantity of very detailed information, characterising soil types at specific locations, defining the chemical and physical properties of the soils and their suitability for agricultural and other uses. Some of these data have been published in the form of maps, at scales of 1:250,000 1:100,000 1:63,360 1:50,000 1:25,000 and 1:10,000 (Bullock, 1991), and explanatory Memoirs, Records, Technical Monographs, and Special Surveys (Soil Survey staff, 1983, 1984). Other details have been summarised in numerous scientific publications and textbooks but the vast majority of the detailed information gathered by the Survey still remains in the form of paper records and physical collections (of specimens and samples).

An information system requires the collection, organisation, analysis and processing of data. It must also make these data accessible to end-users and satisfy the information policy of the organisation responsible for the data. The decision to develop LandIS was made on the sound foundation of good quality soil and land data. The soil classification and archives, together with the expert knowledge of the staff, are the foundation of this process.
A series of interpretative models had been developed by the start of the 1980s and these form the framework for making the data available to end-users. Most of the models were built to address issues concerned with productive agriculture, but many have since been modified or extended to address new environmental applications of land information. The interpretative models are now wide ranging as demonstrated by Jones et al. (1993), Bullock and Jones (1996).

The first phase of the Information Base is now complete (1997). However, there still remains a vast amount of information still in paper form. Strategic decisions need to be made about access to this information and the future funding and use of LandIS.

Contents of the system

The statistics about LandIS are impressive. The Information Base comprises more than 130 key databases containing information for over 600 soil, climate and land attributes in the UK. The main groups of databases include:

- National Soil Map (NATMAP): raster data containing a unique soil identification (map unit) code for each of the 15.5 million 1ha pixels that make up the country;
- vector data comprising ARC/INFO and related coverages.
- National Catalogue of Soils (NATCAT): providing detailed information on all the nationally important soil series (>720).
- National Soil Inventory (NSI): comprising data from over 6000 sites (>20,000 horizons) at 5km intervals across England and Wales. Analytical data from more than 5600 samples collected are augmented by over 50000 computed and interpreted values.
- Agroclimatic Databank (AGROCLIM): containing historical data for 80 climatic parameters interpolated for each of almost 6500 5km × 5km grid points.
- Auger borehole records (AUGERS): comprising recoverable records of more than 150,000 auger bores (>450,000 horizons) made during various mapping projects.
- Representative profile records (PROFILES): More than 2400 representative profile pits with over 11,000 horizons have been identified, described and sampled. There are more than 102,000 results from the analysis of these samples. More than 120 kinds of analysis have been performed including physical determinations (water retention and density) on over 3400 horizons from the representative profile pits.

In addition, the system contains more than 100 interpretative models relating to agricultural and environmental issues and many of these are expressed as functions rather than databases.

The original concept

The concept of a computerized information system for the storage of soil and land data was born in 1979 when it was recognised that handling large volumes of data by traditional methods was expensive and inefficient. At that time, the Soil Survey of England and Wales (SSEW) was the organisation responsible for collecting, processing, storing and disseminating information on the soils of the two countries. Survey operations were organised from 17 regional offices, and the headquarters at Rothamsted Experimental Station.

Rothamsted had been famous since the mid-nineteenth century for agricultural research (RES, 1983), particularly with respect to soils. It also housed the computing centre for the whole of the Agricultural Research Council, a facility that had grown from the strong statistical research group based there (Fisher and Yates, 1963).

The first steps towards a comprehensive information system for the Soil Survey were taken in 1976 when computer compatible recording systems were designed for field observations (Hazelden et al., 1976) and the data processed from 80 column Hollerith type cards. A Fortran program DECODE (Webster et al., 1977) for processing soil description (morphological) data was developed and, in 1979, field recording cards were designed (also on an 80 column format) for recording auger bore observations and the National Soil Inventory descriptions. Computers were also used during this period to run GENSTAT for general statistical analysis of soil data (Hodgson et al., 1976; Hollis et al., 1977).
To aid the automation process, the Survey began routine recording of field descriptions and analytical results in computer-compatible format (Hodgson, 1976), and storing the data on what became known as the Soil Information System, SIS (Ragg and Proctor, 1983). The original intention was to store data collected by the Soil Survey and various groups within MAFF (e.g. the Resource Planning Group and the Soil and Water Service) and to build a Common Soil Information System (CSIS). This remained an objective until MAFF was reorganised and the Soil Survey was transferred to Cranfield in 1987.

Development

Between 1979-82, a programme to complete a National Soil Map of England and Wales at 1:250,000 scale, NATMAP, was undertaken by the staff of SSEW. The Map was published in six sheets (Soil Survey Staff, 1983) with explanatory bulletins describing the 296 soil mapping units distinguished for England and Wales (Soil Survey Staff, 1984). A similar programme was undertaken for Scotland by the Soil Survey Department of the Macaulay Institute for Soil Research (now MLURI). Concurrently, a logical design for the national soil information system (SIS), based on the latest principles of relational database management systems, was completed in 1982. This prototype, and the peripheral developments such as the DECODE software, were transferred from an ICL System 4/70-72 mainframe computer to a Digital VAX 11/750 acquired by Rothamsted in 1983.

In the same year, LaserScan of Cambridge was commissioned to produce a digital version of the National Soil Map by raster-scanning. The resulting vector images of the soil polygons were converted to raster form by purpose written software (Proctor, unpub.) and the raster images of the map stored in a relational database structure.

Between 1984 and 1986, an agroclimatic databank (Jones and Thomasson, 1985) and some simple models of soil-climate
interactions were incorporated into LandIS. The inclusion of a modelling capability marked a significant addition to the SIS beyond its traditional functions of data storage and retrieval.

A raster version of NATMAP was made operational in 1986 and, at the same time, the SIS changed its name to LandIS, the Land Information System, to reflect new categories of data (e.g., for land and climate) in addition to those for soils. In 1987, LandIS development was transferred to a dedicated VAX sited at Cranfield’s Silsoe site.

From 1987 to 1994, remote access to an operational version of LandIS (Figure 2) was provided for the regional offices of the UK Ministry of Agriculture Fisheries and Food (MAFF), via the national wide area network (WAN). This service allowed agricultural extension officers to view and extract LandIS data at their own desktops. It served up to 20 simultaneous MAFF users and was governed by a formal service level agreement. This was the first known on-line access to environmental data in the UK.

The development of LandIS continued in parallel with periodic upgrades to the operational version.

Overall design

The logical design for LandIS was completed in 1982, before the hardware platform to succeed the ICL mainframe had been selected. It was therefore necessary for this design to be as flexible as possible, as well as conforming to Codd’s (1970) relational theory.

The requirements specification for the system defined that it should be capable of:

- handling large volumes of data efficiently;
- accepting all kinds of earth science data, including spatial data;
- validating, correcting and converting data;
- updating data sets regularly;
- providing secure storage for the data;
- retrieving data on the basis of values of and relationships between any attributes held;
- interfacing with other software, e.g., GENSTAT;
- producing output in the forms of reports, tables, graphs and maps.

It was also acknowledged that:

1. the computing facility would probably change radically within the 3-4 years that followed;
2. the DBMS would not be known until the new platform had been chosen;
3. large volumes of data were being collected which required immediate processing.

The overall concept of the information system is that it would comprise:

1. a number of satellite systems for validating and pre-processing raw data and updating central databases;
2. a set of relational databases:
   - held in a form independent of any specific application;
   - capable of being shared and supporting different views;
   - held and managed centrally;
   - having secure, controlled access and controlled duplication/distribution;
3. a number of satellite systems for manipulating central databases;
4. a menu system for user-friendly on-line processing.

A general purpose data validation, conversion, error correction, report generator and file updating system was designed to accommodate the many different formats of raw data entering the system. This could serve any DBMS and, since it was parameter driven, could be adapted as additional data types were acquired. The logical design of the original LandIS (as functioning on the VAX) is shown in Figure 3.
Implementation

In 1984, the system was implemented on a VAX 11/750 running the VMS operating system. It was built around relationally structured databases and Digital software comprising Datatrieve (DTR), a fourth generation language for file definition, management, manipulation and retrieval, and a common data dictionary (CDD). A user interface, programmed in Pascal, comprised a hierarchical menu system providing access to standard data sets. Originally accessed via dumb terminals, this service was eventually provided on PCs through terminal emulation software. The CDD and DTR together provided the relational database management system.

Data entry and validation software was written in SPITBOL, an interpretive language chosen because of string handling efficiency, flexibility and machine independence. In later years (1991-95), data entry systems were based on PCs with software written in Clipper (Computer Associates, 1992).

After more than 8 years functioning on the VAX platform, MAFF commissioned a feasibility study on the future of LandIS (Jones et al., 1992). A required logical design for future implementations of the system was produced (Figure 4) and funds provided by MAFF for a 4 year project, LandIS_2000, to update the hardware and software platforms for LandIS. A cornerstone of this project was the setting up of a Reference Site at Silsoe and the development of PC applications system to facilitate access to the data.
Reference Site

This comprises hardware, software, data and human resources. Currently, a dedicated Digital Alpha (3600) server, running the Digital UNIX (formerly OSF) operating system, provides the main storage and processing capability for the LandIS ORACLE databases and applications (Figure 5). Access is provided via two Alpha (3300x) RISC workstations (also running UNIX) and four PC client machines. Oracle Developer/2000 software is installed on the PC machines to provide user interfaces to the data. The VAX-based system has remained operational throughout the life of the LandIS_2000 project (1993-97).

In addition, a GIS component comprises ARC/INFO running on the Alpha workstations and ArcView on the PCs. The ARC/INFO software provides the capability for visualization of spatial data and the production of maps. It is an industry-standard GIS in the research environment and is now supported by the mapping package ArcView.
Figure 4: Required logical design for the LandIS 2000 project
Analysis and Design

The Datatrieve system on the VAX provided the starting point for a thorough analysis and design of the required new system leading to the choice of Tablespace design. A Required Objects Specification for each of the 11 Tablespaces containing LandIS data, currently included in the database (Siddons et al., unpub.), was constructed. The specifications include the detailed descriptions of tables and attributes, indexes and other constraints, functions, and any additional information regarding data conversion.

Database tables were created, loaded, indexed and modified using SQL scripts to facilitate any necessary re-working. Routine queries were written to report the current state of the system. For example, up-to-date listings of tables, attributes, constraints and functions; the status of user roles and privileges etc. Entity Life Histories and Entity Relationship Diagrams are maintained for all data tables.

Figure 5: Hardware platforms for LandIS 2000

LandIS ORACLE Conversion

Data were transferred, (using NFS), from the VAX to the Alpha server running Oracle. Where necessary data were converted to conform to a standardised format. For example, all Ordnance Survey National Grid (UK) References were converted to 1 metre resolution in ‘fields’ large enough
to include sites in Scotland. Previously, grid references were stored to the nearest 10m. Data were validated against existing Datatrieve versions using purpose-written procedures. In some cases, the data were revalidated using scientific advice from staff at SSLRC.

Procedures for backing up the data have been designed and implemented. Full backups on a weekly basis are automated under the UNIX operating system. Additionally, a full export of the database is made periodically and archived by the Database Administrator (DBA) to provide further security. The backup/archive media are held in secure fireproof storage.

**Access**

User roles and privileges have been organised and implemented. General users may access selected tables via Developer/2000, a Oracle Product for Microsoft Windows, which provides a user-friendly front-end for simple queries (Figure 6). Functions and more complex queries are written in PL/SQL on a user demand basis.

Several prototype applications using Developer/2000 have been written. Examples include: APTAB, which allows a user to enter a number of parameters, produces a report of available water in the soil for different crops; National Map Reporter which accesses the raster version of the soil map; Profile Reporter which accesses the auger borehole, representative profile and National Soil Inventory data. Other applications have been developed to evaluate and demonstrate some of the functionality of Developer/2000.

**Figure 6: Configuration of hardware and software for LandIS 2000**

**PC system**

Also under the LandIS_2000 Project, most of the applications, data retrievals and interpretations, previously available through the on-line VAX menu system, have been rewritten for the PC platform under the MS-Windows operating system (version 3.1 or 95). Each application is a separate stand-alone module which runs on a standard IBM compatible Intel 486 or Pentium PC. Windows 3.1 applications will run satisfactorily.
on a 486 with 8Mb RAM but, under Windows 95, a Pentium processor with 16Mb or preferably 32Mb RAM is recommended.

A hard disk capacity of at least 500Mb is advisable, if the machine is actively being used to run other applications software. In practice most PCs now have hard disks of much larger capacity (2-6Gb). The PC applications have greatly improved on the original system, including the ability to select points from a map and to map the parameters presented in the text reports.

Analysis and design

Object orientation was adopted for developing PC applications to guarantee that they were developed to the highest, most-up-to date standards. Moving to object orientation was not an easy process however. Project managers and software developers alike had to adapt to the new dynamics of object orientation. Traditional methodologies of system design could not be used and a totally new approach had to be adopted.

The method chosen for the analysis and design of the applications was the Object Modelling Technique (OMT) devised by Rumbaugh et al. (1991). A computer aided software engineering (CASE) tool called “Paradigm Plus” produced by Cadre Ltd. was also purchased to assist in the analysis and design of the classes.

Implementation

The software was written in the C++ programming language and compiled using a Borland compiler (Borland, 1994). As a large part of the applications development was data handling, it was decided to build an object oriented database using the POET software (POET, 1995), to ensure full advantage of an object oriented system.

The graphical user interface (GUI) for the applications was designed based on the Microsoft guidelines for designing a user interface for Windows-Based applications (Microsoft, 1992) using the zApp Factory package. There was wide consultation with potential users to ensure that the GUI design was appropriate and sufficiently user friendly.

The PC applications were written to run under Microsoft Windows 3.1, but have now been upgraded to run under Windows 95 or NT. The data contained in the applications database are a snapshot of the Reference Site data and will be updated when major changes are made to the Reference Site databases. The following sections describe the individual PC applications.

Spatial Data Reporter

This application allows the user to generate either a text report or a map for the following parameters:

- Accumulated Temperatures (Jones, 1985; Hallett and Jones, 1993)
- Rainfall (Jones and Thomasson, 1985)
- National Soil Map (NATMAP) Associations (Soil Survey Staff, 1983, 1984)
- National Soil Inventory (NSI) Data (McGrath and Loveland, 1992)

A text report is generated for every 5km grid square (Ragg et al., 1988) within a user selected area. A map is produced for a single parameter chosen from a list of 37 parameters including dominant soil group, percentage organic carbon and pH of soil.

National Catalogue of Soils

This application allows the user to select a soil series (Clayden and Hollis, 1984; Hollis and Avery, 1997) either by selecting from a list or typing in the required series name in full. Once the series has been chosen, a text report is generated including a description of the soil and chemical and physical analyses of the representative horizons for the soil series.

Land Suitability

This application generates a text report or a map. The text report contains the suitability class (Jones and Thomasson, 1987) of the selected area to grow the selected crops and the data used to calculate this suitability. This package runs the model for each selected point using either data from the database or data input by the user. Maps can be drawn of any crop suitability, the associated droughtiness for each crop and the machinery work days in spring and autumn.

Agricultural and environmental uses of LandIS

To date LandIS has been used to address a wide range of problems and applications relating to the land. These include:

- Development of the revised Agricultural Land Classification for England and Wales (MAFF, 1988; Met. Office, 1989)
• Suitability of land for a range of traditional arable crops (Jones and Thomasson 1987; Thomasson and Jones, 1991) and alternative arable crops (Siddons et al., 1994).
• Assessment of drought and workability/trafficability of soils (Thomasson, 1979, 1982; Thomasson and Jones, 1989a; Rounsevell and Jones, 1993).
• Suitability of land for farm waste disposal (Clarke et al., 1992).
• Environmental risk assessment: particularly nitrate (Jones et al., 1989, 1990) and pesticide pollution (Hollis et al., 1997) and the derivation of soil vulnerability classes for a National Groundwater Protection Policy (Hollis, 1991).
• Environmental appraisals of new pesticides (Brown et al., 1995; Brown and Hollis, 1994, 1996).
• Geotechnical problems such as corrosion in buried pipes (Jarvis and Hedges, 1994; Dufour et al., 1998).
• RIMNET: environmental modelling facility for national radiation monitoring network.
• SEISMIC - Spatial Environmental Information System for Monitoring the Impact of Chemicals, which is specifically targeted at pesticides (Hallett et al., 1995).
• Source of data for local Contaminated Land registries.
• Modelling for climate change impacts (Bullock et al., 1996; Rounsevell and Loveland, 1994; Rounsevell et al., 1996).
• National Critical Loads Advisory Group: atmospheric deposition and its effect on soil (Hornung et al., 1995).

• Land Planning (Thomasson and Jones, 1989b; Thompson and Peccol, 1995).

Because of the nature of many of these uses, LandIS can be regarded as an environmental information system (Hallett et al., 1996). There are also a number of potential operational requirements in the agricultural and environmental sectors which will need LandIS information and its processing capabilities in the future. These include:

• Establishment of UK soil quality standards
• Framework for national soil quality monitoring programme
• Environmental fate and behaviour reviews for industrial chemicals
• Implementation of EU Directives such as the Nitrates Directive (EC, 1980) together with Action Programmes for vulnerable zones
• Inputs to European Environmental Agency
• National environmental economics studies

Conclusions

The Land Information System, LandIS, is the national computerized database system for soil and related land information in England and Wales. It is the only system of its kind in the UK and is one of the largest computerized systems containing soil and land data in Europe.

The information base comprises a large number of key databases (>130) containing information about more than 600 soil, climate and land attributes in the UK. It includes the digitised National Soil Map (at 1:250,000 scale), the National Catalogue of Soils (for 720 nationally recognised soil series in England and Wales, the National Soil Inventory, and an Agroclimatic Databank. Digital Terrain (DTM) data.

LandIS now provides secure storage for:

• information about the distribution, properties, quality and potential use of the nation’s soils;
• a basis for model development in support of a range of agricultural and environmental issues;
• a mechanism to support research and policy through assessments at local (field, farm or forest), catchment, regional or national level and for integrating or alternating between them;
• the potential for links with other national and international databases in the environmental sector.

The LandIS_2000 project (1993-97) has enabled a thorough updating of the central LandIS databases. The transfer of subsets of the data to PCs has improved access for external users. The creation of the appropriate expertise for managing and expanding the system into the future now exists.

A secure operational Reference Site for LandIS has been established to sustain the ORACLE relational database management system (RDBMS). This is an industry standard RDBMS for managing environmental databases and is capable, flexible, potentially expandable and runs on a powerful and stable hardware platform.

Additional data for the UK that should ideally be added to LandIS, include:
Nitrate Sensitive Areas (NSA) and Nitrate Vulnerable Zones (NVZ)

Environment Agency

Groundwater Vulnerability Map boundaries

Post Codes

Local Government Authority Boundaries

Health Authority Boundaries

Socio economic data (e.g. population density)

Gazetteer of place names

Other types of environmental data to support model development and other applications will also be incorporated, for example:

- Land contamination data
- Land suitability data
- Land use/land cover (remotely sensed) data
- Climate (real time)
- Soil hydrology data
- Models of Environmental Risk Assessment
- Topographical data

Habitat data

Infrastructure (e.g. roads, railways etc.)

Funding agencies, such as the UK Government, are increasingly requesting that links be established with other environmental databases to form a distributed network in the UK capable of supplying the user community which increasingly requires an integrated approach to problem solving. Something similar is needed at EU level.

LandIS is a unique national asset and is the most comprehensive for the nation’s soils. It represents a significant investment of time and money and, after 15 years of use, it is now one of the best organised systems of its kind in the world. One of its great strengths is that it is supported by a strong professional team.

The structural degradation, contamination, pollution, acidification, erosion and salinisation of soils are amongst the many agricultural and environmental problems causing concern. Although traditionally regarded as problems of the Developing World, it is now realised that many of them are now becoming severe in Europe, North America and Australasia.

The European Commission is drawing up plans for a Soil Protection Policy which will include appropriate legislation and monitoring programmes for soil quality. Success in the development of adequate conservation and recovery programmes in any country will depend on a comprehensive and up to date land information base such as that provided by LandIS for the UK. It is therefore essential to preserve such systems where they exist and to develop them where they do not.

Acknowledgement

From the first conception of this system in the late 1970s until the present, LandIS has been supported by Cranfield University with the majority of funding from MAFF. The authors are deeply indebted to Professor Peter Bulloch, Director of SSLRC from 1985-1997, and Michael Jarvis, the current Director, for their unstinting support and encouragement throughout the ‘life of LandIS’.

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Section 4: Techniques and Technologies
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An integrated agrometeorological forecasting system for Bulgaria  
G. Georgiev

Three-dimensional Soil Prediction: Fuzzy Rules and a GIS  
M. Ameskamp, J. Lamp

Architecture of the NIBIS Soil Information System of Lower Saxony, Germany  
H.-U. Bartsch

Multivariate distance methods for geomorphographic relief classification  
K. Friedrich

Baden-Württemberg pedological information system – principal aspects of system conception  
C. Fritz, F. Waldmann

Preparation of MMK documentary Form A for practical applications  
K. - J. Hartmann, G. Günther, D. Bothmer

Definition and Use of Functional Soil Horizons as Keys in Spatial Land Information Systems  
J. Lamp, M. Ameskamp

Integrating GIS and process models for land resource planning  
A. K. Bregt, J. Bulens

Linking digital soil maps and databases to simulation models: functional soil map aggregation in The Netherlands  

Neural computing approach to soil monitoring systems in Poland  
T. Stuczyński, J. Pauly, H. Terelak

The Romanian PROFISOL Database  
A. Canarache, V. Vlad, I. Munteanu, N. Florea, Anisora Rasoveanu, Daniela Popa
An integrated agrometeorological forecasting system for Bulgaria

Summary

This paper reviews a National Agrometeorological Data Management and Forecasting System. Its development started in 1990 in Bulgaria under the sponsorship of the National Science Foundation. The main system components, such as data collection, data codification and de-codification, data transfer, data management, interpretation, integration of heterogeneous data, and output products are briefly described. Implementation of data from other sources to a standard agrometeorological database is essential for forecasting. A chart of different data flows is presented. Additional effects of the proposed system on the development of Decision Support Systems and regional Geographic Information Systems are considered.

Introduction

In the National Institute of Meteorology and Hydrology, development of integrated information systems started in 1990 under a project financed by the National Science Foundation. A precondition for this was the development and acceptance of a new code form to transfer the agrometeorological observation data. This code form was specially designed for computer-based management and processing. In this paper an overview of the existing system is made and its future development is discussed.

Components

The main components of the developed system are presented in Figure 1. The existing modules are indicated by 'solid' boxes, while dashed boxes indicate the modules which are under development. Basically the system was developed to work under a UNIX-like operating system, based on shareware software where possible for the main system, which is set up so that the client machines can be standard terminals, or DOS-based. Of course Windows clients are welcome too. The system is designed for working with a distributed environment and database management. The components can be grouped as shown in Figure 1.

Database and data entry system

This component is responsible for entering, viewing and modifying the data needed for the proper working of the system in an on-line regime (Kazandjiev and Georgiev, 1993). Data are received using the National Institute of Meteorology and Hydrology operational data transfer network. All data are coded using standard World Meteorological Organisation approved code forms, where the international rules are valid, and for agrometeorological data - using a code form, AMK-2M, developed in our institute for internal use (Slavov et al., 1993). We propose submitting this code form for international approval and application. The problem is that regional climate and biology are very diverse in Bulgaria, so that many codes included in the form are site-specific. There is a need therefore to prepare regional code forms.

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237
The database system includes data for a number of parameters.

**Climate**

Mean air temperatures, minimal and maximal air and soil surface temperatures, wind speed, total rainfall, dew, sunshine duration, snow cover and data for observed meteorological phenomena, air pressure, etc., operational data, and long-term means, for a 30-year period from 1960 to 1990.

**Crop data**

Crop identifier and name, crop variety, date of sowing or planting, plant density in different stages of development, phenological stage, crop height and specific crop parameters, expected harvesting date, damage, areal distribution, agrotechnological activities and data for estimating selling prices, will be included in the future.

**Soil data**

Soil identifier and name, different soil constants like wilting point, full saturation soil capacity, pH, physical soil properties, actual soil saturation, etc. All soil profiles are divided into 10cm layers up to 2m depth. The soil moisture content is measured by gravimetric methods.

**Site-specific data**

Farm identifiers, ownership, accounting information field data (individual costs and selling data), soil types, crop types, planting or seeding dates, crop varieties and hybrids, meteorology station identifier, irrigation system type identifier, general map of the communications, roads, buildings, land parcels, rivers, height above sea level, etc. At present the general maps are at very low resolutions, and are made only for general development and testing of the system. It is certain that high resolution data have to be included in the system, but this will require close co-operation between different institutions.
Models

A number of computer-based models have been developed to simulate crop growth on a daily basis. These models have potential for generating forecasts of expected yield in advance of harvest or maturity, as well as soil water balance, water consumption and crop growth. The models included in the system are adapted for Bulgarian varieties and hybrids (Alexandrov et al., 1993, Georgiev et al., 1993, Georgiev, 1996, Slavov et al., 1994), and developed under the International Benchmark Site Network for the Agrotechnological Transfer (IBSNAT) project in co-ordination with the University of Hawaii (G. Y. Tsuji et al., 1994). At the moment we have ready and operational the models for winter wheat, maize and barley, and models for potatoes, soybeans, beans and rice are under development and testing. During 1996 we were included in the MARS project, and the WOFOST model will be adapted for use in Bulgaria.

Remotely sensed data and satellite images

We have been interested in this component for some time, but without practical results. It is one of the main components for express evaluation of crop status and disease development (Kazandjiev et al., 1994). Our entry to the MARS project during 1996 gives us hope that this system component can be developed and will not remain an empty wish.

Geographic Information System

Our investigations led to the decision that the most popular geographic data integrator in Europe and North America is ARC/INFO, developed by the ESRI corporation. To our regret we cannot afford it, so we decided that the tool we used must be cheap, shared, and freely distributed. The system that meets this requirements is the GRASS GIS software, which is widely distributed among research institutes and educational organizations. More than 90 charts for the territory of Bulgaria have been input into this software, including agroclimatological charts for different crop-sensitive characteristics, such as first frost, last frost, average lengths of vegetation period, average data of winter wheat seeding and harvesting, etc. Our efforts are directed to the development of a first working version, after which a more detailed picture will be developed.

Decision Support System

This is the system integrator tool that will allow users to make a decision or at least help them during the decision-making process. The idea included in this module is simple – if we have all available information, such as environmental conditions, crop status, weather forecasts, economic conditions such as prices, and mathematical models as a tool, we can build and visualise the results of all this, integrated on the screen, or printed out as hard copy. Decision support allows us to choose between different probable weather realisations, or between different nutrification scenarios, or different regimes of water supply, or others created by individual users (Georgiev et al., 1994, Dukov et al., 1994, Kazandjiev et al., 1994). The first version of the decision support module is ready and is based on Decision Support System for Agrotechnology Transfer (DSSAT) package developed by the IBSNAT project.

In the future we plan to enrich this module with expert system intelligence (TZANOV at al., 1996). This means to bring human interpretations of the data to the user and avoid being overwhelmed by cumbersome details. This module can reduce demands on the user by transforming circumstantially available data into model-oriented data. The expert system can also usefully serve various functions in the modelling system, but cannot eliminate human initiative in the man-machine dialogue.

Summary and conclusions

The scope of the proposed system is to introduce information modelling to farmers and different authorities in Bulgaria in order to improve forecasts and to help decision-makers, as well as individual farmers or farmers’ unions. The other aim is to provide the National Agrometeorological Service with a powerful tool to facilitate the services which are shown in Figure 2. Above all the system must be user-friendly, graphically oriented, and visually appealing, to maximise its acceptance by non-proficient users. Moreover, the ease-of-use aspects and the opportunities to reduce the cost
and improve efficiency should encourage the extension services and other users to take up the system. Knowledge-based techniques are quite useful for these issues.

As shown in Figure 2, the different ways for external connection to the developed system include telephone and fax access and Internet access. In the future we plan to enrich the system with a WWW server, an agrotechnological software exchange server, and other different tools that can help Bulgarian Agriculture to achieve the returns it must meet as a wholly European country.

Ultimately the objectives of the developed system is to form a basis for integration of the agricultural system supplying customers with various information which is usually kept in different locations, and to help in co-operation among the disparate fields of meteorology, agriculture and decision-support systems.

![Figure 2: Agrometeorological services developed in the National Institute of Meteorology and Hydrology](image)

References


Three-dimensional Soil Prediction: Fuzzy Rules and a GIS

Summary

While a full soil survey based on intensive sampling is probably the best way to determine soil conditions at a large scale, this is not always feasible or necessary. In many cases, predictions by an experienced soil surveyor, based on less expensive information such as topography, aerial photography, or land use data, can be an alternative.

The Three-dimensional Rule-based Continuous Soil Modelling System TRCS provides an environment for formulating fuzzy rules that link soil conditions to landscape information. Soil information is represented in the form of fuzzy profiles based on a set of horizon classes optimized for their predictive powers.

These profiles define a three-dimensional representation of the modelled soil volume with continuous transitions between horizons.

Landscape information is stored in a raster GIS (GRASS) and the modelling system itself is integrated into the GIS user interface. The fuzzy rules can make use of any information available, either by directly referring to a GIS raster file, or by defining a set of qualitative terms (i.e. fuzzy sets) that describe the information.

Introduction

In recent years it has become apparent that soil is a limited resource that is non-renewable within human time scales. This resource is consumed at an increasing rate, often irreversibly, by building, compaction, erosion, and by biological and chemical degradation.

The impacts of different types of soil use depend very much on soil properties. However, one of the main characteristics of soil is its high variability (Beckett and Webster, 1971; Burrough, 1993). While this has often been considered an impediment to the effective use of soil, especially in farming, it has recently been argued that soil variability — or soil diversity, to use a term with more positive connotations — can be seen as a natural ‘risk-aversion strategy’ and thus may be advantageous or even necessary for a sustained use of the soil resource (McBratney, 1992).

Taking soil variation into account requires detailed information. Standard soil maps are not of a sufficiently high resolution for modern precision farming methods that can adapt soil treatment, for example the application of fertilizer, to changes that occur over a few meters — provided information on those changes is available in advance (Lamp and Ameskamp, 1998).

Soil prediction

The prevalent method of soil inventory combines taking soil samples with predicting soil conditions between sample sites. These prediction are based on a knowledge of relations between landscape and soil conditions. Landscape elements that are important for soil prediction can (with some overlap) be divided into soil factors that influence soil formation, such as relief or vegetation, and soil indicators that show soil conditions, such as topsoil colour or structure (Jenny, 1941; Dent and Young, 1981; Lamp and Ameskamp, 1998).

These patterns of correlation between soil and landscape are also called soil-landscape models: ‘predictive models used to make statements about soil

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classes and their spatial arrangements or soil properties and their trends from observations of landscape features' (Hewitt, 1993, p.306). Since these soil-landscape models are frequently ‘mental’ models, results of the survey may be hard to check or to reproduce by other surveyors. In addition, the finished map does not contain any explicit information about the model itself — this is unrecorded and lost.

**Modelling soil prediction**

The authors have developed an interactive soil modelling system – called TRCS for Three-dimensional Rule-based Continuous Soil modelling – that employs a computational representation of the mental soil-landscape model of an experienced soil surveyor to predict soil conditions from widely available landscape information such as relief or air photos. Unlike other researchers (Lagacherie et al., 1995; Odeh et al., 1994) who use (geo-)statistical models to infer relations between soil samples and landscape information, we proceed from the assumption that experienced soil surveyors can provide valuable information about ‘their’ area.

The advantages of codifying this information are twofold. First, we get a soil model. While not as ‘exact’ as a full survey, this ‘educated guess’ combines a large amount of information relevant to local soil conditions in a useful form, and where a survey is not economically feasible, e.g. when applying precision farming methods, it provides a low-cost alternative.

Secondly, we get access to the soil-landscape model itself. Representing this model provides a way of separating evidence (landscape information) from interpretation (the expert’s conclusions). This means that the model can be applied to different sets of landscape data, that the models of different experts can be compared, and that the effects of changes to the model and the landscape information can be observed.

TRCS can best be described in terms of three models. One is the soil-landscape model introduced above, and the others are: a landscape model and a soil model. Landscape and soil models provide landscape and soil information, respectively, as a function of geographical position. The operation of these models can be shown by the following example.

A soil surveyor might reason: ‘There is a dark depression here, so the soil will be peaty.’ While generally, this whole statement might be considered part of a (mental) soil-landscape model, we use this concept in a more restricted sense. The soil-landscape model only ‘knows’ that depressions are marshy. It has no information on the occurrence of depressions in the survey area; in fact, it has no spatial information whatsoever. In contrast, the landscape model provides the information that there is a depression ‘here’, say at position (xd,yd), and the soil model associates this position with the soil information ‘marshy’.

**The landscape model**

The TRCS landscape model is based on a raster GIS (GRASS - Geographical Resources Analysis Support System (CERL, 1993)). While TRCS imposes no restrictions on the type of landscape data that can be used in the soil-landscape model, the most important sources of landscape information are the relief and aerial photographs. In Germany, a nation-wide soil rating survey, conducted mainly in 1934–1939 and updated where necessary, provides texture soil information.

Some processing is necessary to use this information in soil prediction: Neither an absolute grey value nor an absolute elevation is very useful for this purpose. In the case of the air photos, georeferencing is usually necessary as well as some radiometric corrections to compensate for global trends. In the case of relief information, various methods have been proposed for an interpretation that yields useful ‘features’ (e.g. Moore et al., 1993). In the example application presented below, we used a thin-plate spline interpolation method (Mitasa and Hofierka, 1993) to compute an elevation raster from digitized contours, and the relief analysis system SARA - System zur Automatischen Relief-Analyse (Köthe and Lehmeier, 1994) - was used to compute relative relief positions (Ameskamp, 1997).

A GIS does not always provide landscape information in terms that are immediately useful for input into the soil-landscape model. The example of a black-and-white aerial image (in the
following simply ‘image’) illustrates the problem. The GIS stores an image in terms of grey-values, normally integer values between 0 and 255. The soil surveyor is more likely to think in terms of ‘bright’ or ‘very bright’ areas of an image without wanting to specify too precisely the range of either term.

The concepts of linguistic variables and values prove helpful here (Zadeh, 1975). When interpreting the grey-value of an image at a given location as a linguistic variable ‘image’, terms like ‘bright’ and ‘very bright’ can be defined as linguistic values of this variable, i.e. fuzzy subsets of the set [0:255] of crisp grey-values (see Figure 1). The question of whether an image is bright at some point (x,y) can then be answered by first querying the GIS for the grey-value at (x,y), say, 57, and then looking up the membership grade of 57 in the fuzzy set. This value, 0.72 in Figure 1, is a measure for the ‘truth’ of the fuzzy statement ‘image is bright’ at the point (x,y).

TRCS represents soil in formation in terms of horizon classes. While an earlier system (BOGS, see Ameskamp et al., 1993) provided a ‘crisp’ soil model by assigning one horizon class to each point in the (three-dimensional) model range, TRCS extends this to a continuous or fuzzy soil model by using sets of weighted horizon classes (with weights summing to unity). A continuous transition from a ‘pure’ Ap horizon to an equally pure Bv horizon can be modelled by a series of sets of weighted horizons of the form (Ap, w1),(Bv, w2) , with w1 varying from 0 to 1, w2 varying from 1 to 0, and w2 = 1 - w1 everywhere. An alternative way of describing a set of weighted classes like this is the (fuzzy) class vector, where each component of the vector corresponds to one of the horizon classes used.

A profile in the sense of a vertical soil sample is the way in which soil is normally encountered in the field. In addition, a profile in the sense of a vertical sequence of horizon classes defines the type of a soil in most classification systems. In TRCS, following the fuzzification of horizon information from the crisp horizon class to the fuzzy class vector, a fuzzy profile is used to present model information for one point in the plane, from the surface to the parent material (usually at a depth of about 2 m), as a vertical sequence of class vectors. Fig. 2 shows an example of a fuzzy profile describing an ‘eroded Para Brown Earth’. These fuzzy profiles can be interactively defined by the expert, but an alternative is to extract the information from a soil database like Solum (Lamp and Ameskamp, 1998).
The soil-landscape model

In addition to providing a vehicle for the output of soil model information, the second important use of the fuzzy profile in TRCS is in the soil-landscape model. This model, which must represent correlations between the continuous domains of landscape and soil, should itself be fuzzy, and we implement it using a system of fuzzy rules that are similar to those used in fuzzy logic control (Mamdani, 1993).

The general form of these rules is ‘if landscape is L then soil is p’.

A specific example is:

\[
\begin{align*}
\text{if} & \quad \text{relief} & \quad \text{is} & \quad \text{midslope} \\
\text{and} & \quad \text{texture} & \quad \text{is} & \quad \text{loamy} \\
\text{and} & \quad \text{image} & \quad \text{is} & \quad \text{medium} \\
\text{then} & \quad \text{soil} & \quad \text{is} & \quad S
\end{align*}
\]

where S is a name for a fuzzy profile - in this case a 'Pseudogley', a soil affected by frequent waterlogging - relief, texture, and image are the names of linguistic variables, and midslope, loamy, and medium are fuzzy sets or linguistic labels defined for these parameters. Using fuzzy profiles in the then-part (consequent) of soil-landscape rules keeps these rules very close to the terminology of the soil surveyor. Also, the profile bridges the ‘dimension gap’ between two-dimensional landscape information and three-dimensional soil information through the inclusion of expert knowledge on the third dimension, namely the vertical sequence of horizon class vectors expressed by the profile.

The evaluation of a fuzzy soil-landscape rule for a point \((x,y)\) in the plane proceeds as follows: Querying the GIS at \((x,y)\) yields three (numerical) values. The minimum (the conjunction denoted by ‘and’ by the minimum operator.) of the membership grades of these values in the fuzzy sets midslope, loamy, and medium, also called the ‘weight’ of the rule, is a measure for how well landscape conditions at \((x,y)\) match the antecedent of the rule. The result of evaluating the rule at \((x,y)\) is the consequent profile \(S\) in the example) together with the rule weight.

In general, a TRCS soil-landscape model consists of more than one rule, and several rules may have a positive degree of firing for any one point \((x,y)\). In this case, the weighted profiles are aggregated into a new fuzzy profile. The aggregation method, which is described in detail in Lamp and Ameskamp (1998), is based on the horizon structure of the fuzzy profiles. An example is given in Figure 3.
Figure 3: Air photo and relative relief position (white = hill top, black = depression) for Kühren application. Grid lines are 100 m apart.

Figure 4: 40 % isosurfaces for M, Bt, and nH horizons

The example application shown in this section is for an area in the eastern part of Schleswig-Holstein, about 25 km south-east of Kiel (lat. 54°12′ N, long. 10°17′ E). Fig. 3a shows a 400 m by 400 m section of the air photo for this area, and Fig. 3b shows relative relief positions for the same area, with white corresponding to hill top and black showing depressions. A system of 15 rules was evaluated on a 40×40×40 grid of points, resulting in a three-dimensional raster of class vectors for 12 horizons classes. Fig. 4 shows 40 % isosurfaces for three of these horizons, generated with SGI Explorer. The M horizon (colluvium), is primarily found at footslopes and can be seen to form a 'ring' round the depression in the middle of the image. There is a patch of nH (peat) in the middle of the depression, and Bt horizons (clay-enriched subsoil) are found near 'hill tops' that correspond to bright areas in the air photo.
Summary

The modelling system TRCS presented in this paper provides a way of making an important part of the experience of a soil surveyor ‘operational’. Used in conjunction with widely available landscape information, TRCS is able to compute a three-dimensional continuous soil model. This model, which combines different sources of information into tangible soil structures, is a low-cost alternative to a full soil survey, especially in situations where a very high level of accuracy or detail of soil information is not required, such as some precision farming applications. Pedotransfer functions can be defined that translate the fuzzy soil model into a two-dimensional map of relevant soil parameter estimates (Lamp and Ameskamp, 1998).

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Architecture of the NIBIS Soil Information System of Lower Saxony, Germany

Abstract

Soil information systems incorporate data and data evaluation methods using several conceptual, logical, and physical models. Working with soil information systems tends to be rather demanding for users, because they can hardly be expected to be familiar with all the scientific and technical aspects of the system. For that reason, a layer of supporting functions has been introduced into NIBIS. These functions enable users to identify, to query, and to select the system contents, as well as to visualize results obtained, or to use evaluation methods.

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Introduction

Soil information systems incorporate models which are not complete, neither in coverage of space and time, nor in coverage of subjects or themes. The models, their data and methods, originate from different sources, are made for different purposes, and have to be applied in order to serve the various purposes and fields of application of a soil information system. Soil information systems are intended for scientific, administrative, political, and private uses. Obviously, they have to accommodate users with different levels of knowledge of soil-related topics, and of technical experience, and with different expectations related to system contents and desired results.

The architecture of a soil information system must be able to satisfy the range of users outlined above with their different demands to soil-related data and methods. This paper gives an overview of the architectural approach of the NIBIS Soil Information System of Lower Saxony, against this background.

The NIBIS approach

Relating user tasks with system contents

Working with an information system implies for users a knowledge of or ability to identify its contents, i.e. different types of data like soil maps or sample data, as well as methods to calculate groundwater recharge rates, for instance. The identification not only has to be seen as a process of finding the different data types and methods, but also of understanding their often complex semantics. Contents known to the user must be easily selected, queried and evaluated. The resulting data is to be displayed, or, generally speaking, to be edited, stored, and documented. NIBIS assumes that, using an information system, a user generates data and employs methods, usually in different steps, in order to obtain the desired results, like thematic maps, etc.

This understanding of an information system leads to the concept of NIBIS. NIBIS is designed to support three principal tasks:

- identification of data and methods
- data selection, querying, and data evaluation
• disposition of results including display and documentation.

The NIBIS approach started with the definition of tasks to be performed, and is based on the idea that these tasks can be supported by an information system. This approach is in contrast to traditional designs of information systems which are structured according to their internal functions (Burrough, 1986).

To ensure that users access and employ system contents in accordance with their semantic properties, NIBIS introduces a layer of metadata. On the conceptual level, the metadata is constituted by a catalogue explaining the system contents to users. This catalogue is closely related to another one which contains formal descriptions of system contents, to support selecting and querying, etc. The second catalogue is supplemented by a third, which contains metadata to support data evaluation, methods etc. The base for this structuring is the idea that different kinds of metadata are related to different tasks, and that different kinds of metadata describe different kinds of system contents.

Additionally, the different metadata catalogues set up different views of system contents: the first catalogue explains system contents as they should be interpreted by users, and the second and third catalogue describes system contents as they should be interpreted automatically by system functions.

In the context of a soil information system, geometric and attribute data, and different programs for evaluation, display, storage, and documentation of data, and the applicability of these are described within the metadata. Through the metadata, users access these system contents indirectly within a proper semantic context. This generic concept builds a framework for controlled information system use, and can be applied to information systems of different domains.

Logical Overview of NIBIS architecture

The logical structure of NIBIS is a straightforward refinement and extension of the concept discussed. NIBIS is logically divided into three parts or levels. Figure 1 gives an overview of the architecture. The base level is built by information system specific data and functions. This base level is described in the metadata of the second level. These descriptions are supposed to help users in executing their tasks. The metadata is generic in purpose and structure, and specific in contents. This means that the given set of metadata structures can be filled with descriptions of different specific contents in the lower level. To enforce and to facilitate the use of the metadata, a third level is introduced, which is built by components that comprise sets of functions to support the user.

The components, metadata, and data of NIBIS are (cf. Fig. 1):

- The identification components help users to identify system contents available. Using these components, users are able to identify available data either by navigating within a network of textual descriptions (thematic catalogue), or by taking a spatial approach (spatial catalogue). The identification components are supported by the thematic catalogue database, and the spatial catalogue database, respectively.

- The data supply components help users selecting and querying data (data description) and data evaluation modules (methods). These components ensure that data supplied is correct and meaningful in terms of completeness and contents. In order to support data evaluation, the methods component activates and controls data evaluation modules on user demand. The methods component (Bartsch, 1997) controls and introduces alternative methods for the same datatypes, calculation of input data needed, according to user specified criteria relating to output data, and testing for valid input data. In contrast to other approaches that try to formalise modelling techniques and specific algorithms of methods, NIBIS describes methods in terms of input and output data (Bartsch, 1997). The data supply components are supported by the data description and method database, respectively. Both describe the available data and methods formally, and supplement the contents of the thematic catalogue database and the spatial catalogue database.
The document contains a logical overview of the architecture of the soil information system of Lower Saxony (NIBIS). It highlights the set of generic functions provided by components, including thematic catalogue database, spatial catalogue database, data description database, method database, user storage metadata-base, geometric and attribute database, modules, visualization/output programs, user storage database, and databases for user interface, communication, and data supply. The metadata is generic in purpose and structure, specific in contents.

Figure 1: Logical overview
The disposition components handle data according to the demands of users. The visualization component controls data display and data export by employing system specific display and export tools. The user data component supports the user in handling data and metadata produced by the user. These components are supported by the data description database and by the user storage metadatabase, respectively.

The thematic catalogue database contains textual descriptions related with, or pointing to specific data and data evaluation methods. The items of descriptions (topics) are modelled into a hierarchy.

The spatial catalogue database contains pointers to space related data.

The data description database describes data available in terms of location, structure etc. The descriptions also include applicable methods described in the method database, visualization programs, and selection criteria.

The method database describes methods available in terms of data evaluation and production modules. For module programs, physical locations, input, output data etc are stored. The descriptions include ordering and homomorphism relations between modules.

**Implementation overview**

The implementation of NIBIS is driven by the logical structure and the technique chosen for inter process communication. The implementation realized out in the MS-Windows environment which allows to follow a document centered approach. Figure 2 gives an overview of the implementation.

- The user storage metadatabase describes data produced by data evaluation methods in a fashion specific for each user.
- The geometric and attribute database contains system specific data. The modules are programs for data evaluation. Modules produce new data. Examples are pedotransfer functions or numerical simulation models.
- The visualization/output programs export data from NIBIS and put them under direct user control.
- The user storage database contains data produced by methods invoked by the user.

The logical structure of NIBIS is likely to be implemented following a cooperative component design. All components (cf. Fig. 1) interact in a client server fashion, and therefore have to use inter process communication facilities (communication). If necessary, they also have to be able to cooperate with databases (database access) and the user (user interfaces). In Fig. 1 these facilities are only shown for the none database components depicted as boxes.

To illustrate the document centered approach, the upper level depicits documents instead of functional components. These documents belong to different classes, are designed to support one ore more user tasks, and are accessible to users like any other document, e.g. MS-Word document. The documents are related to, and are generated according to metadata describing the specific information system contents.

The NIBIS specific document classes can be used together as demanded by a specific system. This enables users to use prepared networks and to build their own network of primary information system contents, and of results produced with the information system. The different document classes, metadata, and specific data, as well as functions of the implementation are:

- Topic directory documents describe system contents thematically. Inside a directory, topics are organised into a hierarchy which is inherited from a thematic catalogue database. Topics have descriptive attributes, and act as a container for related material like texts, pictures, spreadsheets etc. In particular, they contain information documents (see below). In order to find system contents available, users can navigate between topics. Topic directory documents are one main entry point into the system, and can be copied by users and adjusted to their needs.
- Spatial directory documents contain information documents (see below), which refers to spatial data. Spatial directory documents are used by communicating the geographical coordinates of the region of interest to them. They will respond with lists of information documents which identify data available within the specified region. Spatial directory documents are a second main entry point into the system.
Information documents describe data available in terms of adequate selection criteria, methods for production, visualization programs, and output of data. These attributes are predefined within data description and method databases, and are inherited by the information document. Users can tune information to their needs by filling out criteria and choosing methods and visualizations. If data is produced by the application of methods from an information document, this data can be labelled as being generated by this information document. Information documents can be reused and be related to other NIBIS and non-NIBIS documents. Using information documents means to have a controlled access to system contents within the limits and applicability of data and methods. All data provided via information is explained in catalogues and is guaranteed to be consistent with the user’s request.

The catalogue databases contain textual descriptions related with data and data evaluation methods available. The single units of description, called topics, are modelled into a hierarchy.

The data description and method databases describe data and methods available. Data is described in terms of location, structure etc. The data descriptions also include applicable methods of the method database, visualization programs, and selection criteria. The methods are described in terms of data evaluation and production modules. For module programs, storage location, input, and output data are stored. The descriptions include ordering and homomorphism relations between modules.

The geometric and attribute database contains system specific data.

The purpose of the method programs is data evaluation. Their semantics is to produce new data using existing data. Examples are pedotransfer functions or numerical simulation modules. The output programs export data from NIBIS, and the user has a direct control of the data afterwards. Examples are mapping or spreadsheets tools.

Technical features

NIBIS follows the client-server architecture as defined by the OLE-technology. This technique determines the inter process communication. NIBIS uses this technique to deposit and to identify information documents, and to exchange queries between different components and the user. Components (cf. Fig. 2) allow users to modify queries with selection criteria, modify queries and produce result data by themselves with methods and allow users to display results within the limits defined by metadata.

NIBIS supports different document classes and servers, and is integrated into Microsoft’s OLE technology. NIBIS cooperates with other OLE-tools like the Microsoft Office products. NIBIS documents can act as a container for other OLE-documents and can be linked to or embedded into OLE-documents.

NIBIS documents can be manipulated by users. Possible actions are saving, copying, linking, embedding etc.

The functional and metadata components of NIBIS supporting user tasks can be replaced or added. Examples for possible extensions are catalogue components and catalogue databases dealing with time series, new visualisation programs, or new domains and their methods.

For database access, NIBIS relies on Open DataBase Connectivity (ODBC) technology. This enables the system to have access to databases of a wide range of database management systems.

Conclusions

The NIBIS approach is hoped to give access to data and methods stored in the soil information system to a wide range of different users. This is done by describing and providing soil related data and methods in a context which assures that they are used only within proper limitations and where their applicability and significance have been established.

The implementation of NIBIS as a set of cooperative components allows for an extension, if needed. The NIBIS architecture is open to the scientific evolution and to the requirements of other disciplines.

The NIBIS concept is widely accepted within Germany, and has been recommended for implementation of soil information systems by the conference of the environmental ministers of the German states and the Federal Republic (Labo, 1994 a and b, Heineke and Eckelmann, 1998).
architecture of the soil information system of Lower Saxony (NIBIS)

user documents, their mutual relations, and their connection to metadata in the NIBIS implementation

metadata, generic in purpose and structure, specific in contents

information system specific data and functions

NIBIS, in its entirety, consists of different parts, relations, and functions.

Figure 2: Implementation overview
References


Multivariate distance methods for geomorphographic relief classification

Summary

Methods of relief classification have been used increasingly in the geosciences, especially in geomorphology, soil and geological mapping. In the last 10 years these methods have undergone rapid progress. Of the new developments, the classification of the relief into homogenous morphographic units, has become an important tool for delimiting geomorphological, petrographical and soil units during the mapping process.

Introduction

Since the 1980’s, the demands for area-related geoscientific data, especially for digital soil maps has, and still is, growing in the FRG. The need for geomorphographic surface data has grown accordingly. This demand has been fostered mainly by the simple availability of objective geomorphographical basic data which can be derived from digital terrain models (DTM). Digital geomorphographic maps are used especially for soil scientific mapping as well as for the revision of soil maps, their evaluation and interpretation. Above and beyond this, geomorphometric, i.e. geomorphographic data, represent important parameters for the application of pedotransfer functions and models (such as soil water regime, soil erosion). The availability of digital geomorphic data can only be made possible through wide availability of digital terrain models which exist for large regions of Germany (Lehmeier, 1991).

An agglomerative procedure for the derivation of homogenous relief units (which achieves high resolution), has been developed that can be applied universally for geomorphographical relief structuring. Geomorphometrical relief characteristics such as slope, aspect, and curvature serve as basic data.

Methods of relief structuring

Standard methods

A classification of relief attributes and their graphical intersections for the derivation of relief units represents a simple procedure for objective relief structuring. For this purpose, relief form units in the geomorphography are derived in order to describe the curvature of a surface systematically. An
additional subdivision according to slope and aspect are available in the so-called form facets (compare Dikau, 1989). This approach is unsatisfactory, especially in heterogeneous landscapes, since rigid class boundaries (border limits) do not make rational land form structuring possible.

Aside from these simple classification schemes, other complex analytical relief structuring procedures must be considered. With the analysis of cliff profiles or of neighbourhood relationships, classification of a local relief situation independent of rigid values can be undertaken. Solutions are available, for example from Kothe and Lehmeier (1993).

The results of these procedures show distinct advantages compared to a simple structuring, since these take into account local relief discontinuities. Nevertheless, either only one relief attribute was analyzed separately, or only one or two surface dimensions were considered.

For applied geomorphography, relief units in a multidimensional context are interesting with regard to the geomorphodynamics or actual material transport. A procedure of relief structuring must therefore allow a comprehensive examination of surface area forms.

**Multivariate methods and relief structuring**

The application of multivariate distance procedures is traditional in the geosciences and can be considered as a standard method for the structuring, i.e. differentiation of spatial units. The goal of the procedure is to analyse or to differentiate spatial units within a group that has small displacements. The displacements between the groups should be large in comparison.

In geomorphology the use of the multivariate approach is limited for the most part to the analysis of individual surface objects with the help of geophotometrical data. In contrast, the use of statistical procedures for space structuring occurs above all in remote sensing. The procedures for the evaluation of multispectral scanner data are highly developed. Commonly used standard procedures are supervised and discrimination methods, such as the maximum probability method and unsupervised methods such as an iterative cluster analysis.

The use of multivariate displacement procedures for morphographic relief structuring arises from the use of the same procedure in satellite image analysis. Several observation dimensions of a relief are available with the derivation of morphometrical relief data (curvature, slope, and so forth). Combination of all partial aspects describing a relief result in a picture of the relief just as in the combination of multispectral data.

The application of standard cluster procedures allows a relatively good structuring of relief units (compare Kundert, 1988, Friedrich, 1996). A commercial GIS with cluster analysis procedure for the construction of relief units is available with ARC/INFO (ARC GRID) Version 7.x.

If a supervised method is applied, the result of the analysis can be influenced directly with regard to the desired units. In contrast to the spectral data, which exhibit distinctive groups in the scatter-diagram because of the different land uses, these groups are normally lacking in the relief data. Changes in the relief are mostly not abrupt; the single forms flow into each other. This makes a spatial demarcation decisively more difficult.

**Distance grouping method for deriving homogenous relief units**

One method for the solution of the problem of supervised and unsupervised distance procedures is the coupling of agglomerative distance procedures with a spatial neighbourhood analysis.

The basic idea of the method is that two neighbouring sites, which are alike or very similar can be put together in a local spatial unit. This corresponds basically to the approach of the statistical agglomerate procedure. Only those basic units will be put together which on the one hand have very small displacements to each other in multivariate space, but on the other hand are spatial neighbours in the data matrix. Thus with grid data, only neighbouring grid cells of a grid with a very small Euclidian displacement are combined in a multidimensional variable space (relief attributes) to a surface unit. The application of Euclidian displacements proves to be very advantageous, since it allows the possibility of selective weighting of the single variables.

At the beginning of the process a grid point is considered as an autonomous class. With a grid field of 10 * 5, 50 classes are available. These are enumerated
from 1 to 50 (Figure 1). Every grid cell has 8 neighbours, and on the edges correspondingly less. The Euclidean displacement of the related variable vectors \((x_1, \ldots, x_n)\) and \((y_1, \ldots, y_n)\) is calculated for every pair of neighbouring cells.

Starting from the calculated distances, both neighbouring grid cells are combined which have the smallest displacement within the whole data matrix. The neighbourhood has to be newly defined after the combination. As is shown in Figure 1 the grid cells 23 and 24 are combined. The new class becomes the class number 23'. In order to put the new class in relation to the neighbourhood, the maximum displacement of the individual grid cells to all neighbours of the newly built class 23' have to be searched.

The process of agglomeration has to be carried out until a given number of spatial classes is reached. The degree of generalization is set with the stipulation of this break-off point. In Figure 2 three break-off situations are shown which illustrate the different degrees of generalization.

The spatial limitation of individual surface objects (spatial classes) is therewith closed. A map with the limits of the surface objects can be produced corresponding to the displacement relationships to neighbouring surfaces. The border lines indicate correspondingly the displacement to neighbours with different signatures. Attribute data which allow further evaluation are available for each surface object. The most important are:

- surface area object number
- neighbourhood objects with displacements
- number of grid cells
- for variables 1 to n
- minimum
- maximum
- median
- average
- standard deviation

The combination of the individual surface objects to classes takes place through a second procedural step. The surface objects can be assigned directly to a given class or legend unit on the basis of a statistical parameter. For the most part a classification according to average values takes place as shown on the example of the transverse curvature.

In a second option, an iterative cluster analysis can follow by which variable average values of the individual surface objects serve as basic data.

### Data fundamentals and data preparation

Above all the relief form plays an important role in the derivation of geomorphographic units. These can be represented morphometrically by using the curvature. In geomorphology mostly the plane, and horizontal curvature are used (Evans, 1980; Dikau, 1992). Strictly speaking, the plane curvature does not represent a parameter for the description of surface form. Nevertheless, it has established itself in the geomorphology since it corresponds to the curvature of the contour lines. If Figure 4 is considered, it can be recognized that by shifting the plane curvature of the point \(P\) to the top or to the equatorial plane shows very different curvatures that are monotonically dependent on the slope. For the form description the transverse curvature which stands orthogonal to the profile curvature should therefore be used more frequently.

The reciprocal of the calculated radian is used for digital relief analysis. But the special data segment also has to be weighted. For example, in mountainous regions the radii between 50 m and 1000 m are of interest, whereas radii larger than 3000 m can be considered as stretched. Therefore these curvature ranges must be weighted dependent on the problem at hand and the landscape being considered. This requires the simple equation

\[
f(k) = k/ (|k| + T)
\]

with \(k\) being the reciprocal of the radius and \(T\) the transfer constant (reciprocal of the radius that is 0.5 on the y-axis). The results of relief structuring with various transfer constants are shown in the example of transverse curvature in Figure 6.

Aside from the use of the procedure in the applied geomorphography with geomorphometric data, it is also possible to use the method to analyse multispectral data. In this case, experiments with airborne scanner data have just begun. Quantities of available soil water, biomass or actual evapotranspiration can be well differentiated.

### Software utilized

The geomorphometric basis attributes are determined by the program PENK. This is a WINDOWS 3.x application for the calculation of slope, aspect, plane, horizontal, transverse and run-off curvature. The evaluation of homogenous relief units is carried out by the program IVHG. The C++ program puts high demands on CPU and on the working storage capacity of the
computer being used. At present it is running on SGI workstations with ≥96MB working storage capacity. Further automated processing of the analysis results is handled with an ARC macro language application under ARC/INFO 7.x.

Conclusions

The derivation of homogenous geomorphological relief units independent of landscape type is possible with the method described here. The optional choice and weighting of the input variables and degree of generalization are applicable to manifold problems in geomorphography.

At the Hessian State Soil Survey (Hessisches Landesamt für Bodenforschung) the digital relief structuring can serve for the moment as basis for the soil mapping and the revision of soil maps. Above and beyond this, with the completion of the soil map 1 : 50 000 of the federal state of Hesse, the soil units will be subject to an automated relief analysis. Thereby it is planned to subdivide the units recognized as soil associations further on the basis of a relief analysis. In this manner those subunits can be assigned detailed soil descriptions and a high resolution of the description of soil functions can be achieved.

References


Figure 1:

- Neighbours of unit 23
- Neighbours of unit 24
- Neighbours of unit 23/24

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Figure 2:

Generalisation step: 97.3 %
Generalisation step: 98.4 %
Generalisation step: 99.5 %

Frontier line of homogeneous relief units:
- multivariate distance to neighbourhood area
  - small
  - medium
  - large

Variable: plan curvature
Constant for weighting function: 0.00074 (radius 1350 meter)
Original Scale: 1 : 20 000
Figure 3:

Figure 4:
Figure 5:

Figure 6:
Baden-Württemberg pedological information system – principal aspects of system conception

Introduction

Since 1986, one of the main activities of the State Geological Survey of Baden-Württemberg has been to create a state-wide soil-mapping programme on a scale of 1:25,000 and 1:200,000. Traditionally, soil data from field surveys have been used to make soil maps, but increasingly these have been managed, evaluated and distributed by information systems, taking advantage of automatic data processing.

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F. Waldmann

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Object modelling

Applying the Entity Relationship Model proposed by Chen (1976), one of the principal aspects of modelling concerns the spatial structuring of the soil cover into hierarchical soil associations depending on the mapping scale. For example, at its upper level the Soil Map of Baden-Württemberg at the 1:200,000 scale shows the soil region entity, which has a relationship to soil landscapes (Figure 2). The smallest entity marked off on the map is a map unit, consisting of soil groups, and one soil group is composed of soil units.

System conception

The development of a knowledge-based pedological information system which is also easy to use demands an open dialogue between the pedologist, the programmer and the user. The interests of all participants should be equally considered with regard to the technical implementation of a semantic model of the real world. Therefore, the system concept of the Baden-Württemberg Pedological Information System involves a model of all system-related objects, as well as evaluation methods to generate user-orientated data sets with a graphical user interface (Figure 1).

As standardized mapping procedures are used for object modelling a homogeneous database is guaranteed. This meets the requirements to generate physico-chemical parameters by predefined evaluation methods concerning soil permeability, soil aeration, soil erosion, water and sorption
capacity. Furthermore, complex soil potentials can be determined including external sources of data such as land use, climate and relief.

**Empirical evaluation methods**

At the moment, the evaluation methods of the Baden-Württemberg Pedological Information System represent only deterministic models based on simple empirical relationships. For example, the available water capacity of a soil unit is calculated by the field parameters soil texture, humus content, soil density, soil type and parent material (Figure 4). The rules of deduction are taken from the German Soil Mapping Guide (Bodenkundliche Kartieranleitung, 1982), modified to suit local conditions, taking into consideration the laboratory data set of representative soil profiles of Baden-Württemberg.

As geometric data are only available of map units and not of soil groups and soil units, a spatial transformation of soil unit-related parameters up to the level of map units is necessary. Regarding this, at first the average values of a parameter for each soil group (SG) of a map unit (MU) have to be determined by the values of the soil group-related soil units (SU) by equation (1).

\[ \bar{x}_{SG} = \frac{1}{n_{SU}} \sum_{j=1}^{n_{SU}} x_j \]  

(1)

Considering the estimated surface area (a) in % of each soil group of a map unit, the map unit-related average value of a parameter may be calculated by equation (2).

\[ \bar{x}_{MU} = \frac{1}{100} \sum_{j=1}^{n_{SU}} \bar{x}_{SU_j} \cdot a_j \]  

(2)

**System application**

Main constituents of the Baden-Württemberg Pedological Information System are, beside method modules for pedological evaluations programmed in C, FORTRAN and PL/SQL, the Database Management System ORACLE and the Geographical Information System ARC/INFO. The latter manages the geometric data and is used as a development tool to establish a graphical user interface by ARC Macro Language (AML) and the ARC Tools concept (Figure 5).

A session with the user interface starts with the user selecting an object in the PICKER window. Currently, data sets of the objects Soil Map 1:25,000 and Soil Map 1:200,000 and a few examples of the Agricultural Land Appraisal at 1:10,000 are available. If the user has chosen an element of the object, the attribute in which he is interested can be displayed in the ARCPLOT window.

The graphical output is manipulated by different “Drawing Functions” of the TOOLS window. Also, additional data sets of external objects can be selected and loaded into the actual working process using the “Draw Environment” tool. The “GIS Functions” tool allows them to intersect with layers of internal objects. In this way, new information layers can be created and passed on to the query and drawing routines in the PICKER and TOOLS window. For advanced users, command-orientated working with the text editor “SQL/ARCPLOT” is also possible.

**Application example**

Initiated by the Baden-Württemberg Soil Protection Law which came into force in 1991, the development of an effective instrument for decision support processes, in particular for agricultural production, land management and environmental protection, is becoming more and more important. The following application example demonstrates the total evaluation of filter and buffer capacity of soils for organic and inorganic pollutants and acids, using a method taken from a supplementary guideline to the Soil Protection Law developed by the State Environment Department (Umweltministerium Baden-Württemberg, 1995). The input data required are the amount of clay and humus, humus type, soil acidity and hydromorphic properties of soil units.

As shown by an area of the Swabian Alb the total evaluation of filter and buffer capacity, generated by the data base of the object Soil Map 1:200,000, is medium on plateaux and steep slopes (Fig 5). Relatively low clay and humus amounts are responsible for this, as well as low soil acidity of the soil units Rendzina, Braunerde and Terra fusca-Rendzina of mostly shallow depth from silty and silty-clayey loam over weathered limestone or from coarse angular fragments of the Upper Jurassic.

On footslopes, the high filter and buffer capacity of the Braunerde and Braunerde-Pelosol soil units from silty-clayey loam over gravelly clayey loam and loamy clay as well as over weathered claystone, marlstone and limestone of the Upper Dogger is caused by low soil acidity and...
relatively high clay and humus amounts.

A high filter and buffer capacity is also characteristic for the clay and humus-rich Pelosol, Pelosol-Braunerde and Pseudogley-Pelosol from silty and silty-clayey loam over gravelly loamy clay of the Lower Dogger in the Alb foreland. In the flood plains of the valleys the filter and buffer capacity of weakly groundwater influenced soil units such as Brauner Auenboden and Auengley-Brauner Auenboden from gravelly, silty and silty-loamy loam is very high.

Conclusions

Methods used recently for modelling the complexity and diversity of the pedosphere by linking entities such as soil units and soil associations of different level in hierarchical relations are conceptual simplifications of reality. Future models must give more consideration to the interactions between the associated entities described by ecologically relevant processes. Additional investigations will also be carried out to replace existing empirical evaluation methods with numerical simulation models, using soil data resulting from wide-area mapping programs, supplemented by data from remote sensing. Furthermore, specific information systems like the Baden-Württemberg Pedological Information System must be extended to Land Information Systems in a geographical sense, because multidisciplinary databases and methods are needed to support planning for sustainable land use.

References


Figure 1: Concept of the Baden-Württemberg Pedological Information System

Figure 2: Entity-Relationship model of the Soil Map of Baden-Württemberg at scale 1:1,000,000
Figure 3. Examples of encoded attributes of “soil unit” entity

<table>
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<td>Attribute</td>
<td>Soil Type</td>
</tr>
<tr>
<td>Code</td>
<td>LT</td>
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<tr>
<td>Meaning</td>
<td>Parabraunerde of intermediate depth(*)</td>
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(*) classified by German Soil Mapping Guide (Bodenkundliche Kartieranleitung, 1982)

Figure 4: Field parameters to determine the available water capacity (aWC)
Figure 5: Visualising the filter and buffer capacity of soils by a graphical user interface
Preparation of MMK documentary Form A for practical applications

Introduction

Increasing environmental awareness has led to the realisation that soil, ground water and air, which are the basis of life, are not renewable. Governments need appraisals of and information about the soil to recognise, avoid and protect it effectively from detrimental effects. Digital data processing has a special importance for allocating the necessary information.

In 1987 the environment minister set up a special working group (SAG 1989) on soil conservation to develop a concept for a soil information system (BIS) over all the Länder (regions) of the Federal Republic of Germany.

According to this concept, a BIS is built from an operating system and several science information systems (FIS) (Vinken, 1992). One of these is the Soil Conservation FIS. An essential digital database for eastern Germany in this FIS is the mesoscale mapping of agrarian sites (MMK) that is available for the whole region. This homogenous map makes possible the presentation of pedological base parameters and area descriptions or method applications (Kues et al., 1992).

The MMK is divided into three hierarchic levels. The lowest level contains an area database that allows many different interpretations, but the data was not easily accessible. This was the reason for developing a user-friendly application for the MMK in the Sachsen-Anhalt geological survey’s soil information system.

contain soil associations with the typical combination of the main soil type and all other soil types in an area. (Kues et al., 1992). The MMK is divided into three levels (Schmidt and Diemann, 1981).

habitat region (StR):
lowest level with soil type inventory (pedologic and substrate conditions), soil water conditions and relief characteristics

habitat type (StT):
middle level, synoptic of the corresponding StR characteristic substrate, soil water conditions and/or soil type

habitat group (StG):
highest level, synoptic legend unit of the significant differences in the substrate and water conditions of the soil

An important classification element of the StG is the geological parent material of the soil taxonomic data (Table 1), (except for the habitats where dumping has occurred). One StG contains several StTs.

Basic elements of the MMK

The MMK is a map of agricultural land use built from an evaluation of available data and completed by ground examinations. The map units

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Table 1: Structure of the StG (Schmidt, 1987)

<table>
<thead>
<tr>
<th>Sign</th>
<th>geological parent material</th>
<th>STG</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>diluvium, loose sediment and loose rock from glacial and tertiary parent material</td>
<td>1 - 4</td>
</tr>
<tr>
<td>Al</td>
<td>alluvium age, postglacial loose sediment from soil separation in layers and depositions of fluid water and sluggish streams including moors (Mo)</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Lö</td>
<td>loess, wind-laid loose sediment</td>
<td>9 - 11</td>
</tr>
<tr>
<td>V</td>
<td>weathered material, soil-forming on solid rock</td>
<td>12 - 14</td>
</tr>
<tr>
<td>K</td>
<td>dumping floor habitat</td>
<td>15</td>
</tr>
</tbody>
</table>

The StT of D-, Lö- and V-habitats results from the natural habitats of tilth (NSiE), which are deduced by the soil characteristic and the geologic initial material of the soil taxonomic data (Table 2). Mo- and Al-habitats are deduced by another method (Schilling et al., 1965).

Table 2: Natural habitat unit of tilth (Schilling et al., 1965)

<table>
<thead>
<tr>
<th>Soil characteristic</th>
<th>&lt; 27</th>
<th>28 - 33</th>
<th>34 - 44</th>
<th>45 - 54</th>
<th>55 - 75</th>
<th>75 &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSiE</td>
<td>D1/2 D3 D4 D5 D6 Lö5/6 Lö1</td>
<td>V7/8/9 V3/5 V2/4 V1 Lö2/3/4 All1/3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The StT is described by a sign that contains the following information represented by a capital letter, a figure and a small letter (Schmidt, 1987):

capital: geological origin, oriented at the soil taxonomy, completes by Mo for moor and K for dumping
figure: corresponding to the figures of Schilling et al. (1965) (Table 2)
small letter: a = free from water, percolation water dominated soil (anhydromorph soil)
b = dam and/or ground water dominated soil (hydromorph)
c = special characteristic of the soil and substrate layers

One StT is formed by a number of StRs between 3 and ten. The StRs contain, in the form of a post-positioned figure, completed information about substrate, slope, hydromorph, main and other soil types with typical frequency distribution (Schmidt and Diemann, 1981). Further information about the StRs is provided by the documentary Form A (Table 3).

The digitally available documentary Form A is the base for interpretation and thematic treatment. Because of the hierarchical structure of the MMK, it is possible to use the information from Form A after generalization for evaluation of the StT and StG.

Digital appropriation and deduction

In the 1980s the contours and documentary Forms A were digitized using the technology available at that time, which allowed thematic treatments and interpretations to be performed only by data-processing experts. In the 1990s the BGR revised the contents of the MMK, correcting the contours and putting the different versions of documentary Form A on one level (Adler et al., 1995). Now the contours were in ARC/INFO and Form A was available as an ASCII data record. The form and the contours are connected by a label number. This constellation needed extensive special data knowledge by the operator for thematic treatment. This was the reason for developing a data-model in the
ORACLE relational database system and transferring the information from Form A into this structure, which has an interface to the commonly available user software EXCEL (Figure 1). In this case, Form A of the StR was completed with the ST and StG, which can be derived from the StR. For map applications and cartographic work, the GIS tools ARC/VIEW and WINKAT are used. These interface with ARC/INFO, in which the contours are stored. To complement this, a flat sheet screen at the scale of 1:25,000 is available. It is possible to work on freely defined polygons as well as on one or several joined flat sheets.

Table 3: Digital information from the documentary Form A (not complete)

<table>
<thead>
<tr>
<th>field-nr.</th>
<th>field name</th>
<th>content (explanation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>ST</td>
<td>habitat type</td>
</tr>
<tr>
<td>½</td>
<td>Leitbofo</td>
<td>soil type/form</td>
</tr>
<tr>
<td>1/3</td>
<td>Gefuege</td>
<td>distribution of associated soil types in the area</td>
</tr>
<tr>
<td>8</td>
<td>Geolog</td>
<td>geology</td>
</tr>
<tr>
<td>8.1 I/1</td>
<td>Domlil</td>
<td>dominant lithology/petrography</td>
</tr>
<tr>
<td>8.1 I/2</td>
<td>Domlig</td>
<td>dominant lithogenesis/petrography</td>
</tr>
<tr>
<td>8.1 II/1</td>
<td>Sdomlil</td>
<td>subdominant lithology/petrography</td>
</tr>
<tr>
<td>8.1 II/2</td>
<td>Sdomlig</td>
<td>subdominant lithogenesis/petrography</td>
</tr>
<tr>
<td>8.2 1</td>
<td>Domstra</td>
<td>dominant stratigraphy</td>
</tr>
<tr>
<td>8.2 2</td>
<td>Sdomstra</td>
<td>subdominant stratigraphy</td>
</tr>
<tr>
<td>9</td>
<td>Carbonat</td>
<td>depth where carbonate is found, classification in units</td>
</tr>
<tr>
<td>10</td>
<td>Subwechs</td>
<td>depth where the substrate changes, classification in units</td>
</tr>
<tr>
<td>11.1</td>
<td>Steinob</td>
<td>stone quantity in the upper soil, classification in units</td>
</tr>
<tr>
<td>11.2</td>
<td>Steinub</td>
<td>stone quantity in the bottom soil, classification in units</td>
</tr>
<tr>
<td>12</td>
<td>Mesorel</td>
<td>meso relief</td>
</tr>
<tr>
<td>13</td>
<td>Hangneig</td>
<td>slope (parts of slope groups in %)</td>
</tr>
<tr>
<td>15</td>
<td>NFT</td>
<td>slope area type (summary of the slope groups)</td>
</tr>
<tr>
<td>16.1 (1-10)</td>
<td>Relpos</td>
<td>relief position (relief positions of the legend unit)</td>
</tr>
<tr>
<td>16.2 (1-10)</td>
<td>Boform</td>
<td>soil form (soil types/forms of the legend unit)</td>
</tr>
<tr>
<td>16.3 (1-10)</td>
<td>Flaant</td>
<td>area part (area parts of the soil types/forms of the legend unit)</td>
</tr>
<tr>
<td>17.1</td>
<td>Grundwas</td>
<td>ground water (characterization of the ground water influence in four units)</td>
</tr>
<tr>
<td>17.2</td>
<td>Stauwas</td>
<td>dam water (characterization of the impounded water influence in four units)</td>
</tr>
<tr>
<td>17.3</td>
<td>Spezwas</td>
<td>special water ratio</td>
</tr>
<tr>
<td>18</td>
<td>Raumhnet</td>
<td>heterogeneity in area</td>
</tr>
<tr>
<td>19</td>
<td>Inhet</td>
<td>heterogeneity of the main soil type and all other soil types in the area</td>
</tr>
<tr>
<td>22.1</td>
<td>SFT</td>
<td>substrate area type (area parts of the substrate conditions)</td>
</tr>
<tr>
<td>23.1</td>
<td>HFT</td>
<td>hydromorph area type (area parts of the water conditions)</td>
</tr>
</tbody>
</table>

The operation works as follows:
1. Definition of a working area. This could be the whole territory, one or several flat maps at 1:25,000 scale, rural districts or a freely defined polygon.
2. Input of Form A information about the area into EXCEL soft ware.
3. Selection of the required information in EXCEL.
4. Thematic treatment of the selected information and creation of a new legend.
5. Cartographic presentation of the results in ARC/INFO or WINKAT.
6. Printing a plot.
Examples of contents and thematic treatment

The content of the MMK legend sign and the Form A information give many possibilities for applications and thematic treatments from different viewpoints. Some examples are:

1. Presentation of the Form A origin information, for example the substrate area type, hydromorph area type or slope area type (Altermann, 1995).
2. Review of the soil taxonomy (soil characteristics) for estimation of crop suitability and agricultural yield potential of arable soil. This information can be used to deduce the suitability of the habitats as arable and grassland use, as well as the potential for development of a biotope.
3. Interpretation and summarising of the soil and substratum information for the soil survey chart at the 1:200,000 scale (Hartmann et al., 1995).
4. Evaluation tables for cultivation suitability, accessibility for agricultural machinery and suitability for improvement, based on an interpretation of the MMK data with regard to specific questions (Schmidt and Diemann 1981).
5. Deduction of the soil and habitat suitability for tillage and other processes to control agricultural land utilisation, cropping plans and land development (Thiere et al., 1994).
7. Application of methods and models for groundwater recharge, retention capacity for heavy metals in the upper soil and heavy metal risk to groundwater (Hartmann and Schmidt, 1995). The parameter requirements of the methods require the application of complementary data.

For the examples listed, maps of different areas are available. The treatments apply for flat maps at 1:25,000 scale and administrative districts. The methods can be used across the whole MMK. The application scale depends on the resolution of the contours, the number of legend units and the requirement of the methods. Scales between 1:50,000 and 1:200,000 have been successfully used.

Prospect

The application constructed makes user-friendly utilisation of the whole MMK database possible by the operator in charge. In the future the content of Form A should be enlarged by the use of soil profiles. Digitally available soil profiles, which are stored with a co-ordinate reference in a soil profile data record will be connected with the contours of the MMK, sorted by the legend units and levels and interpreted for the single legend unit (Figure 2).
The area data sets of Form A and the related contours should be completed according to the content, which is harmonized at federation level. This way of working enlarges the Form A database and the methodical treatment potential. The available methods can be used for treatments of the whole country or of single regions.

Today about 180 digital and 4,000 analogous soil profiles on forms are available, which can be used as the basis for such an application. In this case the supplementation of the MMK is a base for the continuing specification and unification of soil data.

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**Figure 2: Plan to extend the information of Form A**

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**References**


SAG (1989). Vorschlag für die Einrichtung eines länderübergreifenden Bodeninformationssystems, Arbeitsgruppe Bodeninformationssysteme der Sonderarbeitsgruppe Informationsgrundlagen für den Bodenschutz der Umweltministerkonferenz


Definition and Use of Functional Soil Horizons as Keys in Spatial Land Information Systems

Summary

Local soil management, which combines economical production with ecological protection of soils requires specific and detailed information about the soil continuum. Precision Farming in particular is a challenge to Soil Informatics for developing Soil Information Systems (SIS). Tools are needed which support the most effective, safe and efficient transfer of soil and land characteristics to the integrated evaluation and sustainable use of land. A Three-dimensional Rule-based Continuous Soil-modelling system (TRCS) has been constructed which uses horizon classes as the main carrier for information transfer and integrates the local knowledge of soil experts.

The evaluation of the intra-class variances and discriminant analysis of horizon classes at the main and sub horizon, as well as at the texture level – based on a profile database of German soils (ca. 10,000 horizons) – shows that the definition of horizon classifications should

- not be oversophisticated pedogenetically;
- include geogenetical information about the origin of and human impacts on erosion and compaction of horizons;
- be localized and adapted to the soil conditions of interest.

The definition of horizon designations was applied to the soils of Holstein (North Germany) for optimal prediction of ecological ‘horizon transfer functions’.

Challenges of local soil management

Soils, central parts of land, have come under severe dual stress: increasing populations require more and better food, and manifold degradations endanger or destroy the non-renewable natural resource. Unavoidably, soils have both to be protected and used more intensively. This dilemma can partly be solved with the help of Soil Information Systems (SIS) which extend in four directions. The land user and protector, separated or as one person, urgently need more information about the

- soil-factor relationships. Soil genetics can forecast future processes of soils induced by local and global changes of ecosystems.
- soil attribute space. Increasingly, data about physical, chemical and biological aspects of soils needs analysis and evaluation.
- soil functions. Soils are not only the main crop production factor, but they also affect many alternative land uses by their functions in heat, water and chemicals transfer, as well as in traffic, housing and recreation.
- soil distribution. With increasing precision, the geo-referenced occurrence of the above items should be inventorized and disseminated to various land users.

There are not only degradation risks in soil and land use, but also consequences and challenges. Detailed soil surveys and assessments in drinking water recharge areas, focal sites of alternative land use, show clearly that optimized soil management varies significantly at local level. Differences in water storage, humus binding or denitrification potentials, for example, cause soil-specific risks or inevitable nitrate and pesticide leaching. Therefore, detailed functional soil maps are a very cost-effective prerequisite for land under intensive and competing use in Europe. In these areas, the annual value of a claim for agroproduction
quantity versus drinking water quality, say a hundred Ecu per hectare, may exceed the total survey cost. Of course, the intensity and scale of surveys depend very much on the lateral variability of the soils, but also on the smallest units of land management, traditionally the fields.

As much as a decade ago, a new approach for local soil management was initiated for conditions in North America (Robert and Anderson, 1987) and Europe (Lamp and Knoop, 1988). Differential Global Positioning Systems linked to a computer and ‘yieldometer’ as well as to sensors on farm machinery are state-of-the-art and offered by competing vendors to farmers (Robert et al., 1992; Olesen, 1995). Even though the reliability of electronic devices has still to be adapted to the rough conditions of farming, this approach, called Precision Farming, is now capturing the interests of farmers.

Accordingly, a new functional soil unit has been defined as follows (Lamp, 1986):

- The pedocell is the smallest agrotechnical soil unit which can be treated as unique in local soil management. Its lateral size is defined by point errors of surveying, positioning, steering and recording as well as by the width of tractor lanes (mostly 12-24 m). The lower vertical boundary is determined by the effects on and from the roots of main crops (down to approximately 1.5 m). Based on a detailed farmland inventory, monitoring pedocells are selected which represent all main soil and management units and from which mixed samples are taken by replicates at different soil depths in order to obtain representative analyses.

Local soil management depends on detailed information and is thus confronted with two key questions: Is conventional soil science willing and able to take up these challenges, making a shift from semi-detailed surveys (often 1:25,000 maps) to more specific and detailed inventories, both in the attribute- and the geo-space? How can Soil Information Systems (SIS) help to capture and transfer soil and land characteristics for the evaluation of land qualities at local scale?

**Soil Informatics: goals of a new discipline**

These questions have to be answered by Soil Informatics, a new discipline between soil and computer science. An important concept is the conservation of information when characteristics (survey data) are transmitted to the assessment of soil qualities for sustainable land use (FAO, 1983; Smyth and Dumanski, 1993). A basic rule is to delay the inevitable loss of information due to classification until the final steps within this knowledge transfer. The main topics of Soil Informatics – methodology and control of the information transfer process – are guided by criteria of

- **effectiveness** (predicting the most relevant soil functions),
- **safety** (minimum information loss, best possible correlations) and
- **efficiency** (the most simple and practical methods in relation to effort).

How can we survey soil variation in detail, and transfer information for local soil management, both for better crop production and environmental protection?

One often encounters the misconception that soil variation becomes less prominent at the local scale. Investigations in soil regionalization and geostatistics have shown that each scale has its own sources, methods and interpretations of soil variation, but the relative magnitude is roughly the same. Stepping from the regional to the local scale of variation will increase the need to represent soils not as crisp, sharply bordered pseudo-objects or as association of objects (poly-pedons or complex map units), but to treat soils as they are defined theoretically in textbooks of pedology: as four-dimensional (4D) continuous systems in time and space (e.g. Schroeder, 1994). For inventory purposes only, this system can be reduced to a *3D soil continuum*.

A straightforward approach would be to describe, analyze and map soils in a 3D geo-space by spanning at each observation point an attribute-space of m *continuous variables* whose values have to be determined by intensive analyses. Based on probability theory, *geostatistics* offer variogram analyses and Kriging-interpolation in order to plan and evaluate point surveys and generate isoline maps of variables describing the soil continuum. Variograms from surveys in North Germany show repeatedly that the *efficient distances* which account for half of the relevant semivariance between the nugget effect and the sill are mostly between 40m and 80m for young and old morainic soils, respectively (Otte, 1988). The geostatistical approach may be appropriate for sites of scientific ecosystem research, but it faces problems in practical applications for local soil management. Even soil analyses at a 50m grid, which still do not
meet all steerable soil variation within fields of many soil landscapes, will not be accepted by farmers due to economic restrictions. Therefore, an approach requiring less effort has been developed which aims to make use of available landscape and soil data and to take advantage of the knowledge that soil experts have accumulated through many present and past inventories. The ability in contextual thinking of human experts still exceeds that of computers by orders of magnitude.

In acting as a tool for local soil inventories, a Three-dimensional Rule-based Continuous Soil Modelling System (TRCS, Ameskamp, 1997) was created. Its functions are explained by Ameskamp and Lamp (1998), but the characteristics are summarized as follows:

- **Three-dimensional:** Soils are treated as they are defined in textbooks. 3D modelling stresses the mental concepts of pedologists about soil covers. In contrast to conventional soil mapping, early and irreversible information losses are avoided.
- **Continuous:** The Fuzzy set theory is applied to soil continua in order to represent gradual changes within the often 'diffuse' contents of the soil cover by the membership of horizons.
- **Rule-based:** The model aims to accept and use the expert knowledge of soil surveyors (loc.cit). In TRCS, rules can be defined interactively in order to link landscape features, as given in standard data sets, to models of the soil cover.
- **Horizon-based:** Continuous variables defining the soil continuum are not available at appropriate distances for applying direct interpolation techniques. Even experienced soil surveyors find it difficult to think within the soil geo-space in more than a limited number of additional attribute dimensions. Both reasons forced the use of soil horizons as the main carrier of information.

Spatial models of the solid soil are essential for landscape balances which take into account not only matter inputs and outputs of profiles, but also the effects of lateral translocations caused by water and tillage erosion as well as soil interflow. They are also important for the monitoring and prevention of ecologically risky substances, like phosphate, nitrogen and pesticides, and are a prerequisite to 3D dynamic modelling. Lateral translocations play major roles in most sloping European landscapes but levelled soils derived from fluvial and marine stratified sediments show significant lateral matter transfer, too. Horizons open the 'understanding' of soils to expert modelling, but imply a rather early classification. Therefore, horizon concepts will be discussed in detail and solutions offered to avoid or minimize information losses.

### Concepts of horizon taxonomy

Traditionally, soils are described by horizons, horizontally stratified layers within the soil continuum, which specify the genetical status of choral developments within and of soils.

The early designations A - B - C, originated by Dokuchaev, represent the effects or products of soil processes by three horizons: A signifies an ongoing period of topsoil humus accumulation, B summarizes transformations and translocations of minerals in the subsoil, and C is the unchanged parent material. Since then, various systems of designating horizons have been developed at international and national levels as summarized by Bridges, (1990, also ISSS 1985, Fitzpatrick, 1993). The German federal soil surveys use a system – more extended than others – of 15 main symbols (capital letters) combinable with 25 pre- and 31 suffixes (small letters and numbers). Preferably, it describes relative differences of attributes within soil profiles. Following the diagnostic chain of the survey manual and classification system (Arbeitsgruppe Boden 1994, WG on Soil Informatics 1985), values of basic field attributes, complemented by laboratory analyses, define horizon designations, and combinations of these the pedogenetical soil ‘classes’, ‘types’, ‘subtypes’ and ‘variations’. Subdivided by geogenetical criteria of texture stratification, 'local soil forms' are used at the lowest level to describe the contents of semi-detailed soil maps. Thus, horizons play a basic role in the information transfer of German soil surveys.

A background for horizon taxonomy is given by the extended chain of pedogenesis and pedofunction (Fig. 1; Schroeder and Lamp, 1976): based on the identity of factors and eco-components in a feedback ecosystem, a bundle of factors steer a combination of processes (isogeneous soils) which manifest themselves in similar attributes (isomorphic soils). These effect the same functions within the ecosystem.
(isofunctional soils) and extend mainly at the same location (isotopical soils). By this chain, all soil taxa defined from the different views should in principle coincide. The departures from this ideal which often occur in practice can in turn be used to optimize the system.

The four principles of soil classification — affinity, similarity, functionality and neighborhood — characterize the most important views on soils. They have entered TRCS as follows.

**Affinity:** This principle relates soil attributes to external eco-components, especially the pedogenetical factors: climate, organisms, relief, parent material and time. Jenny (1942) was the first to formalize this view and to describe the cause-effect relationships under *ceteris-paribus* conditions: litho-, bio-, topo-, and chronosequences provide an idealized description of the pattern of soils in the landscape. Thus, *pedogenetics* was founded by Dokuchaev and extended by more than three generations of pedologists and soil surveyors. It is summarized in many textbooks, publications and map reports, and as the paradigm of soil surveys it is still the basis for making maps. Relief and vegetation data especially can easily be captured in the field, and by including parent material where geological maps are available, these sources are used to map soils indirectly, thus reducing the efforts of soil augering. *Soil indicators*, especially topsoil colour and structure which can be sensed remotely, increase the prediction power. The US Soil Survey uses colour air photos with great advantage, but also in North Germany the survey effort can be reduced with the aid of stereo-images to 40% (without quality loss in mapping: Jakob, 1981). Therefore, TRCS uses panchromatic images and base topographic maps, including 1m elevation isolines, and the soil rating data which are available for all agrarian landscapes of Germany. These standard sources are transferred via fuzzification into the landscape model which is related to the soil model by means of rules about the factor-soil relationships. In order to include the local pedogenetical knowledge, these rules are interactively defined by soil experts and constitute the soil-landscape model.

**Similarity** is based on assumptions about internal relationships of soil attributes which can be investigated by various techniques of multivariate inference, ordination and cluster analyses. If soil taxa are treated as independent (class) variates, the relative *intra-class-variance* of special soil attributes can be evaluated and interpreted as a morphometric measure of the classification quality. *Profile databases* can be used to answer these questions and another about the *depth function* of horizon taxa which will help to set up and

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**Figure 1: Extended chain of pedogenesis and pedofunction**

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282
improve the taxonomic soil model as used in TRCS.

**Functionality:** Other questions applicable to soil databases concern the correlations and regressions between basic field data that are easy to retrieve and laboratory attributes of soils which represent functional aspects or land qualities. This leads to the concept of (internal or external) pedo-transfer functions (PTF) (Lamp and Kneib 1981, Bouma and Van Lanen 1987) which are used to predict from basic soil data the parameters of water storage and permeability or of buffer capacities for agrochemicals, for example. A severe shortcoming of PTFs is that even basic field data which derive from soil borings are rarely available in survey areas. Therefore, we use horizon transfer functions which are defined from the database by means of horizon class statistics.

**Neighbourhood:** Soil attributes as well as factors or eco-components tend to change only gradually over landscapes. Neighbouring soils at adjacent locations therefore tend to belong to the same taxon and define soil units at the local or topological scale. Soil taxa should be designed to support the contiguity of soils and be thus mappable. TRCS uses this principle to generate the soil-landscape model from the fuzzified parameter of the landscape without internal interpolation of (non-existent) point soil data. If the dimension is extended from the local to the regional and global scale, soils are more heterogenous and due to the increasing complexity of the systems – show lower correlations within soils and between soils and factors or eco-components.

**Results from a Profile Database**

**Design of the database**

A relational profile database is designed and can be linked to TRCS in order to handle all kinds of point and tabular soil data which are connected with surveys. Older (ASCII and dBASE) files containing data from various sources in Germany (dissertations, special projects, map reports; Lamp, 1982) have been updated and incorporated into an ACCESS database which can be linked via ODBC to central systems. A general problem of amalgamating soil data from different sources, whether at inter-state level in Germany or in Europe, is the data heterogeneity which is caused by the fact that soil surveyors often use differing criteria such as:

- representative volumes: e.g. pH-values have different ‘backgrounds’ if taken from a small boring, or as volume-mixed samples from a profile pit or from a pedocell.
- organization levels: attributes used differently at area, site, horizon, ped level (see below).
- attribute sets in field or laboratory data: results are missing values and attributes that will be left out either from the database or evaluations.
- method versions in coding or measuring values of soil attributes: this results in ambivalent values of attribute fields within a database, e.g. pH-values measured in different solutions.
- subjective coding: soil classifications, especially at profile or horizon level, may lead to subjective results which mirror differences in schools rather than in soils.

Data heterogeneity is a severe obstacle for any consistent evaluation of soil databases. Therefore, if it cannot be avoided from the very beginning, important parts of soil databases are the metadata and method bases. Their main functions are to keep track of the attribute sets, method versions and survey conditions for each unique survey project, as well as of the methods and rules used for any evaluation. Built-in tools may also be used to fill in missing, but essential, data via regression statistics from given data. The soil database, called SOLUM, is designed to fulfil these functions and also includes a bi-lingual data dictionary by which soil attributes and their values can be defined in two languages: the standards are international terms which are linked to updatable local equivalents. A simplified scheme of the database is shown in Figure 2.

**Taxometric results**

For this profile database, which includes field and extended laboratory data of about 10,000 horizons, taxometric results are given. Figure 3 shows relative intra-class variances of several quantitative soil attributes on three classification levels. As discussed by Lamp (1982) in greater detail, these statistical indicators of isomorphy drop from 89 and 83% intra-class variance for purely pedogenetically defined main and sub-horizons, e.g. Ah and AhBv horizons, to 54% when the origin and texture of horizons is added to the class definition (e.g. AhBv from loess). Consequently, it is very important for any functional
classification to include texture and stratification information about soils.

Figure 4 also shows the attribute variation on the two pedo-genetical horizon levels, but the statistical background is more complex: the 90% class variance is plotted against the first two canonical variates which – derived from discriminant analysis – account for about 50% of the total variance of all attributes. On the level of main horizons a good differentiation between BC and Bv into Bt and Bs horizons is given and only one-third of the samples were reclassified. The spread ellipses of Bt and Bs horizons support the theory that the processes of clay and sesquioxide leaching are quite distinct: Podzols do not develop from Luvisols. Notice that on the subhorizon level the misclassification increased to nearly 60%. This is probably a result of an oversophisticated soil classification: as judged from morphometric analysis; surveyors seemed to have difficulty in assessing the correct class. This diminishes the overall functional use of the classification.

Quantification and localization effects on pedotransfer functions

The canonical diagrams of horizon taxa given above confirm results from many investigations in soil variation: the groupings of sample points within the soil attribute space show rather fuzzy overlaps and vague class boundaries. Correspondingly low are the concordance of object points as well as the correlation of attributes, the latter measured by the squared correlation coefficient $r^2$. Examples are given by figures 5 and 6 which show the effect of different data sets on the regression fit of pedotransfer functions, here the cation exchange capacity (CEC), the available water capacity (aFC) and the organic matter (Corg) of horizons. Both the inclusion of quantitative (but costly) analyses
and the localization of sample sets (using only data from North Germany or Holstein instead of taking data from all of Germany) increases the fits of the PTFs (Otte, 1988). Figure 5 may be taken to evaluate marginal effects of survey quantification and Figure 6 shows the effects of adapting transfer functions to local conditions. This is also emphasised for the use of TRCS: the rules of transferring the landscape into the soil model should preferably be done by experts who are capable of inferring local soil knowledge.

Defining horizons for surveys of local soil management

The soil ‘universes’ of concern are agrarian soilscapes within Pleistocene regions of Holstein, North Germany. In a ‘rolling’ terrain developed from young (Weichselian) moraines, Cambior Luvisols in upper positions intergrade to Stagno- and Gleysoils on slopes and Histosols in depressions. On tilled land, these soils are modified by erosion and colluviation which predominate at slope shoulders and footslopes, respectively. Standard pre-information available for these landscapes has been used: 1: 5,000 topographical maps with 1m elevation isolines, mainly 1:12,000 panchromatic stereo images from several flight sorties, and from the German pre- and post war soil rating system (Bodenschätzung) the class boundaries on 1:2,000 maps and the field descriptions of 3-4 layers from characteristic pits. Farmers resisting pressures to intensify follow an economical production of fodder (silage grass and maize) and market crops (winter wheat, barley and rape seed). The main potential soil and water degradations are erosion and compaction as well as nitrate and pesticide leaching.
Adapting horizon designations

From the main horizons of the German survey manual, only the upper case designations A, B, C, S, G, H, M and - following international convention - the letter E are relevant for the area. The German system lists many suffixes denoting pedogenetic attributes and variations of the main horizons. Only the ones listed in Table 2 are of interest in Holstein agrarian landscapes. For proper pedofunction prediction, Ap horizons are differentiated by - and + signs in order to handle the relative increase and decrease of organic matter in topsoils which are important for nitrogen transfer, pesticide binding and erosivity assessments.

Following the German rules, prefixes denote geo- and anthropogenetical factors or effects. Therefore, the bulk density which is needed for many functional calculations has to be specified by deviations from normal density depth functions (w and d: see these and other symbols in Table 2). Texture coding is also essential, but kept apart from horizon symbols: usually two letters designate the main texture classes. Due to their strong influence on water holding and management qualities, sands should always be subdivided and greater amounts of stones be recorded.

Transition principles

In Table 2, only a small number of horizons have been summarized, leaving out all transitions which often occur in soils and which may be coded at the main as well as the prefix and suffix level. Only up to two transitions should be used for horizons of (real) field profiles, both at the main and the pre- or suffix level. The second symbols always designate dominance. Theoretically, the term interstate can be used to denote a transition in attribute space, and the term intergrade to designate transition in geo-space, both vertically and laterally. But both kinds of transition are difficult to differentiate in practice and their effects on pedofunction predictions are small. The vertical combination of two horizons with increasing depth are separated with a slash (/) and intergrades of two designations within the same horizon by a minus (-).

Computer models demand a precise nomenclature of horizon designation including rules for transitions in the geo-space (Ameskamp and Lamp, 1998). Therefore, rules for ordering along formal and genetico-factorial trendlines are set up as follows.

- Humus accumulation: The humus content is raised by water excess (indicated by soil hydromorphy). In comparison to normal (terrestrial) Ap horizons often with 2–4% humus, the content of hydromorphic soils may have doubled where Gleysols occur.
and reach even 100% in depressions with (relictic) Bog Soils where earlier ponds have been drained. The full sequence in humus contents of tilled topsoils is: Ai / A- /Ap /A+ /Aa /Hn.

- **Humus mass redistribution:** Water and tillage erosion along hill slopes lead to a redistribution of the humus mass from steadily eroded and ‘decapitated’ soils, mainly at slope shoulders, to colluvia of more than 1m thickness, mainly at the foot of slopes. There, the vertical sequence is: Ap+ / M / X (X = any horizons, often fA, S, Go, also Bv or Bt).

- **Translocation by descending or ascending water:** Weathering generates the Ah / Bv / C combination of Brown Earths. Additional leaching of clay-humus complexes by descending water leads on loams to the Ah / Et / Bt / C profile of Para Brown Earths or on sandy soils with increasing acidification to an Ah / Es /Bhs / Bs / C of Podzols. Stagnating water caused by impermeable layers creates the Ah / wS / dS (C) combination of Stagnosols and ascending water in soils with high ground-water tables generates an Ah / Go / Gr of Gleysols.

From these main sequences of pedogenesis, the rules for intergrading can be derived for soils with normal (simple, un-sequential) development. For example, the following intergrades of a Para Brown Earth and a Pseudogley or Brown Earth and Gleysols can be generated (parentheses denote facultatives and | alternatives).

**Pseudogley-ParaBrownEarth:**

\[ \text{Ah|Ap} / (wS-Et) / dSBt / dSC(c) \]

(minor effects of mottling)

\[ \text{ParaBrownEarth-Pseudogley:} \]

\[ \text{Ah|Ap} / \text{Et-wS} / \text{BtDS} / (Cc-)S \]

(major effects of mottling)

\[ \text{Gleysol-BrownEarth:} \]

\[ \text{Ah|Ap} / \text{Go-Bv} / \text{Bv-Go} / \text{Gr} \]

(groundwater lower)

\[ \text{BrownEarth-Gleysol:} \]

\[ \text{Ah|Ap} / \text{BvGo} / \text{Go} / \text{Gr} \]

(groundwater higher)

**Horizon depth functions**

From the profile database Solum, simple statistics of the lower boundaries of the horizons (mean, standard deviation, skewness) were generated from global and local datasets and used to construct the curves in Figure 7. These horizon depth functions were used to specify the profile models in TRCS and describe the transition of horizons within the main soil taxa of the area. The Ap horizon, for example, always has a sharp lower boundary due to the ploughing depth, fixed by the German farmers:to a mean of 28 cm and by the Holstein farmers to 31 cm (for other differences of global versus local depth statistics see the example of the Para Brown Earth). Statistics of more detailed subdivisions exist and are stored in files, but are not shown here.

**Horizon transfer functions**

Soil qualities which are important for local soil management in Holstein can be assessed directly from local horizon classes by means of interpretation or transfer tables. The means and standard deviations of selected function values, as given in Table 2, were evaluated from the profile database SOLUM, but because of the reduced sample sizes of the local data sets, the results were supplemented by the national field manual (Arbeitsgruppe Boden 1994). The examples are not exhaustive, but show special effects of varying humus contents and texture classes for tilled topsoils and Bv subsoils, only. Notice that capacity functions are related to a unit horizon thickness of 10 cm. They can be summed over the total thickness of the horizons as modelled by TRCS. For these functions the fuzzy class membership can also be included to achieve a total (weighted) function of the soil continuum (Ameskamp and Lamp, 1998).
<table>
<thead>
<tr>
<th>Prefix description (Geo-/Anthrogenesis)</th>
<th>Main horizon</th>
<th>Suffix description and diagnostics (Pedogenesis and morphology)</th>
</tr>
</thead>
<tbody>
<tr>
<td>optional: e, a, f lower peat</td>
<td>F</td>
<td>Horizon formed under water (lake debris)</td>
</tr>
<tr>
<td>(fossil, relictic)</td>
<td>H</td>
<td>Bog horizon, OM &gt; 30%</td>
</tr>
<tr>
<td>A</td>
<td>a</td>
<td>Anmoor, OM 15-30%</td>
</tr>
<tr>
<td>f,r</td>
<td>h</td>
<td>OM &lt; 15%, strong decrease with depth</td>
</tr>
<tr>
<td>natural deposit</td>
<td>A</td>
<td>+ 2) Enriched plough horizon, OM 4-14%</td>
</tr>
<tr>
<td>artificial deposit</td>
<td>J</td>
<td>Bog horizon, OM &gt; 3%</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>Normal plough horizon, OM 3-4%</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>Eroded plough horizon, OM &lt; 3%</td>
</tr>
<tr>
<td>loose, water bearing</td>
<td>W</td>
<td>Colluviated, under Ap, OM &gt; 1%</td>
</tr>
<tr>
<td>dense, compact</td>
<td>D</td>
<td>Loss of clay (often decapitated, =Al)</td>
</tr>
<tr>
<td>optional: e, a, f</td>
<td>I</td>
<td>Loss of oxides ( ,, , =Ae)</td>
</tr>
<tr>
<td>interflow at slopes</td>
<td>G</td>
<td>Bleached by water excess</td>
</tr>
<tr>
<td>marly(2-25% carb.)</td>
<td>E</td>
<td>Weathered, brownish (OM &lt; 1 %)</td>
</tr>
<tr>
<td>Strata w.OM(alluvial)</td>
<td>A</td>
<td>,, ,, , but clay enriched (&gt;1 class)</td>
</tr>
<tr>
<td>,, , no ,, (fluviogl.)</td>
<td>C</td>
<td>Oxide enriched</td>
</tr>
<tr>
<td>Stones (&gt;2mm)</td>
<td>X</td>
<td>Many redox mottles (&gt; 70%) by stagnating</td>
</tr>
<tr>
<td>Sand(y) (2-0.6mm)</td>
<td>S</td>
<td>water, 'introverted' Fe</td>
</tr>
<tr>
<td>Silt(y) (63-2 µm)</td>
<td>U</td>
<td>Oxidized groundwater horizon (&gt; 3 % ox, Fe)</td>
</tr>
<tr>
<td>Loam(y)</td>
<td>L</td>
<td>Reduced groundwater horizon (&lt; 2 % ox, Fe)</td>
</tr>
<tr>
<td>Clay(ey) (&lt;2µm)</td>
<td>T</td>
<td>Parent material with carbonates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbonatefree parent material</td>
</tr>
<tr>
<td>Duplex symbols specify intergrades, eg.</td>
<td></td>
<td>s                  Duplex symbols specify intergrades, eg. si</td>
</tr>
<tr>
<td>stones (2-0.6mm)</td>
<td>s</td>
<td>t</td>
</tr>
<tr>
<td>stones (63-2 µm)</td>
<td>u</td>
<td>t</td>
</tr>
<tr>
<td>stones (&lt;2µm)</td>
<td>l</td>
<td>t</td>
</tr>
<tr>
<td>stones (&gt;2mm)</td>
<td>x</td>
<td>t</td>
</tr>
</tbody>
</table>

1) One prefix or suffix per main symbol only, prefixes are optional, suffixes obligatory (if given). The second position of duplex letters always specifies dominance.

2) Loss and surplus of organic matter (OM) in Ap horizons (p may be omitted).

3) d and w designate difference of soil density caused mostly by geogenesis (ice compaction in C and S horizons), management (in A, B, M, S) and sometimes pedogenesis (SBt).

4) Fossil (buried) horizons are situated beneath the normal horizon combination and can be recognized automatically. Formed in periglacial or wetter periods, many S and G horizons are relicted now, especially when land is drained (but r is difficult to recognize).
Figure 7: Depth statistics of selected horizons in German soils

Table 2: Horizon transfer functions (means and standard errors) of selected horizons in Holstein soils.
Conclusions

The need for local soil management, both for better crop production and for environmental protection, is a challenge to Soil Informatics to develop effective, safe and efficient methods for the detailed surveying and modelling of soils.

An essential part of soil modelling is the ability to handle soils as continuous three-dimensional systems, and to allow the incorporation of the knowledge of soil experts about the structure of the local soil continua. Therefore, soil horizon classes are introduced as the main carriers of information in the modelling and knowledge transfer process. In order to reduce early information losses due to classification, the horizon have to be adapted to the local conditions and functional aspects of the soils and their local management.

References


Integrating GIS and process models for land resource planning

Summary
The use of Geographical Information Systems (GIS) for the storage, analysis and presentation of land resource data has diversified rapidly during the last ten years. The major emphasis of the current GIS applications is, however, on the storage, management and presentation of spatial data. Until now, the analysis or modelling applications of GIS have been quite limited in number and complexity.

On the other hand, a large number of scientists in the world have developed computer models for erosion, leaching and crop production, and for the simulation of all kinds of processes.

Most of the current models are good for describing the process under study, but they are lacking proper tools for the input and management of spatial data needed to run the models, and have limited facilities for presentation of the results. These are aspects in which GIS has its strength, so a combination of GIS and process models is attractive from both sides.

In this paper the subject of integrating GIS and process models for land resource planning are discussed from three viewpoints. First, the conceptual aspects of the integration, especially the space and time data requirements of the process models, are considered, and the potential of current commercial GIS to meet these requirements is discussed. Second, the subject will be viewed from a technical implementation angle. Two main types of integration are distinguished: loose and tight. Advantages and disadvantages and technical consequences of both integration forms are described. Third, a few practical examples of the integration of GIS and process models in the field of land resource planning are presented.

Introduction
During the last ten years, GIS applications have been developed for a large variety of fields, ranging from land use planning and utility management at local level, to global warming and acid deposition on a global scale. Current GIS applications, however, tend to concentrate on the storage, management and presentation of spatial data, not the analysis or modelling applications. This is partly due to the limited functionality in this regard provided by commercial GIS software houses.

Many scientists, however, have developed process models to demonstrate pesticide leaching, erosion, hydrological features, acid deposition, crop production and the simulation of all kinds of processes. Many current models lack proper tools for data input and management, and have poor presentation facilities. GIS is strong in these areas. The main focus of this paper is on the conceptual aspects of integrating GIS and process models. When referring to GIS in this paper, the meaning of commercial GIS is taken to be as described by Goodchild et al. (1992):

"a database containing a discrete representation of geographical reality in the form of static, two-dimensional geometrical objects and associated attributes, with a functionality largely limited to primitive geometrical operations to create new objects or to compute relationships between objects, and to simple query and summary descriptions."
Describing the real world

The real world can be considered as a continuum in four dimensions: three dimensions in space and one in time. A great variety of processes take place, which change the status of the world continuously. These processes may have quite different spatial and temporal scales. For instance, daily processes due to the input of solar energy, yearly processes due to seasonal variation in weather and processes on a time scale of millions of years like the formation of mountains. Some of the processes are discrete in time (e.g. earthquakes), some have a continuous character. All these processes and their interactions lead to a world which changes from second to second and is so complex that we will never be able to describe all aspects to their full extent.

To achieve an understanding of the world, people have collected data about the status of the world and studied the processes which take place. In addition to pure scientific interest, the main reasons for doing so is that we need this information for the management of our environment today and that we want to know how things might change in the future. It is, however, impossible to get an exact description of our world. An exact description is also not necessary; it is enough that we construct models of our environment which satisfy our information requirements.

In the process of obtaining user-specific information of the world, various steps can be distinguished (Bregt, 1992). These steps are presented in Figure 1.

In the first step, data about the real world are collected and processes are described. As we are dealing in this paper with geographical information systems and process models, the storage of data in a database and the implementation of a described process in an algorithm are included in the first step. In the second step (analysis), the data or a combination of data and process model are used in an analysis to derive the requested information. Note that in this step, data alone can be analyzed, but that process models are applied only in combination with data. In the third step, the information obtained is presented (presentation) and may be used to initiate certain actions which influence the world.

The current domain of GIS includes data collection, storage, analysis and presentation. It does not, however, include the application of process models.

Data models

Geographical reality can be described completely by recording all possible attributes at all possible points in space and time, or in other words what (attribute) appears where (space) and when (time). It is obvious that this is impossible in practice, so the activity of capturing reality must involve simplification and generalization. Geographical data have been collected and are
For geographical data a variety of data models are used. Reviews of data models in use have been published by Peuquet (1984) and Goodchild (1992b). According to Goodchild (1992b), data models for geographical data can take two broad forms, depending on whether reality is perceived as an empty space populated by objects, or as a set of layers or fields, each defining the variation of one or more variables. Although both data models describe geographical reality in a discrete way, the conceptual view of the earth is different. The first approach describes discrete geographical objects (object) and in the second approach, continuous geographical phenomena (field). In general terms the object data models are more relevant for data in the areas of utility management, cadastral inventories and social sciences. The field data models are in general more relevant to environmental and physical sciences. In Table 1, the characteristics of the most commonly used data models in commercial GIS packages are presented. For more information see Goodchild (1992b) and Kemp (1993).

The first four field models (cell grids, polygons, TIN and contour) provide a complete coverage of the Earth’s surface. The last two field models (point grid and irregular points) only provide information at some points. In order to obtain a representation of a continuous surface, some form of interpolation needs to be applied, for which a large variety of methods are available (Burrough, 1986; Stein, 1991).

Table 1: Characteristics of commonly used data models.

<table>
<thead>
<tr>
<th>Model category</th>
<th>Model</th>
<th>Dimensions</th>
<th>Measurement scale of attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>object</td>
<td>point</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>object</td>
<td>line</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>object</td>
<td>area</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>object</td>
<td>volume</td>
<td>x,y,z</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>field</td>
<td>cell grids</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>field</td>
<td>polygon</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>field</td>
<td>TIN</td>
<td>x,y</td>
<td>quantitative</td>
</tr>
<tr>
<td>field</td>
<td>contour</td>
<td>x,y</td>
<td>quantitative</td>
</tr>
<tr>
<td>field</td>
<td>grid points</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
<tr>
<td>field</td>
<td>irregular points</td>
<td>x,y</td>
<td>qualitative, quantitative</td>
</tr>
</tbody>
</table>

TIN = Triangulated Irregular Network

If we consider the data models in Table 1, we see that in most models in use the z and t dimension is missing. There are various reasons for this:

- the models were proposed before the introduction of geographical information systems. They originate from a period when the main use of the data model was to visualize geographical data on a map. As a map can display geographical data in two dimensions it is obvious why the two-dimensional models in space (x,y) dominate. When GIS was introduced, the main focus was on the management and presentation of geographical data using digital technology. Hardly any attention was paid in the
beginning to the question of how this new technology could be used to improve the description of geographical reality. To quote Openshaw (1987): “Such systems are basically concerned with describing the Earth’s surface rather than analyzing it. Or if you prefer, traditional 19th-century geography reinvented and clothed in 20th-century digital technology.”

- collection of geographical data is generally an extremely time-consuming activity. Quite often only one realization in time is obtained, and data collection often takes place at the Earth’s surface. For these data the two dimensional, timeless data models fit quite well.

As shown by Kemp (1993), there is quite a complex relationship between data model and data structures. The two main data structures in use are raster and vector. The object data models point, line, area and volume can be implemented in both the vector and the raster data structure. The field models polygons, TINs and contours are implemented in the vector data structure, and for grid points and irregular points both the raster and vector data structure are used. Cell grids are implemented in the raster data structure.

**Process models**

A process model is a mathematical equation or a set of equations which represents the behaviour of a process in the real world. For example, process models exist for the flow of water, crop growth, soil erosion, soil acidification and climate change. As a model is always an approximation of reality, only those aspects of the process are described (modelled) which are relevant for our goal. A large variety of process models has been developed for basically the same real world processes. The reasons for this are:

- due to scientific research our knowledge about the actual processes increases, which results in a continuous improvement of our models;
- for the application of a model input data is required. The amount of input data available differs greatly depending on the scale (local, regional or global) and the area for which the model must be applied. This has resulted in diversity of models tailored towards the amount of input data available.

The stages of creating models for processes following an inductive approach are (Burrough, 1992):  

1. observe a relationship between an output value of the process and the values of attributes that can be taken as inputs;
2. make an empirical description of that relationship;
3. test the generality of the empirical description;
4. unravel the physical processes underlying the relationship followed by a description of the process in terms of natural physical or stochastic laws.

There seems to be no general accepted classification of process models. Examples of model types found in literature (France and Thornley, 1984; Burrough, 1989) are:

- **empirical and mechanistic models.** An empirical model describes a process based on empiricism, whereas a mechanistic model attempts to give a description with understanding.
- **static and dynamic models.** A static model does not contain time as a variable. Any specifically time-dependent components of the behaviour of the system are ignored. Since all processes in the world involve change, a static model is always an approximation. It might be a good approximation perhaps because the phenomena are close to equilibrium. A dynamic model, on the other hand, contains the time variable in the equations.
- **deterministic and stochastic models.** A deterministic model is one that makes definite predictions for quantities (such as crop yield, rainfall), without any associated probability distribution. A stochastic model, on the other hand, contains some random elements or probability distributions. The model can not only predict the expected value of a quantity, but also the variance. The greater the uncertainty in the behaviour of the process, the more important it is to follow a stochastic line. Stochastic models tend to be technically difficult to handle and can quickly become very complex. Another approach in dealing with uncertainty is to use a combination of a deterministic model and Monte Carlo simulation to obtain probability estimates.
- **spatial dimensions modelled.** We can distinguish between one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) models.
- **qualitative and quantitative models.** A qualitative model
makes predictions on a qualitative level, such as not suitable, suitable or highly suitable. The input for a qualitative model can be both qualitative and quantitative. A quantitative model, on the other hand, produces quantitative output.

Models constructed for real-world processes often contain combinations of the model types described above. For example, we may have a dynamic deterministic quantitative one-dimensional model for describing crop growth (Van Diepen et al. 1989) or a static empirical qualitative one-dimensional model for land evaluation (Van Lanen, 1991).

For the integration with GIS the characteristics, ‘dimensions’ and ‘static-dynamic’ are of major importance, because they have direct consequences for the data model to be applied. In Table 2, the general data requirements of the different model types are given.

Table 2: General data requirements of model types.

<table>
<thead>
<tr>
<th>Model type</th>
<th>Data requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>static-1D</td>
<td>x,y</td>
</tr>
<tr>
<td>static-2D</td>
<td>x,y,(z)</td>
</tr>
<tr>
<td>static-3D</td>
<td>x,y,z</td>
</tr>
<tr>
<td>dynamic-1D</td>
<td>x,y,t</td>
</tr>
<tr>
<td>dynamic-2D</td>
<td>x,y,(z),t</td>
</tr>
<tr>
<td>dynamic-3D</td>
<td>x,y,z,t</td>
</tr>
</tbody>
</table>

For the application of a model, the location or the area for which the obtained results apply is important, so even when a one-dimensional model is used, the minimum data requirement is the location of the input data. In the case of a two-dimensional model, the data requirements depend on the dimensions modelled. When we model space in the x and y dimensions, as, for instance, in erosion models, the data requirements are the location (x and y) of the data. When modelling also includes the z dimension then x,y and z are required.

Integration

An important step in answering users’ questions is analysis, and in a number of publications (Burrough, 1986; Goodchild, 1992b; Goodchild et al., 1992) this aspect is often stressed as the major benefit of GIS. At the same time, it is concluded that current analysis methods in GIS are limited. As stated before, a combination of GIS and process models opens the door to a large variety of new analyses.

Conceptual constraints

The aspects in which GIS can play a role are indicated. The data stored in the GIS and analytical capabilities of GIS (overlay, interpolation, transformation, etc.) can be used to prepare input
data for the process model. The output can be visualized with the GIS.

The possibilities of the GIS/process model integration depend on the ability of GIS to support the data requirements of the model. From a conceptual point of view, the possibilities can be detected by combining Table 1 and Table 2. It can be seen that at this moment only static one- and two-dimensional models are supported by current commercial GIS.

**Implementation alternatives**

Until now the GIS-process model integration has been approached from a conceptual point of view. It is also worthwhile looking at the integration from an implementation point of view. Bulens *et al.* (1991) make a distinction between *ad hoc*, partial and full integration when integrating GIS and process models. Stuart and Stocks (1993) distinguish between a loose-coupled and a tight-coupled approach. As the difference between the *ad hoc* and the partial integration of Bulens *et al.* (1990) represents more a difference in the advanced nature of the interface than a conceptual difference in integration, the classification of Stuart and Stocks (1993) is used here. In the loose-coupled approach of Stuart and Stocks (1993), the process model and GIS are linked loosely through an interface. This interface may consist of simple manual transfer of ASCII data files. In general the data are selected from GIS and stored in ASCII files; the files are used as input for the model, sometimes together with other data (time series). The output from the model is imported into GIS for presentation. The loose coupling is flexible and a large number of models can be integrated.

On the other hand, this approach has some drawbacks. The integration involves a lot a interactive work and the fit between model and GIS is, at best, reasonable. In situations where many scenarios need to be executed, the manual procedures may become a large obstacle. A more sophisticated form of a loose-coupled approach involves the development of programs which ease the transfer of data. The process model might have been changed to read the data directly from the database, or a menu might have been developed which combines operations. Also the development of special tool boxes which support the integration fall in this category. Such a tool box contains special functions or procedures which support the integration. In other words, an application has been developed which controls the integration. Disregarding the additional programming required to ease the integration, the main characteristic of the loose-coupled approach is that GIS and process model remain separate items.

In the tightly-coupled approach, the model is encoded within the GIS and directly accesses the data structures and procedures of the GIS (Figure 3). Encoding of the model can be done by the user or even by the GIS vendor. The advantage of the last option is that the model is documented, supported and available to all users of the package. It is, however, doubtful if this option will yield useful results in the near future. As mentioned before, the main emphasis of commercial GIS is still on data management and, as there are a large variety of process models, the market for any particular model implementation might be quite limited.

The choice for a particular type of integration (loose or tight) depends on the situation at hand. In the case of a complicated dynamic process model, loose integration is the only practical option at the moment. Also, the large investment in encoding process models combined with the limited functionality of GIS to implement process models implies that a loose coupling to GIS is the best solution for the more advanced applications. In the case of relatively simple models, a tight integration with GIS is recommended, as these applications are easier to develop and maintain, and allow for easier animation of the model results.

**Examples**

The integration of GIS and process models has been a subject of research in the last five years. In Table 3 a summary is presented.
Figure 3: Different forms (loose, a; tight, b) of integrating GIS and process models.
Table 3: Examples of GIS process model integration

<table>
<thead>
<tr>
<th>Reference</th>
<th>Application</th>
<th>Process</th>
<th>Model type</th>
<th>GIS-package</th>
<th>Data of int. stored in GIS data structure</th>
<th>Type</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vieux, 1991</td>
<td>Hydrology</td>
<td>AgNPS</td>
<td>Dynamic, 2D</td>
<td>ARC/INFO</td>
<td>TIN, Loose No</td>
<td>Loose</td>
<td>No</td>
</tr>
<tr>
<td>Roo et al., 1989</td>
<td>Soil erosion</td>
<td>ANSWERS</td>
<td>Dynamic, 2D</td>
<td>Deltamap</td>
<td>cell grids, Loose No</td>
<td>Loose</td>
<td>No</td>
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<tr>
<td>Lal et al., 1993</td>
<td>Crop growth</td>
<td>BEANGRO</td>
<td>Dynamic, 1D</td>
<td>ARC/INFO</td>
<td>Loose No</td>
<td>Loose</td>
<td>No</td>
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<tr>
<td>Zack &amp; Minnich, 1991</td>
<td>Fire management</td>
<td>KRISY</td>
<td>Dynamic</td>
<td>ARC/INFO</td>
<td>polygon, Loose No</td>
<td>Loose</td>
<td>No</td>
</tr>
<tr>
<td>Stuebe &amp; Johnston, 1990</td>
<td>Hydrology</td>
<td>RCN</td>
<td>Static, 1D</td>
<td>GRASS</td>
<td>cell grids, Tight Yes</td>
<td>Tight</td>
<td>Yes</td>
</tr>
<tr>
<td>Stuart &amp; Stocks, 1993</td>
<td>Hydrology</td>
<td>TOPMODEL</td>
<td>Dynamic, 2D</td>
<td>SPANS</td>
<td>cell grids, Tight Yes</td>
<td>Tight</td>
<td>Yes</td>
</tr>
<tr>
<td>Van Deursen &amp; Kwadijk, 1993</td>
<td>Hydrology</td>
<td>RHINEFLOW</td>
<td>Dynamic, 2D</td>
<td>PC-raster</td>
<td>cell grids, Tight Yes</td>
<td>Tight</td>
<td>Yes</td>
</tr>
<tr>
<td>Van Lanen, 1992</td>
<td>Crop growth</td>
<td>WOFOST</td>
<td>Dynamic, 1D</td>
<td>ARC/INFO</td>
<td>polygon, Loose No</td>
<td>Loose</td>
<td>No</td>
</tr>
<tr>
<td>Grunblatt et al., 1991</td>
<td>Desertification</td>
<td>?</td>
<td>Static, 1D</td>
<td>?</td>
<td>polygon, Tight Yes</td>
<td>Tight</td>
<td>Yes</td>
</tr>
<tr>
<td>Burke et al., 1990</td>
<td>Ecology</td>
<td>Century</td>
<td>Static, 1D</td>
<td>Arc/Info</td>
<td>polygon, Loose No</td>
<td>Loose</td>
<td>Yes</td>
</tr>
</tbody>
</table>

ML = Model implemented in GIS macro language

Only a few publications deal with the subject from a theoretical point of view (Burrough, 1992; Wheeler, 1983; Kusse, 1993). In Burrough (1992) and Wheeler (1993) a large number of obstacles, points for consideration and suggestions are presented for a successful linkage between GIS and process models. Their recommendations are fairly generalised, and can therefore be better regarded as research items for the future.

However, the majority of the publications describe integration of GIS with a particular process model. The greatest progress appears to have been made in the field of hydrology. Various articles appeared in this field which describe the integration of GIS and a particular hydrological model (Stuebe and Johnston, 1990; Connors and Gardner, 1991; Vieux, 1991; Bonvoisin and Moore, 1993; De Lange and Van Der Meij, 1993; Kienzle, 1993). An overview of the work done before 1990 is presented by Zhang et al. (1990). Recent reviews are presented by Devantier and Feldman (1993) and Maidment (1993).

A full integration between GIS and a process model is reported by Stuebe and Johnston (1990) and Van Deursen and Kwadijk (1993). Stuebe and Johnston implemented a relatively simple runoff model in a raster GIS (GRASS). Van Deursen and Kwadijk implemented a model for the calculation of the changes in the water balance of the River Rhine in a raster GIS. An interesting feature of their GIS (PC Raster Package) is the ability to handle data from time series. Weismann et al. (1993) developed a tool box for integration of GIS and hydrological models.

In other research fields Zack and Minnich (1991) apply a loose coupling approach to integrate vector GIS with the diagnostic wind field model KRISSY for fire management. De Roo et al. (1989) integrate GIS with the runoff and soil erosion model ANSWERS, and Bulens et al. (1990) integrate GIS with the crop growth model WOFOST for assessment of the potential crop production in the European Community. Kusse et al. (1993) and Bregt (1993) describe GIS-process model integration for environmental applications.

The above-mentioned studies illustrate that research prototypes have been developed which successfully integrate GIS and process models. In all studies where dynamic modelling is involved, special local developments were necessary to achieve such integration. The main reason for this is the lack of a time dimension in the data models underlying commercial GIS. The aspect of incorporating the time dimension in GIS has received some attention in GIS literature (Langran, 1989; Greve et al., 1993; Langran, 1993) over the last few years, but as indicated by a recent review by Greve et al. (1993) it has not yet resulted in general implementations in commercial GIS.

Framework for the future

Most of the GIS-process model integrations described in the examples combine only one model with GIS, disregarding the type of integration (loose or tight). They can also be regarded
as a one-application oriented approach. Quite often in an organization, other models are used for land resource planning, for instance a water-balance model, a land-evaluation model and a crop growth model. These models all have their own application field, but the base data required (e.g. soil data) are partly the same. This means that any one model-GIS integration leads to duplication of work, especially in the field of data access and presentation. Also, the maintenance of the different applications is difficult and time-consuming. A solution to this problem is to think in infrastructures, rather than in single applications. This infrastructure consists of the following components (Figure 4):

- data layer;
- model layer;
- presentation layer;
- process control layer.

The data layer contains the base data of the organization such as spatial data stored in a GIS and time series data stored in a database. Project-specific data can be added to this layer.

The model layer contains the different models of an organization. This can be process and/or data conversion models (e.g. pedotransfer functions), ranging from simple to complex.

The presentation layer contains the tools for presenting the model input and modelling the results as maps, tables and graphs.

In order to manage the combination of data, models and presentation, a process management function has been added to the infrastructure. The framework described can only be implemented in practice if some form of data standardization for transfer of information between the layers is achieved. A prototype of the framework described above has been implemented at the DLO-Winand Staring Centre, Wageningen, NL.

Conclusions

The integration of GIS and process models offers interesting possibilities for enlarging the analysis of our environment. GIS forms a good platform for the storage and management of model input data and the presentation of model results, while the process model provides the analysis capabilities lacking in current GIS. Or to put it even more strongly, the integration of GIS and process models in the future must be more than a ‘marriage of convenience’ or even ‘a blossoming partnership’ (Burrough et al, 1988). It will be a natural symbiosis, as the application of the process model is practically meaningless in the absence of data, and the analysis with GIS is limited by exclusion of a proper description of real-world processes as provided by process models. Integrating GIS and process models in such a way results in an open interface for geo-processes. This leaves the scientists many opportunities to change components or even add components to the system. In this way geo-processing can be used for different goals, i.e. scenario studies, calibration, validation and sensitivity analysis, so that maximum flexibility is achieved.

If we, however, confront the current data models underlying commercial GIS with the data requirements of the process models, it appears that only simple, static one or two dimensional models can be integrated easily. For the dynamic process models, from an analysis point of view the most interesting ones, GIS can only partly play a role in storage and management of model input data.

In order to increase the integration possibilities, the geometrical data model underlying commercial GIS must be expanded with the time dimension (and z for 3D applications).

In order to obtain maximum flexibility in the GIS process model integration the development of an infrastructure is strongly recommended. This infrastructure consists of a data layer, a model layer, a presentation layer and a process control layer.
Figure 4: Components infrastructure

References


Linking digital soil maps and databases to simulation models: functional soil map aggregation in The Netherlands

Summary

Simulation models are increasingly used in the Netherlands to evaluate current and possible policy measures at both national and regional scale. Methods to feed these models the appropriate input data are still under development. Both the georeferencing of model inputs and results, and the definition of representative input data, are matters to be dealt with. To provide models with appropriate data, two successive stages are distinguished: spatial aggregation and data aggregation.

Spatial aggregation methods developed in this study imply the use of qualitative land evaluation methods to define clusters of soil map units with comparable behaviour in N- and P-fate models. Data aggregation methods imply the selection of appropriate profile data, the application of pedotransfer functions and the averaging of data for the spatial clusters already defined. Both stages have been implemented into computer software, and are currently being tested. It is concluded that the formalization of spatial aggregation methods, pedotransfer functions and data aggregation methods into computer code has alleviated the parameter problem, but has not solved it completely.

Introduction

Soil and water quality studies are developing from mere state descriptions based on monitoring and sampling to analysis of scenarios based on simulation modelling. On national and regional scales this increasingly involves the use of simulation models to calculate N- and P-fluxes to ground water and surface water. The N- and P-fate models used are developed at field scale, so an upscaling step must be part of the analysis to enable national or regional scale calculations. For the practical reason that the models are operational, and time and funds are usually not available to construct regional versions of these models, upscaling is usually done by aggregation of the model input data to a higher scale level. Aggregation of soil data is therefore an important preparative phase in simulation exercises at higher scale levels. Another matter that needs attention is the parameter crisis, which is felt at almost any scale.

This paper addresses aspects of aggregation of soil data to obtain inputs for models which describe the fate of N and P, for studies at both national and regional scale. Theoretical and practical aspects of recently developed aggregation methods are treated. Special attention is paid to the way the parameter problem is tackled and to the implementation of developed methods into computer software.

Functional soil data aggregation: state of the art

The aggregation of soil data is a way to enable the application of field-scale simulation models at larger scales. This upscaling involves both the application of the model in areas where it has not been tested or developed (spatial extension) and a change (increase) of support. The
increase of support, also called the increase of grain size (McBratney, in press), means that the model result no longer applies to the grain it was developed for (usually an agricultural field or a forest stand), but to a larger area (one or more soil map polygons).

It should be stated, that the aggregation of soil data is only one way of upscaling. Other methods exist, and have been applied elsewhere (e.g. De Vries et al., in press). The current paper limits itself to soil data aggregation, since it is the method currently applied in national and regional N- and P-fate modelling.

Soil data aggregation usually takes place in two consecutive steps: Firstly, soil map polygons are combined into clusters (usually called plots) by interpretation of (aspects of) their map code and, eventually, by their mutual geographical position. This step will be referred to as spatial aggregation. Secondly, clustered polygons are characterized by model parameters representative for that area. This step will be referred to as data aggregation. The net result of both steps is a database of plot data, whereby the number and geo-reference of plots is determined by the spatial aggregation, and the model parameters of each plot follow from the data aggregation. Before focusing on the aggregation methods applied so far, and their drawbacks, the soil databases and the simulation models used in the process will be briefly described.

Soil databases

The Dutch soil profile database BIS contains profile data of three different kinds: (1) soil data from the representative profiles connected to map units of the 1:50,000 soil map of The Netherlands; (2) analytical soil data sampled in the context of regional projects, with various types of analyses; (3) soil profiles sampled in the context of the national stratified random soil sampling programme.

1) The number of representative profiles is fixed. These profiles have been defined to document the major soil map units distinguished in a 1:50,000 map sheet. Due to the recent completion of the national soil mapping programme at this scale, no further representative profiles are added to the database. Representative profiles were not recorded during the first 20 years of the soil mapping, so not all soil map units are covered by these data. Representative profiles are not geo-referenced in the database, and contain few basic analyses, like texture and organic matter content. Typically, more analytical data are available.

2) The soil profile data sampled in regional projects contain analytical data of various kind, since these regional projects had different objectives. Also, soil profiles may be only partly sampled, due to the scope of the research being limited. The size of this part of the database is still increasing.

3) One reason for initiating the national stratified random soil sampling programmes has been to fill the data gaps in the BIS. In this ongoing sampling programme, groups of soil map units serve as strata to be characterized by random sampling. Part of the sampling is dedicated to obtaining analytical data which were previously hardly sampled, e.g. P-content and Fe-ox and Al-ox, all samples are minimally characterized by estimations of texture and organic matter content. This part of the database is still under development.

Simulation models

The models which are used mostly to calculate N- and P-fate in agricultural soils, are SWAP and ANIMO. SWAP, which is based on SWACROP (Feddes et al., 1988), is a one-dimensional hydrological model, which calculates water flow in the unsaturated zone by solving the Richards equation. Since the model is able to calculate fluxes to different drainage media as well as towards and from groundwater (seepage and leakage fluxes), it can be used in regional studies too. ANIMO simulates N-cycling in agricultural soils, and covers processes such as volatilization, denitrification and mineralization of N from different pools of organic and inorganic N in the soil as well as the adsorption of ammonia and plant uptake. The fate of P is simulated by processes such as sorption, solution equilibrium, plant uptake and fixation by organic matter. ANIMO uses flux data from SWAP to calculate the transport of N and P in solution. For a detailed description of ANIMO, see Berghuijs-Van Dijk et al. (1985) and Kroes (1993).

Spatial aggregation

Spatial aggregation is necessary for a number of reasons. One of the first applications on the national scale for N- and P-fate modelling in The Netherlands was in the explorative water systems analysis study during the
Data aggregation

Data aggregation is the estimation of 'representative' model parameters for a plot which was constructed during the spatial aggregation phase. During the explorative water systems analysis study, water retention and hydraulic conductivity characteristics for top- and subsoils were estimated by the Staring Series class pedotransfer function (Wösten et al., 1994). Texture class and organic matter content class from the soil map legend were used as input to the Staring Series. The BIS-database was used to assign soil chemical properties like oxalate-extractable Al and Fe to top- and subsoils.

Weaknesses of the current method

The aggregation methods for the explorative water systems analysis have greatly improved the possibilities of simulation modelling for the analysis of environmental policy options. Nevertheless, the application of the aggregation methods raised several points of criticism.

A drawback from the applied spatial aggregation method was, that it did not maximally exploit existing knowledge on the heterogeneity of soil chemical behaviour to define clusters. For instance, spatial differences by soil type in N released by mineralisation of organic matter were not accounted for systematically. Also, some small map units were aggregated into larger units because of their spatial position and size rather than by their behaviour, which might 'hide' sensitive soils in a cluster of soils insensitive to P-leaching, for example.

Most of the disadvantages of the applied data aggregation method relate to the method of estimating representative data. Firstly, it has been questioned whether the 'representative profiles', defined by the soil surveyor during mapping from the perspective of soil genesis, do also behave representatively in the context of a simulation model. Finke et al. (1996) performed an analysis in the largest soil map unit of the soil map of The Netherlands, scale 1:50,000. They compared the behaviour of a set of soil profiles at randomly drawn locations with the behaviour of the 'representative' profiles from three map sheets, using one-dimensional convective-dispersive water- and solute transport models. The behaviour was expressed by 5 quantitative variables computed from the output of the model: (i) days with a good workability; (ii) days with a good aeration; (iii) time to 10% breakthrough of an inert tracer; (iv) percentage breakthrough after one year of an inert, adsorbing contaminant (Cd); (v) percentage breakthrough after one year of an adsorbing, degrading herbicide (isoproturon). It was shown, that the representative soil profile put into a model did not describe the average map unit behaviour in 4 out of 5 cases, at 95% confidence. The presumption of representativity of the pedogenetically representative profiles was therefore concluded to be invalid in this study. Also, it was concluded, that soils within the polygons attributed to the soil map unit, that did not correspond to the map unit definition ('map impurities'), showed the most extreme behaviour. Incorporation of the effect of soil variability within the soil map unit was therefore considered important to assess the average behaviour of the soil map unit. Data aggregation should therefore be based on the whole range of soil heterogeneity within the soil map unit.

A second point of criticism is that the parameter problem forced the use of expert estimates rather than measured data, which is associated with an unknown level of confidence. The formalization of expert estimates, preferably by statistically estimated pedotransfer functions, would alleviate this problem. Pedotransfer functions would also allow the use of data previously ignored. Additionally, the use of expert estimates instead of formalized and implemented pedotransfer functions or pedotransfer rules made the data aggregation step labour-intensive.
Apart from these points of criticism, a number of additional needs have emerged:

1) The number of regional applications has developed greatly. Regional customers want more geographical detail, therefore a more detailed soil data aggregation is needed.
2) The data problem should be dealt with as effectively as possible by using all available data at the time the data aggregation occurs.
3) Both the spatial and the data aggregation process should be less time-consuming.

Functional soil data aggregation: developments

Research questions

The above criticism and needs, with respect to the functional soil data aggregation method used until now, have resulted in a number of research questions:

1. How can spatial and data-aggregation methods be improved?
2. How can obtained knowledge and expertise be best used?
3. How to resolve the data problems?
4. How can the aggregation process be accelerated?

These questions are being answered in an ongoing project. Concepts and methods developed within this project will be treated hereunder with respect to the three above-mentioned research questions. Some examples will be given from a research area in the Netherlands.

Research area

Functional soil data aggregation methods are generic, but have been tested during development in an area in the southern part of The Netherlands, the Beerze/Reusel/Rosep area (Figure 1a).

The area is characterized by a coversand plateau with little relief, in which two large and one small brook valleys developed during the late Pleistocene period. The area is named after these three brooks: the Beerze, Reusel and Rosep (Figure 1b). Soils occurring in the coversand plateau are predominantly Gleyic and Haplic Podzols and occasionally Fimic Anthrosols. Locally, sand dunes have formed in which Dystric Regosols are found. The brook valleys are characterized by Mollic and Eutric Fluvisols in the upstream area, and by Terric Histosols in the downstream area. Groundwater tables typically vary between 50 to 80 cm (in winter) and deeper than 120 cm (in summer) in the coversand plateau. In areas with dunes, variation may be high. Groundwater tables in the brook valleys typically vary between 10-40 cm (winter) and around 80 cm (summer).

Mainly due to intensive pig farming, large N- and P-pollution problems exist in the area. Locally, zinc smelters have caused pollution with heavy metals such as cadmium and zinc. The area is being studied to evaluate the effects of raising groundwater tables on N- and P-leaching to the environment.

Spatial aggregation method

The spatial aggregation method developed in this study uses qualitative land evaluation methods, which are partly comparable to those of the FAO-framework for land evaluation. The approach involves:

1. Land Use Requirements (LUR) are defined, which are of importance with respect to the leaching of N and P. As defined in the FAO framework, Land Use Requirements refer to ‘the set of land qualities that determine the production and management conditions of a kind of land use’. In this study, we defined this set as ‘the set of land qualities that determine the potential for N- and P-leaching of a kind of land use’. These relevant LUR are given in Table 1. It should be noted that the LUR ‘Moisture Supply Capacity’ and ‘pH’ depend on the land use. Three types of land use were incorporated in the procedure (arable land, grassland and forest), so in total 10 LUR were used as the LUR-set. Denitrification Capacity has not been defined as an LUR, because this property is strongly related to the same parameters that determine the drainage status and N-mineralisation capacity, and hence would not add information relevant for the spatial aggregation.

2. A method to obtain ratings for the LUR from easily available soil data was developed. This involves both the identification of relevant Land Characteristics (LC) to estimate the LUR-class and the definition method. The LC used are also given in Table 1. The LC are in most cases derived from data from representative profiles and sometimes estimated from the soil map legend. The derivation of LUR from LC can be simple, as in case of the Ammonium Adsorption Capacity, or complex, as in case of the moisture supply capacity. N-
mineralisation capacity is an intermediate case and is given as an example in Table 2.

3. To each soil map unit a rating is attributed for each LUR from the set in Table 1. All map units that have equal LUR-ratings are combined into spatial clusters.

The classification of soil map units into functional spatial clusters, according to the above described methodology was done using the Automated Land Evaluation System (ALES), developed by Rossiter (1990). An advantage of the use of ALES is, that modifications to the classification trees used to estimate LUR are easily implemented and executed. In this study, variants of the method described above were implemented by:

(a) application to all three (arable land, grassland and forest) or only one (arable land) land use type (Table 1)
(b) using the standard and a low number (3) of LUR-classes (Table 1)
(c) inclusion or exclusion of the LUR `moisture supply capacity' in the computation of the LUR-ratings.

Data aggregation methods

From the spatial aggregation method, clusters of soil map units are derived that presumably will behave different from the perspective of N- and P-modelling. How different is not clear a priori, since a qualitative land evaluation method was used to make distinctions between clusters of soil map units. The outcomes of model simulations will determine how differently the clusters behave. A necessary initial step is data aggregation to provide input parameters to these models.

Usually, it is hypothesized that the simulation models themselves respond linearly to spatial variation of the model parameters within a plot constructed during the spatial aggregation phase. An implication of this linear behaviour is, that running the model with 'averaged data' will produce 'the average result'. Kros et al. (1993) concluded that this assumption holds in case of an acidification model. Since for most studies 'the average result' is sufficient to characterize the behaviour in a plot, within-plot variability is not considered, and data aggregation is essentially the estimation of plot-average model parameters.

Because some soil map units may have a high internal variability, due perhaps to the occurrence of different soil types or parent materials within the map units, it may be unrealistic to average all data blindly. Therefore, four methods of averaging profile data have been designed:

1. For every layer (5cm intervals) average all the data from the dominant soil type in the plot, using only data from the dominant soil layer at the current depth.
2. For every layer (5cm intervals) average all the data from the dominant soil type in the plot, using data from all soil layers at the current depth.
3. For every layer (5cm intervals) average all the data from all occurring soil types in the plot, using only data from the dominant soil layer at the current depth.
4. For every layer (5cm intervals) average all the data from all occurring soil types in the plot, using data from all soil layers at the current depth.

Method 4 corresponds to the above-mentioned blind averaging, but has the advantage that it uses all available data. Method 1 is very critical in its use of data, which may be a practical disadvantage.

Before any averaging takes place, pedotransfer functions must be employed to estimate process-parameters from basic soil data. Table 3 summarizes the pedotransfer functions that were used. If possible, continuous pedotransfer functions were applied, usually stratified to sand, clay and peat soils. Some parameters cannot simply be averaged, since they are mutually correlated. Examples are the Van Genuchten parameters for soil hydraulic functions between h, \( \Theta \) and K. Representative parameters are obtained by fitting these parameters to averaged water retention and hydraulic conductivity curves simultaneously (Van Genuchten et al., 1991).
Table 1: Land Use Requirements to distinguish functional soil map unit clusters

<table>
<thead>
<tr>
<th>Land Use Requirements</th>
<th>Number of LUR-classes</th>
<th>Land Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Adsorption Capacity</td>
<td>3 or 6</td>
<td>CEC-topsoil (from OMC and CL)</td>
</tr>
<tr>
<td>Phosphate Sorption Capacity</td>
<td>3 or 10</td>
<td>MHW, Fe/Al&lt;sub&gt;ox&lt;/sub&gt;-topsoil</td>
</tr>
<tr>
<td>Drainage Status</td>
<td>3 or 5</td>
<td>MHW, soil type</td>
</tr>
<tr>
<td>N-Mineralisation Capacity</td>
<td>3 or 6</td>
<td>soil type, evt. peat type, CL, OMC</td>
</tr>
<tr>
<td>Moisture Supply Capacity</td>
<td>3 or 5</td>
<td>ROOT, MHW, MLW, MSW, soil type, OMC, CL, SI</td>
</tr>
<tr>
<td>pH (arable/grass/forest)</td>
<td>3 or 6</td>
<td>pH</td>
</tr>
</tbody>
</table>

CEC= Cation Exchange Capacity, OMC=Organic Matter Content, CL=CLay content, SI=SIlt content, MHW=Mean Highest Watertable, Fe/Al<sub>ox</sub>=oxalate extractable Iron/Aluminum, ROOT=rootable depth, MLW=Mean Lowest Watertable, MSW=Mean Spring Watertable

Table 2: Determination table of LUR ‘N-mineralization capacity’.

<table>
<thead>
<tr>
<th>N-mineralization capacity class</th>
<th>Soil type</th>
<th>Peat type</th>
<th>Clay content (%)</th>
<th>Organic matter content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Peat</td>
<td>eutrophic</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>2</td>
<td>Peat</td>
<td>mesotrophic,</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>oligotrophic</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>3</td>
<td>Peaty sand, loam</td>
<td>.</td>
<td>.</td>
<td>&gt;15</td>
</tr>
<tr>
<td>4</td>
<td>sand, loam</td>
<td>.</td>
<td>≤12</td>
<td>&gt;9</td>
</tr>
<tr>
<td></td>
<td>clay</td>
<td>.</td>
<td>12-25</td>
<td>&gt;10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>24-35</td>
<td>&gt;11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>35-50</td>
<td>&gt;12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>&gt;50</td>
<td>&gt;14</td>
</tr>
<tr>
<td>5</td>
<td>sand, loam</td>
<td>.</td>
<td>≤12</td>
<td>3-8</td>
</tr>
<tr>
<td></td>
<td>clay</td>
<td>.</td>
<td>12-25</td>
<td>2.5-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>24-35</td>
<td>2.5-10</td>
</tr>
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<td>35-50</td>
<td>3-11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>&gt;50</td>
<td>4-14</td>
</tr>
<tr>
<td>6</td>
<td>sand, loam</td>
<td>.</td>
<td>≤25</td>
<td>≤3</td>
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<tr>
<td></td>
<td>clay</td>
<td>.</td>
<td>25-50</td>
<td>≤2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.</td>
<td>&gt;50</td>
<td>≤3</td>
</tr>
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<td></td>
<td></td>
<td>.</td>
<td></td>
<td>≤4</td>
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</tbody>
</table>
Figure 1a (Overview): Test area and its location in The Netherlands.
Figure 1b (Detail): Test area in The Netherlands. Different shading patterns refer to the catchments of the Beerze, Reusel and Rosep brooks and three small polders.
Table 3: Pedotransfer functions (PTF) to model parameters for ANIMO and SWAP.

<table>
<thead>
<tr>
<th>Function</th>
<th>Parameter</th>
<th>Object</th>
<th>Method of estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q(h)</td>
<td>a</td>
<td>profile</td>
<td>class PTF</td>
</tr>
<tr>
<td>Q(h)</td>
<td>b</td>
<td>profile</td>
<td>class PTF</td>
</tr>
<tr>
<td></td>
<td>bulkdensity</td>
<td>layer</td>
<td>stratified continuous PTF</td>
</tr>
<tr>
<td></td>
<td>pH-H$_2$O</td>
<td>layer</td>
<td>stratified continuous PTF</td>
</tr>
<tr>
<td></td>
<td>CEC</td>
<td>layer</td>
<td>stratified continuous PTF</td>
</tr>
<tr>
<td>h-Θ-K</td>
<td>Θres</td>
<td>layer</td>
<td>stratified continuous or class PTF</td>
</tr>
<tr>
<td>h-Θ-K</td>
<td>Θsat</td>
<td>layer</td>
<td>stratified continuous or class PTF</td>
</tr>
<tr>
<td>h-Θ-K</td>
<td>Ksat</td>
<td>layer</td>
<td>stratified continuous or class PTF</td>
</tr>
<tr>
<td>h-Θ-K</td>
<td>α</td>
<td>layer</td>
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<td>h-Θ-K</td>
<td>n</td>
<td>layer</td>
<td>stratified continuous or class PTF</td>
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<tr>
<td>h-Θ-K</td>
<td>l</td>
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</tr>
<tr>
<td>Oxygen diffusion</td>
<td>a</td>
<td>layer</td>
<td>stratified continuous PTF</td>
</tr>
<tr>
<td>Oxygen diffusion</td>
<td>b</td>
<td>layer</td>
<td>stratified continuous PTF</td>
</tr>
</tbody>
</table>

Implementation into software

The functional soil aggregation methods were implemented into software after a functional design had been made. This design basically implied that the development group agreed on two items: (i) main processes to be distinguished and the hardware platforms for their implementation, (ii) data formats to enable the main processes to communicate. Each main process was thereafter designed in more detail by a small group of experts, while one person kept the overview and communicated adaptations to the agreed data formats to all project participants. Main processes and sub-processes were visualized in data-flow diagrams (DFDs). DFDs show the flow and storage of data between processes implemented in computer applications.

Hardware platforms for the development of the software were UNIX workstations and PCs. The selection of relevant soil profile and digital soil map data was implemented within ARC/INFO by AMLs on a workstation. Spatial clustering was done by implementing an ALES-task on PC. Data clustering programs were developed in Borland Pascal on PC. All programs and applications developed will eventually be started from a graphical shell, which runs under Windows on a PC.

Testing of aggregation alternatives

A number of alternative spatial aggregation and data aggregation methods have been formulated with the purpose to investigate the quality of each alternative. The quality is tested statistically by comparing model results at the point level, map unit level and aggregated (plot) level. A typical model result would be the annual N-leaching concentration.

The following definitions are used:

- $y_i$ = the model result at the point scale (at test soil profile $i$),
- $y_{i,mu}$ = the model result at the map unit level, set equal to the model result from the representative profile of map unit $mu$,
- $y_{i,pl}$ = the model result at the plot level, equal to the model result from the plot profile $pl$. 

Assuming that the models are errorless, the prediction errors at the map unit and the plot scales are defined by the formulae:

\[
MSE_{map} = \frac{1}{n} \sum_{i=1}^{n} (y_i - y_{i,m})^2
\]

and

\[
MSE_{plot} = \frac{1}{n} \sum_{i=1}^{n} (y_i - y_{i,p})^2
\]

respectively, where \(n\) is the number of test points.

For any combination of spatial and data aggregation methods, the relative increase of the prediction error due to the spatial and data aggregation methods can be calculated by:

\[
relMSE_{plot} = \frac{MSE_{plot}}{MSE_{map}}
\]

The combination which has the lowest value of \(relMSE_{plot}\) and the lowest number of plots is considered the most attractive, because (i) the low number of plots involves low computing and data storage cost and (ii) the loss of information due to aggregation will be minimal.

### Results

#### Implementation

The data flow diagram for the main processes is given in Figure 2. Process .1 was implemented within ARC/INFO on a workstation, processes .2 to .4 on a PC. Each process consists of one or more computer programs or macros. Currently, processes 1, 2 and 3 are implemented and operational, process 4 is still under development.

Within the processes, temporary data stores to enable communication between computer programs may exist. Figure 3 gives an example for the case of data aggregation, where two programs were written (PTF and CLUSPROF).

#### Aggregation methods

In total, six spatial aggregation methods have been implemented, and were executed for the Beerze/Reuzel/Rosep test area (Table 4). Method F resulted in the smallest number of plots (23), which is a vast reduction relative to the original number of 205 map units in the area. A description of the plots distinguished in method F is given in Table 5.

At a smaller number of plots, it was expected that the number of missing data per plot would be less. Figure 4 gives the relation between completeness of the data needed to run the models and the number of plots, for data aggregation method 4 (all available data used). In case of spatial aggregation method F, which resulted in only 23 clusters, 80% of the datafields could be filled in, and for 84% of the area all necessary input data for the models was generated successfully. When pedotransfer functions are not used, the situation becomes very unfavourable. For no one spatial cluster were sufficient data found in the BIS to generate all input data for the models, and only 19% of the data fields could be filled in. Figure 4 gives the most favourable situation, since it corresponds to data aggregation method 4 where data are used.

Principal missing data are: oxalate-extractable P, Al and Fe. This problem can be dealt with by additional regional sampling, or by extension of the search area for profile data. Some plots correspond to soil map units which occupy very small areas. For practical purposes, these plots should be incorporated into similar plots for which data are
available. It would be best to use the spatial aggregation method implemented into ALES to optimize this situation.

Conclusions

1. The formalization of decision rules and pedotransfer functions into computer software has strongly improved functional soil data aggregation to obtain input for N- and P-fate models. The runtime of the aggregation process was strongly reduced.

2. Although an automated approach to functional soil map aggregation has been implemented, this does not yet provide a solution to the shortage of data. Expert estimates must still be made to obtain complete “data saturation”.

Testing of alternative spatial and data clustering methods remains necessary to define “optimal” methods in the context of the parameter problem.

Figure 2: Data flows between the main processes in the functional soil data aggregation software package. Circles indicate processes, arrows indicate data flows and open boxes are data stores.
Figure 3: Data flows within the main ‘data aggregation’ process. Dotted open boxes and arrows indicate temporary data stores and data flows. Solid lines and circles are data flows and processes recognized by the graphical shell.
Figure 4: The percentage of data fields filled in (A) and the % of the area with complete data (B) as a function of the number of clusters from the spatial aggregation. Solid lines correspond to the use of pedotransfer functions, dotted lines correspond to the situation without pedotransfer functions.
Table 4: Implemented spatial aggregation methods and number of plots

<table>
<thead>
<tr>
<th>Number of LUR-classes</th>
<th>Landuse arable, grazing, forest</th>
<th>Arable landuse only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LUR Moisture Supply Capacity included</td>
<td>LUR Moisture Supply Capacity excluded</td>
</tr>
<tr>
<td>Standard</td>
<td>A, 111</td>
<td>B, 77</td>
</tr>
<tr>
<td>3</td>
<td>D, 40</td>
<td>E, 31</td>
</tr>
</tbody>
</table>

References


EUROPEAN SOIL BUREAU  RESEARCH REPORT NO. 4
Table 5: Plots resulting from spatial aggregation method F
Plot

Map units within plot

Area
(ha)

Description

1

VII, zEZ21 VII*, Hn21 VII, pZn23 VII, zEZ23t VII, cHn21F VII, cY21g VII, zEZ21t VII, zEZ23 VII*, Hn21 VII*, Hn21F VII, Hn21g VII, Hn21gF VII, Y23 VII, Y21 VII*, Y23 VII*

10584

Well-drained podsols, coarse sand

2

Hn23 VII

12.2

Well-drained podsols, loam

3

Zd21 VI, Zn21 VI, pZn21F V*, Zn21 V*, Hn21 V*, pZn23 VI, zEZ23g VI, Hn21tF VI, cHn21G VI, cHn21g VI, zEZ21t VI, cHn21 VI, zEZ21 VI, zEZ23 VI, Hn21F VI, Hn21g VI, Hn21gE VI,
Hn21gF VI, zEZ21g VI, zEZ23t VI, Hn30 VI, Hn30E VI, cHn21t VI, Hn21t VI, pZn23g VI, zEZ21G VI, Hn21 VI, Hn21t III*, pZn21 III*, pZn21t III*, pZn23g V*, zEZ23g V*, zEZ23w V*,
cHn21t V*, cHn23 V*, cHn23t V*, pZg21 V*, pZg21F V*, pZn21 V*, pZn21t V*, zEZ21t V*, pZn23g III*, zEZ23 V*, Hn21g V*, zEZ21g V*, zEZ23t V*, Hn21F V*, Hn21t V*, Hn30 V*

22476

Moderately well-drained podsols, coarse sand

4

Hn23 VI, Hn23g VI, Hn23t VI, pZg23 VI, Hn23g V*, Hn23gF V*, Hn23t V*, EZg23 III*, EZg23g III*, EZg23w III*, Hn23 V*, pZg23t V*

3090

Moderately well-drained podsols, loam

5

zVztF III, zVz II, zVz III

260

Poorly drained peat soils, sand cover

6

zWz III, zWzg III, zWztF III, zWz II, zWzF III

4799

Poorly drained, degraded peat soils,
sand cover

7

Zn21 II, Zn21 III, Zn21F III, Zn21t III, Zn21F V, Zn21t V, Zn21 V, Hn21 V, pRn59 II, Hn21F III, Hn21F V, Hn21G III, Hn21g III, Hn21gE III, Hn21t III, ABz III, EZg21 III, cHn23 V, pZg21t
III, pZn21 III, pZn21F III, pZn21g III, pZn21t III, pZn23 V, pZn23g III, pZn23g V, pZn23t III, zEZ23 V, zEZ23g V, zEZ23t V, Hn21t V, Hn21tF V, cHn21 V, cHn23t V, pZg21 V, pZn21 V,
pZn21g V, pZn21t V, zEZ21 V, zEZ21t V, Hn21G V, Hn21g V, Hn21gE V, Hn21gF V, zEZ21g V, Hn30 III, Hn30 V, pZg30 III, pZn30 III

8998

Poorly drained coarse sandy valley
bottom soils

8

Hn23t V, pZg23t III, pZg23t V, Hn23g III, Hn23g V, Hn23gF V, Hn23t III, pZg23 III, pZg23F III, pZg23g III, EZg23 III, EZg23g III, EZg23t III, EZg23w III, Hn23 III, Hn23 V

4519

Poorly drained podsols, loam

9

zHd21F VII*, zHd21 VII, zEZ23 VII

2302

Well-drained podsols, sand dunes

10

Zn23g VI, Zn23 VI, cHn23 VI, zEZ21 V*, cHn21 V*, pZn23t V*

1108

Moderately well-drained loam

11

kpZg23F III*

332

Poorly drained loam, clay cover

12

Zn23tF III, Zn23tF V, pZn23t V

496

Poorly drained iron-rich loam, clayey
subsoil

13

kpZg21 III, kpZg23 II, pLn5 III

411

Wet loamy soils, clay cover

14

Vz II, aVc II

104

Wet peat soils

15


304

Poorly drained degraded peat soils

16

Hn21 III, pRn59 III

745

Poorly drained alluvial sandy soils

17

cHn23t VI

214

Well-drained podsols, loam, clayey
subsoil

18

pZg23 III*, pZg23t III*, pZg23 V*

610

Poorly drained anthrosols

19

pZg23 V

115

Moderately well-drained anthrosols

20

zEZ23G VI

52

Well-drained anthrosols

21

ABvF III, ABvg II

175

Wet association of peats

22

kpZg23 III

272

Poorly drained loam, clay cover

23

pZg23F III* , pZg23F V*

391

Moderately well-drained iron-rich loam

319


Neural computing approach to soil monitoring systems in Poland

Summary

The total concentrations of heavy metals (Cd, Cu, Ni, Pb, Zn) were analyzed in over 40,000 plant and soil samples collected from the arable land of Poland during the years 1991-1995. Basic soil properties such as pH, organic matter and clay content were also included in the study. The average concentrations of Cd, Cu, Ni, Pb, Zn in the A horizon (0-20 cm) of agricultural soils were as follows, respectively: 0.22, 6.7, 6.5, 13.8, 33.2 mg kg$^{-1}$ of soil.

According to the evaluation criteria used, as much as 80.3% of the total area of agricultural land in Poland exhibits natural concentrations of heavy metals. The elevated levels of metals were found in 17% of soils. Approximately 2.6% of the soils represent different degrees of metal pollution, including heavily and very heavily polluted soils which occupy only 0.3% of arable land.

Digital maps demonstrating spatial distribution of soil pollution with heavy metals were issued and updated every other year. Statistical analysis of the available data, however, showed no relationship between the degree of soil pollution and metals uptake by plants – even in areas that were dramatically contaminated. Multiple regression models involving properties that control metal bioavailability did not improve the predictability. The monitoring data obtained give a general estimate of soil pollution. However, from a practical standpoint the whole effort is still questionable, since the prediction of metal transfer to the food chain cannot be accomplished by traditional means.

We have found that neural networks can be considered as a tool for prediction and spatial analysis of the processes controlling the metal transfer within the soil-plant system. Prediction ability of such models is well over 80% as compared to 20% for typical regression models. A radial basic function network reflects correlations between soil properties and metal content in plants much better than the back-propagation method. Neural computing can support the decision-making processes at different levels, including farms, to improve crop management based on monitoring data and risk assessment of metal transfer from soils to plants.

Introduction

Intensive industrial development in Central and Eastern Europe during past decades caused serious environmental damage in certain regions. Within the last few years, society has become more concerned about environmental protection. A number of publications in different media generated much interest in data concerning the quality of the environment. However, some reports created a fear that the majority of agricultural soils and crops were contaminated to some extent. This situation prompted the Polish Ministry of Agriculture to set up a country-wide soil and crop monitoring programme for detailed evaluation of existing resources in order to identify areas of high risk to the food chain.

However, the results of the monitoring work showed no simple relationship between soil...
contamination with heavy metals and metal uptake by plants. The data obtained could not therefore be directly applied for reliable prediction of metal transfer to the food chain, under given environmental conditions. These difficulties with the interpretation of the data were probably related to the complex nature of metals geochemistry and the physiology of metal uptake by plants.

The interactions between processes in soil and plant are of a very sophisticated pattern that is characterized by a large number of degrees of freedom. Since neural networks have been used successfully in various fields for pattern recognition and classification, providing an alternative methodology for non-linear modelling of complex phenomena, we have been testing neural networks as a tool that promises better prediction of metal transfer from soils to crops. It is important to emphasise that we have been focusing on implementation aspects of neural computing, as applied to the evaluation of monitoring data, rather than on the theoretical and functional background of the networks used. The detailed discussion concerning theoretical aspects of neural computing is covered by Moody and Darken, 1989; Park and Sandberg, 1991 and Poggio and Girosi, 1989:

**Soil and crop monitoring in Poland**

Over 40,000 soil and plant samples were collected throughout Poland and analysed in Regional Agro-Chemical Laboratories (OSCHR). The overall study was co-ordinated by IUNG (Terelak et al., 1994a).

Digital maps at a scale of 1:500,000 demonstrating the degree of soil pollution with heavy metals, according to the classification system used, are being issued by IUNG. The evaluation of soil pollution with metals was based on criteria that had been assumed as important factors controlling metal transfer to the food chain, such as total metal content in soils, pH, organic matter content, and texture (Kabata-Pendias et al., 1993). The results of a survey presented covered the soil and plant sampling programme conducted between 1992-1995. Because of its perceived environmental risk, special emphasis is given to the soils of Silesia, the most polluted smelting and mining region of Poland.

**Heavy metal status in Polish soils**

Background concentrations of cadmium reported in literature for soils of the world range from 0.2 to 1.05 mg kg\(^{-1}\) of soil, depending on the geological origin of the parent material, texture, intensity of weathering processes, organic matter and other factors. Studies by different authors indicated, however, that background cadmium is usually not higher than 0.5 mg kg\(^{-1}\) of soil (Adriano, 1992; Dudka et al., 1994; Kabata-Pendias and Pendias, 1993).

Our present study, based on analyses of 24,000 soil samples, has indicated that cadmium in Polish soils ranges from 0.01 to 49.73 mg kg\(^{-1}\) of soil. The expected range, however, derived by eliminating 5% of extreme values, is 0.1-0.48 mg kg\(^{-1}\) of soil (Table 1).

As suggested by Dudka (1992), using an expected range as opposed to an observed range provides a more realistic characterization of soil metals in a given area. It is evident that the average cadmium concentration and its variability in the agricultural soils of Poland is not substantially different from that in other countries (Kabata-Pendias and Pendias, 1993).

The highest concentrations of cadmium were found in southern Poland, particularly in Silesia. The accumulation of cadmium in these soils is partly related to industrial activities; however, it can also be explained by the composition and geological origin of the parent rock material, which often contain metal ore outcrops. The importance of parent rock material properties as a factor controlling cadmium levels in soils is reflected in data from other studies conducted in Czestochowa and Bielsko Biala Provinces, where high cadmium concentrations were found in many soils that were not exposed to emissions from industry or to land disposal of high cadmium waste (Terelak et al., 1994b, Terelak et al., 1995). As indicated before, there is considerable concern about cadmium in crops in Silesia (Wojewodztwo Katowickie). Table 1 shows that the average concentration of cadmium in the soils of Silesia, a smelting and mining region, is significantly higher than the values typically found in other areas of Poland.

Spatial and geostatistical analyses of our data provide strong evidence that as much as 88.2% of agricultural land in Poland is not contaminated with cadmium and contains only background amounts of this element (0%). It should be emphasized that even
in Silesia, 41.3% of soils are not contaminated with cadmium, according to our rather conservative evaluation criteria (Kabata-Pendias et al., 1993) – see Table 1.

It is important for Silesia that the majority of its soils (70.4%) are either not polluted (0°) or contain only slightly elevated (I°) levels of cadmium. We recommend that such soils be used for production of most crops, however growing vegetables should be limited. Slightly polluted soils (II°) represent 1.2% of agricultural land in Poland; in Silesia their contribution is 12.6% – Table 1. Significant food chain cadmium risk related to higher degrees of soil contamination (III°-V°) is limited to small areas in Poland (0.6%); however, locally in regions such as Silesia these soils can represent as much as 17% of agricultural land – Table 1.

In general, cadmium in the soils of Poland does not pose a particular environmental risk as far as food quality is concerned, except in the heavily industrialized regions such as Silesia.

The average concentration of copper in the soils of Poland is 6.6 mg kg⁻¹ of soil, which is similar to background levels reported for other countries (Kabata-Pendias and Pendias, 1993). According to our studies copper in soils ranges from 0.2 to 293.3 mg kg⁻¹ of soil – Table 1.

Soil contamination with copper poses certain risks only in those areas with copper mining and smelting industry. Even in Silesia (Wojewodztwo Katowickie), the average copper concentration in soils is 11.2 mg kg⁻¹ of soil, which is much below the upper limit of the expected range for the whole country - Table 1. Over 97% of agricultural land in Poland is characterized by natural (0°) concentrations of copper, and even in the Silesia region, 96% of land would be characterized as being at natural concentrations for copper.

As indicated in Table 1, elevated levels of copper were found in 2.2% of Polish soils (I°), mainly located in the copper mining area within Legnica Province. On a national basis, the percentage of soils contaminated with copper to a greater extent (III°-V°) is relatively small. Therefore we conclude, that copper is not a factor of concern, which could limit agricultural production, except in small areas affected by the copper industry and soils formed on a parent rock material which contains high amounts of this element.

The average concentration of nickel in Polish soils is 6.4 mg kg⁻¹ of soil, with a range of 0.1-328 mg kg⁻¹ of soil. It is accepted that a value of 100 mg kg⁻¹ of soil is the maximum permissible level (Kabata-Pendias and Pendias, 1993).

It is important that the upper level of the expected range for nickel (15.4) through the country does not exceed the threshold value. In the Silesia region the average concentration of soil nickel (13.3 mg kg⁻¹ of soil) is also well below the threshold values [5].

We have established that 94.7% of agricultural land in Poland is characterized by a natural content of nickel (0°) – Table 1. In Silesia, only 87% of soils belong to this category. The larger occurrence of soils with elevated nickel levels in Silesia is very probably associated with the use of nickel in smelting and galvanizing processes. Slight pollution with nickel is present sporadically both in Silesia and in other regions; however, it does not exceed 0.4% of the total agricultural land in Poland – Table 1. Up-to-date results demonstrate that soils which have higher degrees (III°-V°) of nickel contamination are very rare. From our findings it can be concluded that nickel distribution in the soils of Poland does not significantly affect agricultural production and crop quality, even in regions such as Silesia.

The average concentration of lead in Polish agricultural soils is 13.8 mg kg⁻¹ of soil with a range of 0.1-1722 mg kg⁻¹ of soil – Table 1. Extreme values were found in a number of locations in Silesia associated with lead and zinc mining. On average, soil lead in this region (50.9 mg kg⁻¹ of soil) is three times higher than that found throughout the rest of the country. The expected range for lead in all soils studied (7.6-25 mg kg⁻¹ of soil) is noticeably narrower than the observed range (0.1-1722 mg kg⁻¹ of soil), which indicates that extremely high concentrations of lead are not very common.

Over 97% of agricultural soils in Poland exhibit a natural content (0°) of lead – Table 1. In the Silesia region, soils not contaminated with lead occupy 61.6% of agricultural land. Areas of soils containing elevated levels of lead (I°) are 2.3% of the total farmland, whereas, in the Silesia region, such soils occupy 21.6% of the agricultural land. Only a small proportion of the agricultural land in Poland (0.3%) is classified as slightly polluted (II°) with lead. In Silesia, however, 8.4% of soils is slightly polluted. Soils representing medium pollution with lead (III°) appear locally in southern Poland,
particularly in Silesia, where 8.2% of land is polluted to this degree – Table 1. Higher degrees of pollution with lead are of little importance, except some locations in Silesia.

The average concentration of zinc in the agricultural soils of Poland is 32.7 mg kg\(^{-1}\) with an observed range of 0.5-2837 mg kg\(^{-1}\) of soil – Table 1. The expected range (16.6-64.6 mg kg\(^{-1}\) of soils), however, is significantly different from the observed one, which indicates that extreme values are not so common throughout the country. Nevertheless, the upper limit of the expected range is significantly higher than the value considered as the natural background (40 mg kg\(^{-1}\) of soil) (Kabata-Pendias and Pendias, 1993). The average concentrations above the natural background are usually found in southern Poland. This can be explained by zinc emission from the smelter industry located in Silesia; however, the origin of parent rock material also plays an important role, particularly in areas which are not directly exposed to industrial pollution.

The total area of farmland characterized by natural zinc content (0°) is 88%. Elevated concentrations of zinc (I°) are found in 10.6% of soils. Environmental and food chain risk caused by elevated levels of zinc in soils becomes an open question since zinc deficiency in diet may be a problem in certain areas. Moreover, zinc seems to play an important role in controlling the cadmium uptake in cadmium-contaminated soils, whenever the ratio Zn:Cd is higher than 100 (Chaney et al., 1995).

Table 1: Content of Cd, Cu, Ni, Pb and Zn in the surface layer (0-20 cm) of agricultural soils and the degree of soil pollution with heavy metals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Area</th>
<th>Geom. mean mg kg(^{-1})</th>
<th>Range mg kg(^{-1})</th>
<th>Percentage of agricultural land exhibiting different degrees of metal pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geom.</td>
<td>observed</td>
<td>expected</td>
<td>0°</td>
</tr>
<tr>
<td>Cd</td>
<td>Silesia</td>
<td>1.06</td>
<td>0.10-49.73</td>
<td>0.37-3.06</td>
</tr>
<tr>
<td></td>
<td>Poland</td>
<td>0.22</td>
<td>0.01-49.73</td>
<td>0.1-0.48</td>
</tr>
<tr>
<td>Cu</td>
<td>Silesia</td>
<td>11.2</td>
<td>1.0-66.5</td>
<td>6.6-19.0</td>
</tr>
<tr>
<td></td>
<td>Poland</td>
<td>6.6</td>
<td>0.2-293.3</td>
<td>3.2-13.5</td>
</tr>
<tr>
<td>Ni</td>
<td>Silesia</td>
<td>13.3</td>
<td>0.5-80.5</td>
<td>6.8-26.1</td>
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<tr>
<td></td>
<td>Poland</td>
<td>6.4</td>
<td>0.1-328.3</td>
<td>2.6-15.4</td>
</tr>
<tr>
<td>Pb</td>
<td>Silesia</td>
<td>50.9</td>
<td>10.0-1722.7</td>
<td>23.1-112.2</td>
</tr>
<tr>
<td></td>
<td>Poland</td>
<td>13.8</td>
<td>0.1-1722.7</td>
<td>7.6-25.0</td>
</tr>
<tr>
<td>Zn</td>
<td>Silesia</td>
<td>116.2</td>
<td>5.0-2837.5</td>
<td>45.9-294.3</td>
</tr>
<tr>
<td></td>
<td>Poland</td>
<td>32.7</td>
<td>0.5-2837.5</td>
<td>16.6-64.6</td>
</tr>
</tbody>
</table>

The Silesia region (Wojewodztwo Katowickie) obviously has the largest areas of zinc contaminated soils; however, even within this polluted region, soils not contaminated (0°) with zinc occupy 41.3% of the land surface. The area of soils with natural and elevated levels of zinc is as high as 74%, however. Therefore in the Silesia region, zinc is a factor that could seriously affect the quality of crops grown on 26% of agricultural soils – Table 1.

The data presented in Table 2 indicated that 80% of farmland in Poland is characterized by natural concentrations (0°) of all the heavy metals studied. In industrialized areas such as Silesia, only 26.7% of soils are classified in this category. About 17% of soils throughout the country are characterized by elevated levels of heavy metals. Slightly polluted soils (II°) occupy 2.1% of the total arable land. The percentage of soils exhibiting higher degrees of metal pollution (III°-V°) is only 0.5%.

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Modelling metal transfer in the soil-plant system

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In the Silesia region, however, such soils occupy 19.7% of the farmland. This land may pose certain risks of metal transfer to the food chain; however, in a
number of cases we did not observe any excessive accumulation of metals in plants, even in areas exhibiting different levels of soil contamination, according to the classification system used.

In contrast, we have observed some cases of excessive metal uptake by plants in clean areas, where land was classified as a background-level soil (0°). Analytical error could not account for these rather surprising situations, since very restrictive quality protocols were followed. We assume that there are some site-specific combinations of factors such as pH, soil mineralogy, redox processes, etc., that may affect metal mobility differently than expected.

However, there are not enough scientific grounds to speculate on this. In general, statistical analysis of our data showed no simple relationships between metal content in soils and the metal uptake by plants. For example, as demonstrated in Figure 1, there is no correlation between log transferred soil cadmium and zinc and their concentration in a wheat grain. The multiple regression models tested, including properties that control metal bioavailability, did not improve the predictability. Apparently, metal mobilization in soils and its transfer to plants are controlled by too many factors of non-linear effects. Therefore, the common statistical procedures are not able to handle all interactions between factors and the resulting estimations are of limited value and accuracy. From a practical standpoint, the data obtained give a general estimate of soil pollution, although the prediction of metal transport to the food chain is not accomplished, unless additional methods can be utilized to improve these prediction capabilities.

Table 2: Percentage of agricultural land polluted with heavy metals (simultaneous pollution)

<table>
<thead>
<tr>
<th>Region</th>
<th>0°</th>
<th>I°</th>
<th>II°</th>
<th>III°</th>
<th>IV°</th>
<th>V°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poland</td>
<td>80.3</td>
<td>17.1</td>
<td>2.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Silesia</td>
<td>26.7</td>
<td>39.6</td>
<td>15.0</td>
<td>10.1</td>
<td>5.6</td>
<td>3.0</td>
</tr>
</tbody>
</table>

In order to find relationships between soil data as an input and metal concentration in plants as an output, Back Propagation algorithm and Radial Basic Function Network (RBFN) were used as provided by the commercially available software NeuralWorks Professional II/Plus (Neural Ware, Pittsburgh, PA). Our preliminary study showed that RBFN network performance was significantly better as compared to the back propagation, therefore we have continued our modelling experiments with RBFN only. Moody/Darken Radial Basic Function Networks is extensively described by Moody and Darken (1989). The type of RBF network we have used in this study consisted of three layers (input layer, hidden layers, and output layer). We have started with a relatively large number of variables loaded into the input layer, subsequently eliminating those that had no significant effect on the learning efficiency and the output response. Eventually, we have ended up with the following set of inputs: sample co-ordinates (latitude, longitude), organic matter content, clay content, pH and log transferred soil cadmium, zinc, nickel, copper, and lead. Log transformations were necessary to normalize the distribution, since we have found that it may greatly affect the learning process. Prior to initializing the network, all input characters, except latitude and longitude, were Fuzzy transformed which resulted in the total number of 75 “artificial” variables on the input side of the model. Fuzzy transformations were conducted using procedures included in Data Sculptor v. 1.53 data engine (Neural Ware Inc. Pittsburgh, PA). The prototype layer, in the example with a wheat grain shown below, consisted of 50 processing elements. Additionally, we have found that introducing the hidden layers may be beneficial in many cases.
The output level consisted of the log transferred concentrations of cadmium, zinc, nickel, copper and lead in a wheat grain. Our best networks were trained using Delta Learning Rule and the Sine transfer function. However, for the monitoring data that we worked with there is no general rule for selecting the number of processing elements and no recommendation of any particular set of momentum term, learning coefficients, etc. to ensure the best results. It is evident from our experience that there is no single network type, learning rule, transfer function and set of parameters that would fit all problems.

In the example shown in Figure 2, plant zinc and cadmium as an output were multiplied by soil clay content. Thus the RBF model was used to predict an “aggregated” variable instead of the original measured value. Such an approach considerably helped the network to learn and to
improve the accuracy of the prediction. Dividing the predicted output values by clay content as an easily measurable property of each soil gives the estimated metal content in plants. As opposed to traditional regressions, RBF was able to find the strong relationship between soil properties and metal uptake by plants. As demonstrated in Table 3, the average difference between predicted and measured concentrations of zinc, cadmium and lead in a wheat grain is relatively small, as compared to the maximum permissible levels accepted for a foodstuff. Results for nickel are not shown in the table because no network that we have been training to date could satisfactorily predict the content of nickel in plants.

Table 3: Differences between measured and predicted concentration of metals in wheat grains using the RBF network

<table>
<thead>
<tr>
<th>Element</th>
<th>Zinc</th>
<th>Cadmium</th>
<th>Lead</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference between measured and predicted value [mg kg⁻¹]</td>
<td>10.3</td>
<td>0.045</td>
<td>0.15</td>
<td>1.4</td>
</tr>
<tr>
<td>Maximum permissible level in foodstuff [mg kg⁻¹]</td>
<td>50</td>
<td>0.15</td>
<td>1.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

We have found that looking for the right combination of parameters and type of variables loaded into the model can be a very time-consuming procedure. It is evident that soil sampling point co-ordinates are crucial for the network validity. Eliminating latitude and longitude from the input layer dramatically affects the results of network testing, which is using randomly selected data that were not part of the training session. This probably means that sample co-ordinates hold important site-specific information. This information most likely refers to such complex factors as the local climate, soil mineralogy, plant cultivars etc., that may control metal mobilization and transfer from soil to plants. Loading these unidentified site-specific factors, as characterized by their co-ordinates, enables the network to detect the interaction between soil properties and the metal uptake by plants.

We have experienced that even well-trained networks may often fail in the testing of “real world” samples due to the significant differences in the distribution patterns of input and output characters between the datasets used for the training and testing procedures.

Conclusions

The studies conducted have demonstrated that average concentrations of Cd, Cu, Ni, Pb, and Zn. in the agricultural soils of Poland, including the highly industrialized region of Silesia (in brackets), are as follows: 0.22 (1.06), 6.6 (11.2), 6.4 (13.3), 13.8 (50.9), 32.7 (116.2) mg kg⁻¹ of soil, respectively. The total area representing the natural content of heavy metals varies depending on the region. The majority of Polish soils can be used for agricultural production without causing concerns about food quality. However, it is obvious that the most limiting factor in some regions, such as Silesia, is soil contamination with cadmium, zinc, and lead. We have found that neural networks can be used as for the prediction of the processes controlling the metal transfer within the soil-plant system. Prediction ability of such models may be well over 80% for most metals versus 20% for traditional regression models. Radial Basic Function Network appears to be the most suitable for modelling the behaviour of metals as characterized by soil and crop monitoring data, however, we need further studies on data clustering and preconditioning to improve the prediction ability of the network. Potentially, neural computing may support the decision-making processes at different levels, including farms, to improve crop management based on the monitoring data and the risk assessment of metal transfer from particular soil to the plant.
References


The Romanian PROFISOL Database

Introduction

The use of databases is becoming more and more frequent in soil science, as in many other scientific fields. Databases referring to soil profile description and analysis are examples of this trend (Van Waveren and Bos, 1988, 1989; Kimble et al., 1990).

An earlier soil profile database was developed in Romania in the 1970s (Mielcescu et al., 1977; Canarache et al., 1981). A Felix-256 computer with FORTRAN and COBOL software was used. The database referred only to soil physical properties.

Based on this early version, a new database, PROFISOL, was later developed. Details, especially on the computer-science procedures, are presented elsewhere (Vlad et al., 1996). A general description of the content and facilities offered by PROFISOL, as well as on possible future developments, is presented in this paper.

Structure and functions of the PROFISOL database

Hardware and software

Two versions of the PROFISOL database are now in use:

- A minicomputer database was developed at an earlier stage. It made use of a DEC PDP-11 compatible minicomputer (CORAL-5030/4021) running FORTRAN (F77) and COBOL 81 under RSX-11M system software. At this stage, data for 120 profiles with complete data, 350 profiles with only physical and chemical data, and 3,400 profiles with only physical data were stored.
- A PC database was later developed using an IBM compatible 486 and Paradox 3.4 running under MS-DOS. Data from the minicomputer database were transferred here, and additional data were stored, bringing the total to 170 profiles with complete data, 450 profiles with physical and chemical data and 4,200 profiles with physical data only.

Input

Representative soil profiles described and analysed during current soil survey work or in any other similar activities are the main input in the PROFISOL database. Each profile is identified by a numeric chronological number. Most of the input data refer to genetic soil horizons, a maximum of 10 horizons being possible for each profile. All input is provided according to current Romanian soil survey methodology (ICPA, 1987).

Three forms for the input data have been developed:

1. M form, 4 sheets, for location and site description (96 items), profile description (24 items) and profile morphology (13 items for each horizon);
2. F form, 2 sheets, for soil physical properties (40 items for each horizon);
3. C form, 2 sheets, for soil chemical properties (34 items for each horizon) and groundwater properties (13 items).

In addition, information on analytical methods used (74
items), methods of drying the soil samples (30 items) and origin of soil physical data (1 item for each horizon) are included on the input forms. Altogether as many as 2167 data items can be stored for a single soil profile. The possibilities of including in the database at a later stage other kinds of soil data, such as microbiology, trace elements or clay mineralogy, are considered.

The existing forms are well suited to soil profiles where all or most properties are available. As in many cases a somewhat less complete description of the soil profile is used, the preparation of an alternative, less detailed, series of input forms is foreseen.

The M form contains mainly coded data. It was designed in such a way as to enable direct filling in during field work. In most cases the “menu” technique was used. The F and C forms contain only numerical data. They repeat some of the basic site and profile data, and the F form also repeats some of the basic chemical data. This way it is possible, when required, to use only one of these forms for several profiles.

Data are introduced to the computer interactively, using a selection of “video-maquettes”, screen images designed to be very similar in format to the input forms. Each form, and various data within the forms, may be entered at any time. Several validation procedures make checking of selected input data possible. Video-maquettes may be displayed on the computer screen for examination and/or validation. All input data are stored. Corrections, changes and updating of data are possible after storage.

The software was developed in a modular way, with independent modules using communication between modules through common, permanent or temporary files. Linkage of software and modules was obtained through a system of hierarchical menus. This resulted in several advantages:

- management of the high complexity of the software system
- flexibility;
- a relatively easy extension of the software system;
- increase in work performance of teams;
- decrease in size and complexity of the individual software components and relative ease of their modification;
- protection in inter-conditional processing;
- better adjustment to the need to perform various operations at different time.

Due to the large number and varied character of the data included in the database, a data dictionary had to be prepared for each entry. It includes names, codes, measuring units, implicit character (when needed), possible range of values (in some cases), formulae used for calculation or estimation. More than 600 different data types are included in the dictionary.

**Processing possibilities**

The existing software makes a series of calculations which provides more complete information on the stored soil profiles. These are:

1. **The identification and/or calculation of new properties not included in the input.** Some of these new properties refer to global site or morphological indicators such as physio-geographic region, texture of specific layers, degree of gleying, degree of salinisation, etc. They are obtained using specific algorithms. Other properties are soil physical and chemical properties resulting from classical formulae, such as total porosity, various pore size classes, available water capacity and C/N ratio.

2. **Calculation of certain data missing from the input, but which may be obtained from classical formulae.** Examples are some particle size classes, contraction index, etc.

3. **Estimation of missing data using pedotransfer functions.** Such estimation procedures are now available in Romania for:

- transformation of Atterberg silt (0.002-0.02 mm) and fine sand (0.02-0.2 mm) into USDA silt (0.002-0.05 mm) and fine sand (0.05-0.2 mm) or vice-versa;
- the parameters of Van Genuchten closed-form water retention capacity (Simota, 1993);
- several soil moisture constants such as wilting point or field capacity (Canarache, 1986);
- saturated hydraulic conductivity (Canarache, 1987) or for resistance to penetration (Canarache, 1990).

They are all continuous pedotransfer functions. The pedotransfer functions use as input mainly clay content and bulk density, and most of them are valid only for mineral soils. For the soil hydraulic properties, the existing pedotransfer functions are prepared as graphs from which spline functions have
been obtained and included in the database. Work is now being done to improve these estimation procedures, to use for estimation a larger variety of input data, to develop multiple regression equations instead of the spline functions, to extend pedotransfer functions for organic soils too, and to develop also class pedotransfer functions estimating texture and bulk density from information on physiogeographic region, soil map legend and soil profile morphology.

4. **Transformation of measuring units.** This type of calculation is being done for soil moisture constants to enable presentation of results as either weight (mass) percentage, volume percentage, or water depth (mm/ha).

5. **Recalculation of data for layers of pre-determined depth of the soil profile.** For many users of soil properties, such as designers of irrigation and drainage systems, there is a need for data to be referred not to soil horizons, but to specified standard soil layers. The PROFISOL software enables calculation of such data for most soil physical properties. The resulting data represent averages weighted according to the thickness and bulk density of the horizons.

6. **Selection of groups of soil profiles.** At present, selection may be done using a listing of soil profiles given by the user. It is foreseen that such selection will also be done automatically, using such criteria as soil classification, soil texture, physiographic region, depth of groundwater, etc.

7. **Statistical treatment of data for groups of soil profiles.** Once profiles of a specific soil group are selected as described above, data for each horizon or layer may be processed according to classical statistical procedures. Means, standard errors, medians, modes, standard deviations, sample variances, kurtosis, skewness, ranges, minimum and maximum values, and confidence levels are calculated. Various regressions may also be calculated. Possibilities exist to use numerical taxonomy techniques. For the next step, adding data treatment for kriging, linkage of the database to the geographical information system and other procedures are envisaged.

As described above, most of the processing possibilities refer to soil physical properties. It is also planned to extend some of these procedures to chemical properties. Automatic diagnosis of soil classification and of soil/land classes is also considered.

Various reports are provided. They include:
- reports with input data, one each for each of the three input data forms;
- report with soil profile morphology description, including also the formula of the land mapping unit;
- reports with physical data for soil horizons, different reports referring to a more or less complete selection of properties (Table 1);
- reports with physical data for soil layers of pre-determined depth, different reports being provided for different methods of subdividing the profile into layers;
- a report with both soil physical and chemical properties;
- a listing of profiles included in a specific group of profiles, including some soil properties of each profile;
- reports with statistical parameters of the main physical properties for a group of soil profiles, with different reports for various selections of statistical parameters.

**Existing applications**

The main use of the PROFISOL database since it was started in the 1970s has been to provide data on soil hydraulic properties needed in design of irrigation and drainage projects. Most of the processing facilities offered – listings of soil profiles, or of average data for groups of profiles were currently used.

The database has also been used to improve existing pedotransfer functions and to develop new ones. Various regression calculation were used to this end.

A synthesis of most data included in the database was performed to characterise the eco-regions into which Romania has recently been subdivided. Soil profiles included in the database were grouped by ecoregions and according to soil classification, and the average of each soil property was calculated.

More recently, a similar approach was used to fulfill requirements of the EU Soil Profile Analytical Database. About a third of the total number of profiles existing in the PROFISOL database was selected for processing, classified according to the FAO/UNESCO World Soil Map Legend and grouped by major soil groupings. Subgroups had to be established to take into account the
significant differences between soil profiles within each major grouping. This subgrouping referred to soil texture in the case of Fluvisols and Gleysols, to the depth of bedrock and of groundwater when present, in some cases to soil units with specific soil horizons, and to land use. The number of soil profiles within each soil group, and the number of soil subgroups, are shown in Table 2. Subsequently, averages and statistical parameters of each soil property and each subgroup were calculated using the facilities offered by the PROFISOL database.

Table 1: Physical and chemical properties of soil profile 006334

<table>
<thead>
<tr>
<th>Horizon</th>
<th>MEAS.</th>
<th>Ap</th>
<th>Am</th>
<th>A/B</th>
<th>Bt1</th>
<th>Bt2</th>
<th>Cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horiz.depth</td>
<td>UNIT</td>
<td>0-18</td>
<td>18-41</td>
<td>42-73</td>
<td>73-105</td>
<td>103-140</td>
<td>140-160</td>
</tr>
<tr>
<td>Samp.depth</td>
<td>0-18</td>
<td>20-30</td>
<td>50-60</td>
<td>80-90</td>
<td>110-120</td>
<td>145-155</td>
<td></td>
</tr>
<tr>
<td>Phys.prop.</td>
<td>% W/W</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coarse frag.</td>
<td>% W/W</td>
<td>0.3</td>
<td>0.6</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>% W/W</td>
<td>32.4</td>
<td>29.1</td>
<td>26.2</td>
<td>27.5</td>
<td>30.0</td>
<td>31.3</td>
</tr>
<tr>
<td>Fine sand</td>
<td>% W/W</td>
<td>26.9</td>
<td>22.9</td>
<td>22.8</td>
<td>24.7</td>
<td>23.6</td>
<td>23.2</td>
</tr>
<tr>
<td>Silt</td>
<td>% W/W</td>
<td>40.4</td>
<td>47.4</td>
<td>50.5</td>
<td>47.3</td>
<td>44.8</td>
<td>45.0</td>
</tr>
<tr>
<td>Clay</td>
<td>% W/W</td>
<td>54.6</td>
<td>62.1</td>
<td>66.6</td>
<td>62.2</td>
<td>58.8</td>
<td>60.0</td>
</tr>
<tr>
<td>Phys. clay</td>
<td>% W/W</td>
<td>15.9</td>
<td>14.4</td>
<td>12.2</td>
<td>8.8</td>
<td>14.5</td>
<td>16.5</td>
</tr>
<tr>
<td>Bulk density</td>
<td>G/CM3</td>
<td>51.6</td>
<td>49.8</td>
<td>47.3</td>
<td>43.6</td>
<td>46.5</td>
<td>48.1</td>
</tr>
<tr>
<td>Total poros.</td>
<td>% V/V</td>
<td>0.0</td>
<td>5.5</td>
<td>11.1</td>
<td>17.2</td>
<td>11.0</td>
<td>8.1</td>
</tr>
<tr>
<td>Air porosity</td>
<td>% V/V</td>
<td>9.0</td>
<td>11.1</td>
<td>12.6</td>
<td>11.5</td>
<td>11.5</td>
<td>11.1</td>
</tr>
<tr>
<td>Comp. degree</td>
<td>% V/V</td>
<td>13.5</td>
<td>16.6</td>
<td>18.6</td>
<td>17.2</td>
<td>17.5</td>
<td>16.6</td>
</tr>
<tr>
<td>Hygr. coeff.</td>
<td>% W/W</td>
<td>27.9</td>
<td>26.6</td>
<td>25.1</td>
<td>23.0</td>
<td>22.7</td>
<td>22.6</td>
</tr>
<tr>
<td>Wilting point</td>
<td>% W/W</td>
<td>40.3</td>
<td>37.4</td>
<td>33.8</td>
<td>28.8</td>
<td>32.5</td>
<td>34.4</td>
</tr>
<tr>
<td>Field capacity</td>
<td>% W/W</td>
<td>14.4</td>
<td>9.9</td>
<td>6.2</td>
<td>5.7</td>
<td>5.1</td>
<td>5.9</td>
</tr>
<tr>
<td>Tot. water. Cap.</td>
<td>% W/W</td>
<td>12.4</td>
<td>10.8</td>
<td>8.7</td>
<td>5.8</td>
<td>10.7</td>
<td>11.8</td>
</tr>
<tr>
<td>Av. moist. cap.</td>
<td>% W/W</td>
<td>1.9</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Water yield</td>
<td>% W/W</td>
<td>14.4</td>
<td>9.9</td>
<td>6.2</td>
<td>5.7</td>
<td>5.1</td>
<td>5.9</td>
</tr>
<tr>
<td>Hydr. conduc</td>
<td>MM/H</td>
<td>4.0</td>
<td>2.5</td>
<td>1.9</td>
<td>1.2</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Chem.prop.</td>
<td>% W/W</td>
<td>0.180</td>
<td>1.120</td>
<td>0.089</td>
<td>0.055</td>
<td>0.033</td>
<td>0.037</td>
</tr>
<tr>
<td>Humus</td>
<td>% W/W</td>
<td>15.0</td>
<td>1.5</td>
<td>14.4</td>
<td>14.6</td>
<td>14.1</td>
<td>14.6</td>
</tr>
<tr>
<td>Total n</td>
<td>% W/W</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>8.2</td>
</tr>
<tr>
<td>C/N</td>
<td>-</td>
<td>6.4</td>
<td>6.3</td>
<td>6.3</td>
<td>6.5</td>
<td>6.9</td>
<td>8.1</td>
</tr>
<tr>
<td>pH in H2O</td>
<td>-</td>
<td>30.4</td>
<td>30.2</td>
<td>31.5</td>
<td>30.3</td>
<td>nd</td>
<td>27.6</td>
</tr>
<tr>
<td>Exch. bases</td>
<td>ME/100 G</td>
<td>24.8</td>
<td>24.1</td>
<td>24.8</td>
<td>24.0</td>
<td>nd</td>
<td>22.7</td>
</tr>
<tr>
<td>Exch. Ca</td>
<td>ME/100 G</td>
<td>4.7</td>
<td>5.4</td>
<td>5.9</td>
<td>5.4</td>
<td>nd</td>
<td>4.0</td>
</tr>
<tr>
<td>Exch. Mg</td>
<td>ME/100 G</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>nd</td>
<td>0.5</td>
</tr>
<tr>
<td>Exch. K</td>
<td>ME/100 G</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
<td>nd</td>
<td>0.4</td>
</tr>
<tr>
<td>Exch. Na</td>
<td>ME/100 G</td>
<td>6.8</td>
<td>6.7</td>
<td>5.3</td>
<td>4.7</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>
Table 2: Number of profiles with stored soil physical properties; selected from the PROFISOL database and classified according to the FAO/UNESCO World Soil Map Legend

<table>
<thead>
<tr>
<th>Major soil grouping</th>
<th>Number of profiles</th>
<th>Number of subgroups</th>
</tr>
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<tbody>
<tr>
<td>Fluvisols 692</td>
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<td>72</td>
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<tr>
<td>Gleysols 50</td>
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<td>7</td>
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<td>Regosols 16</td>
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<td>Leptosols 20</td>
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<td>3</td>
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<td>Arenosols 72</td>
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<td>5</td>
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<tr>
<td>Andosols 19</td>
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<td>2</td>
</tr>
<tr>
<td>Vertisols 33</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Cambisols 69</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Solonetz 19</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Solonchaks 7</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Kastanozems 11</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Chernozems 218</td>
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<td>9</td>
</tr>
<tr>
<td>Phaeozems 277</td>
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<td>15</td>
</tr>
<tr>
<td>Greyzems 16</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Luvisols 166</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Podzols 19</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Histosols 2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong> 1602</td>
<td></td>
<td>68</td>
</tr>
</tbody>
</table>

Conclusions

1. The PROFISOL data-base is a complex tool, including site and soil morphological, physical and chemical characteristics, pedotransfer functions and various processing facilities in an integrated form.

2. At present PROFISOL includes a large number of soil profile characteristics for most agricultural and non-agricultural areas of Romania, especially physical soil properties.

3. The complex software that was developed for PROFISOL achieved a good balance between software modularity, data structure and efficiency. It proved to be well adjusted to processing large amounts of complex and often asynchronous data.

4. PROFISOL has been used in various research projects, significantly contributing to a better knowledge and utilisation of Romanian soils and environment.

5. Future development of the PROFISOL database is envisaged which will include continuous storage of existing and new data; preparation of a simplified version for current use; complete transfer to the PC platform; addition of new and improved pedotransfer functions; new processing procedures; extension to other kinds of data such as trace elements, clay mineralogy, micro-biology; introduction of compatibility with various simulation models, expert systems, decision support systems and with the Romanian soil geographic information system.
References


Section 5: Environmental Applications
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Vulnerability of main Bulgarian soils to acidification
D.A. Stoichev, I.H. Kolchakov

The potential risk of water and wind erosion on the soils of Czech Republic
M. Janecek

SOPIC: A soil information tool for research and environmental planning
K. Friedrich, P. Stock, Th. Vorderbrügge

Pedo-regional representativeness of site-specific data from small-scale soil maps
J. Utermann, G. Adler, O. Düwel, R. Hartwich, R. Hindel

A Land Information System for the application of sewage sludge in Greece
S. P. Theocharopoulos, A. Trikatsoula, D. A. Davidson, F. Tsouloucha, E. Vavoulidou

Esplan – software for engineering assessment of soils in Italy
D. Magaldi, G.L. Ricciardulli

Appraising levels of soil contamination and pollution with heavy metals
R. Lacatusu

Spatial Information Systems for Environmental Impact Assessment in the UK
M.J.D. Dufour, S.H. Hallett, R.J.A. Jones, J.W. Gibbons
Vulnerability of main Bulgarian soils to acidification

Summary

Anthropogenic impacts on terrestrial ecosystems include loading soils with different acid products. Their effect on soil quality and plant productivity depends on the soil vulnerability and land use practices. The soil has higher loading capacity than vegetation and natural water resources, so the changes are not immediately visible. The tolerance of most plants to soil acidity above the optimal values is another reason for delay in the appearance of the negative effects of acidification. Considerable decrease in bioproductivity and in some cases changes in plant cover usually appear when the soil pH is below the typical permitted level for the given plant-soil system.

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It is well-known that the recuperation of acid soils, especially on uplands, is difficult and expensive. It is therefore necessary to identify both natural and technogenic acid soils in the soil information system. The evaluation of soil vulnerability to acid loading will give an opportunity for planning the sustainable use of land resources and for applying more ecologically-friendly soil management practices.

Evaluating vulnerability to acidification

Bulgaria occupies a small land area (11.1 million hectares) and, due to its climatic conditions, geology, hydrogeology, relief and vegetation, has a great variety of soils. The formed soil units differ significantly in their genesis, structure, morphology, chemical, physical and physico-chemical properties. This research concerns the main soil units widespread over Bulgaria presented on the soil map (scale 1:1,000,000). This information is used for the development of the soil map of Central and Eastern European Countries (scale 1:1,000,000). A correlation of soil taxonomic units is done with the FAO Revised Legend, 1990.

The grouping of the main soil units according to their vulnerability to acidification is done using data for pH (H₂O), cation exchange capacity (CEC), base saturation (BS), exchangeable acidity, exchangeable aluminium and clay contents of the top layers of virgin and arable lands. Analysis of data and expert evaluation show that the soils investigated could be classified in four generalized groups (Figure 1):

1. Resistant to acidification

This group is characterized by a pH >7.5, CEC > 35 meq/100g, BS = 100% and high carbonate content from the top of the soil profile.

The group involves: Haplic Kastanozems (KSh), Rendzic Leptosols (LPr), Calceric Fluvisols (FLc), Haplic Solonetz (SNh), Gleyic Solonchacs (SCg), and associated Calceric Regosols (RGc), Lithic Leptosols (LPq), Calceric Phaeozems (PHc).

2. Moderately resistant to acidification

This group is characterized by pH 6.0-7.5, CEC 35-60 meq/100g, BS 85-95%, high clay content (>40%) and dominating clay minerals (2:1).

In this group are included: Haplic Chernozems (CHh), Eutric Vertisols (VRe), Calceric Luvisols (LVx), Chromic Luvisols (LVx), and the associated Eutric Regosols (RGe), Vertic Chromic...
Luvisols (LVxe), Eutric Fluvisols (FLe)

3. Poor resistance to acidification

The main parameters of this group range as follows: pH 4.8-6.0, CEC 25-35 meq/100g, BS 50-85% and rate of the exchangeable aluminium < 10% of CEC. In this group are included: Haplic Luvisols (LVh) and associated Plano Chromic Luvisols (LVxp), Plano Haplic Luvisols (LVhp), Eutric Cambisols (CMe), Eutric Planosols (PLE).

4. Non-resistant

Non-resistant soils are grouped with pH<5.0, CEC<20 meq/100g, BS<50% and the content of the exchangeable aluminium more than 10% of CEC. In this group are included: Dystric Planosols (PLD), Dystric Cambisols (CMd), Humic Cambisols (CMu) Haplic Acrisol (ACh), and associated Umbric Leptosols (LPU), Lithic Leptosols (LPq).

The total area of the soils with pH<7 (groups 2, 3, 4) occupies about 6.5 million hectares which is almost 60% of the whole Bulgarian territory (Figure 1). Part of this land (4.3 million hectares) is covered with soils highly vulnerable to acidification (pH<5.0). Half of these soils have acidity which is toxic for plants, but only 0.45 million hectares of these lands are cultivated (Ganev, 1992a, National Reports on Acid Soils, 1987). Nevertheless, special attention has to be paid to the soil resources that are included in the reserve of arable lands because they are subject to both natural and anthropogenic acid loading. Fertiliser application is assumed to be the most significant anthropogenic impact on the soil acidity, especially when physiological acid fertilisers are applied (Ganev, 1992a, Stoichev and Stoicheva, 1986; Stoichev, 1986; Stoichev et al., 1988).

Effect of fertiliser application on the acidity of arable soils

This research is based on the data from long-term field experiments with corn, grown as a monoculture under irrigation. The fertilisers applied are triple superphosphate and ammonium nitrate. Potassium is not used. The determination of the optimal N-rate is based on full compensation of the nitrogen uptake of 10 tons corn grain per hectare. In three other experimental treatments the rates are 50, 75 and 125% of the calculated optimum. Thus designed, the field experiment is suitable for evaluation of the common N-fertilisation practices:

a) continuous N-deficit,  
b) partial N-uptake compensation  
c) neutral nitrogen balance  
d) overfertilisation.

Analysis of the data shows that long-term fertilisation does not affect the pH values of the Kastenozems and the changes in the arable layer of the Vertisols are not statistically significant. In other soils (Table 1), the changes depend on the rate of the N-fertiliser application. This is confirmed by the pH data when the rate is 50% of N-uptake. As is shown in Table 1, long-term fertilisation with 100-120 kg/ha N does not affect soil pH. In all cases the measured pH values are near those of the control and if there are some changes they do not exceed LSD 0.05 for the respective soil layer. Obviously this rate of fertilisation is ecologically acceptable for the main soils, because it does not provoke significant changes in soil acidity.

Statistically-proved decreases in the pH values of the soils studied begins when the long-term application of the physiological acid fertilisers is above the quoted rates. For example, when the rate of application is 75% of N-uptake at the end of a 16-year period, there are significant changes in the pH values in the 0-20 cm layer. When the fertiliser rate covers 100% of the yield nitrogen uptake, there is a disturbance of the arable layer basic-acid equilibrium for all soils. In some cases even sub-arable layers are influenced (Table 1).

The most significant acidification occurs when the rate of fertiliser application for maintaining a positive nitrogen balance in the soil-plant system is determined. Long-term application of high rates of physiological acid fertilisers leads to additional acidification even of the soils with high natural loading capacity (second group, Figure 1). The increase in the acidity of the top soil layer varies from 0.6 to 1.0 pH units for the soils investigated. Acidification of the 20-40 cm layer appears in three of the studied soils. The data obtained show that the use of ammonium nitrate can be accepted as an anthropogenic loading of the soil that is subject to control and optimisation. The disturbance of the basic-acid equilibrium of some soils is not just a theoretical problem, but exists in common practice (Ganev, 1992a). For example in 1975 the area of acid soils in Plovdiv region (South Bulgaria) covered 34,000
hectares. Ten years later the area of soils with pH <5 had increased to 86,000 hectares. Scientists recommend that about 2.7 million hectares of acid soils in Bulgaria need to be limed. About 1.4 millions ha of these are arable lands in the plains and semi-mountainous regions and the other 1.3 million ha are in the mountain regions (National Reports on Acid Soils, 1987).

Some acidification of the alkaline and neutral soils is considered as a positive process because it provides a better environment for plant roots. The increase in acidity of the naturally acid soils and the higher exchangeable aluminium release in the soil solution can provoke the destruction of clay minerals and increase the podzolic processes in the treated soils. The overview of the existing information shows that acidification of Bulgarian soils as a result of long-term application of the physiological acid fertilisers is in its initial phase and has not significantly affected the structure of the clay minerals of the arable soils (Ganev, 1992a).

Conclusion

Analysis of the results from the soil survey in Bulgaria shows that almost half of the soil resources are vulnerable to anthropogenic acidification. Special attention must be paid to genetically acid soils under cultivation. Their additional acid loading has to be controlled to avoid anthropogenic soil degradation.

Long-term field experiments show that generally, fertiliser application cannot be classified as a negative factor for soil acidification. The rate of ammonium nitrate application (less than 50% of nitrogen uptake compensation) can be accepted as an ecologically friendly soil loading. At such a rate of treatment there are no statistically significant changes in the pH values even after sixteen years of soil fertilisation and growing of corn as a monoculture under irrigation. Continuous positive nitrogen balance did not affect pH values except those of the calcareous chernozem (Kastanozems) and the leached smolnitsa (Eutric Vertisols). In all other soil units under cultivation, the soil acidification as a result of using physiological acid fertilisers occurs with an intensity which depends on soil physico-chemical characteristics and the rate of the acid loading.
Table 1: Effect of long-term fertiliser application on the pH(H$_2$O) value of the soils

<table>
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<tr>
<th>Soils</th>
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<td>6.4</td>
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<td></td>
<td>LSD$_{0.05}$</td>
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<td>0.4</td>
<td>0.3</td>
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<tr>
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<td>Plano-Chromic</td>
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References


The potential risk of water and wind erosion on the soils of Czech Republic

Summary

The first maps of soil erodibility by water and wind for the territory of the Czech Republic were constructed in the 1960s. Since that time, the methodology of erosion evaluation has developed considerably, mainly in association with the advances in computer technology. It was particularly the creation of the geographic information systems (GIS) which boosted the progress. In the context of the delimitation of areas suitable for conversion from arable lands into permanent grasslands or forests (which is part of the programme of reduction of agricultural production in the Czech Republic), the need has appeared for a sound scientific basis allowing the optimization of this process.

As dense grass cover is itself a perfect protection of soil against erosion, attention has been focused on arable lands which are much more susceptible to erosion. The maps of the potential erosion risk by water and wind were constructed using an ARC/INFO geographic information system.

The potential soil loss estimates were averaged over individual cadaster territories. A modified Universal Soil Loss Equation was used to assess the risk of water erosion in such a way that the variable factors (L, C, P) were replaced by constants while the remaining relatively stable factors (K, S) were estimated using the pedologic database of the Research Institute for Soil and Water Conservation (RISWC). To determine the soil erodibility by wind, a methodology previously developed by the author was applied, exploiting the same soil database. The data have been stored on a workstation at RISWC and are available for future interpretations in such areas as reduction of agricultural production; water and wind erosion maps of soil erodibility; and erosion risk.

Introduction

The first synoptic map of soil erodibility by water and wind in Czechoslovakia was constructed by Bučko et al (1964). Zones at risk from both sheet form and gully erosion, as well as the areas susceptible to wind erosion, are identified. The network of gullies is also quantified.

To produce this map, the territory of the whole country was divided into 9 km x 9 km squares by placing a grid over the map. The area of agricultural land endangered by water erosion was determined by the methodology developed at the Department of Irrigation and Drainage of the Faculty of Civil Engineering at the Czech Technical University in Prague (Holý, 1979) and assigned to each square of the grid. The ratio of the endangered area to the overall area of the square was adopted as a “degree of erodibility” of the territory by water erosion. The territory of Czechoslovakia was divided into four categories according to the degree of erodibility:

I. (less than 25% agricultural land endangered)
II. (25-50% a.l.e.),
III. (50-75% a.l.e.)
IV. (more than 75% a.l.e.).

Continuous contours were then drawn through the grid squares to separate the zones of different agricultural land erodibility (by water) by both sheet and gully erosion.

To determine the density of the network of gullies, the territory of the country was then divided into 2 km x 2 km squares. Total length of the gullies was determined within each of these squares.
Three categories of gully network density were then distinguished:
I. (less than 0.1 km/km²)
II. (0.1 - 1 km/km²)
III. (more than 1 km/km²).

Even before that, the Regional Institute of Studies in Brno and, later, the Czechoslovak Academy of Agricultural Sciences at the Brno symposium in 1949 (Cablík and Juva, 1963) attempted to determine the areas subjected to wind erosion in Czechoslovakia. The maps in which this effort was summarized were then produced by the Hydrometeorological Institute. In these maps, the areas susceptible to wind erosion were divided into three categories, depending upon type of the wind prevailing in the area: dry, cold, or the one causing direct soil deflation. Later, Pretl (1963) used the data of the National Water Management Plan of the Czechoslovak Republic (accomplished in 1955), as well as his own research and survey data, to construct other maps of wind erosion.

Pasák and Janeèek (1971a) delimited the areas susceptible to wind erosion in Czechoslovakia using a climatic erosion factor C (expressing the effect of wind speed and soil moisture content) and the existing maps of soil texture classes.

During the following years, the procedures of erosion evaluation as well as computing technology have progressed considerably. Although the idea of geographers to create a computerized system for storage and arrangement of spatial information arose more than thirty years ago, it is only during the last fifteen years that this expanding technology has become widespread. In parallel with the advances in technology, the spectrum of applications of GIS has also been widening and is now capable of providing high-quality cartographic output as well as of evaluating various environmentally relevant properties of the landscape, such as the soil erodibility.

**Material and Methods**

**Water Erosion**

In the context of the ongoing delimitation of the areas suitable for conversion of arable lands into permanent grasslands or forests, which is a part of the programme of reduction of agricultural production in the Czech Republic, a requirement has been formulated that factors other than economic ones should also be taken into account. As the dense grass canopy or a herb layer in the forest provide good protection for that soil against erosion, it is logical that the above-mentioned conversion should mainly apply to shallow, easily erodible soils on slopes.

The most widely-used way of determining the degree to which a soil is endangered by water erosion is the Universal Soil Loss Equation (Wischmeier and Smith, 1965, 1978):

\[ G = R \cdot K \cdot L \cdot S \cdot C \cdot P \]

where:
- \( G \) - long-term average amount of soil loss by water erosion (t/ha/year)
- \( R \) - factor of rainfall erosivity depending upon the frequency of occurrence, amount, intensity and kinetic energy of the rainfall events,
- \( K \) - factor of soil erodibility,
- \( L \) - factor of the slope length,
- \( S \) - factor of the slope steepness
- \( C \) - factor of the protective effect of vegetation cover,
- \( P \) - factor of effectiveness of the erosion-control measures.

The Universal Soil Loss Equation (USLE) is suitable for evaluation of the erosion risk on an arbitrary plot by comparing the USLE - estimated soil loss with the maximum admissible one which is 1 t/ha/year -1 for shallow soils (thinner than 30 cm), 4 t/ha/year -1 for soils of medium depth (30 - 60 cm thick) and 10 t/ha/year -1 for deep soils (thicker than 60 cm). In the case that these limits are exceeded, the protective measures to be taken are proposed and their effectiveness can immediately be checked by the same method. However, before applying this procedure, it is necessary to establish the particular values of the input factors applicable to a specific territory and a particular field.

The factors L and S represent together a so-called topographic factor (LS). This is actually a ratio of the soil loss per unit area of a particular plot to the soil loss per unit area of the standard plot, 22.13 m long and with 9 % slope. During the ongoing process of land privatization in the Czech Republic, considerable changes in shape and area of fields (L-factor) and in the way of their exploitation (C-factor and P-factor) are taking place. The remaining factors (R, K and S) are relatively stable.

Regionalization of the R-factor for the territory of the Czech Republic (Janeèek et al., 1992) was attempted, based on the existing ombrographic records of storm rains obtained at the stations of the Czech Hydrometeorological Institute. However, as the lengths of the records are variable and often insufficient (less than 50 years), an assumption of spatially uniform probability of occurrence of storm rains over the territory of the Czech Republic currently...
seems to be more adequate than a detailed regionalization, even though some local differences certainly exist.

The factor of soil erodibility (K) can be derived from the soil texture, soil organic matter content, soil structure and permeability. Zuska and Nimeeek (1986) published an approximate procedure for the K-factor determination for 60 main soil units, based on the mean soil texture and mean humus content of the soil units concerned. The latter values were obtained by processing the data from about 2,500 soil profiles obtained during the Complex Soil Survey of the Czechoslovak Republic (Mašát and Nimeeek, 1983).

The soil structure and permeability for water were also considered. In this way, the K-factor was related to the units of the basic map resulting from the Complex Soil Survey and to the main soil units according to the system of the Valuated Soil Ecological Units (VSEU). The VSEU characteristics are coded in such a way that the first figure of the code denotes the climatic region, the second and third denote the main soil unit and the fourth figure stands for the slope and its orientation. The information represented by the fourth figure was used to determine the S-factor as a value corresponding to the centre of the interval of slopes to which the particular VSEU was ranked.

These characteristics of VSEU have been stored in a numerical database of the Integrated Soil Information System in the Research Institute for Soil and Water Conservation in Prague and can easily be used for computerized processing.

Assuming that the constant average value of the R-factor is 20 for the territory of the Czech Republic, that the C-factor ranges from 0.2 to 0.3 (which corresponds to an average crop rotation on arable land), assuming no erosion-control measures, i.e. P=1, and taking, hypothetically, the average field length along the slope as being between 60 and 150 m, which gives the values of L-factor between 1.66 and 2.61, we arrive at an approximate factor of ten by which one has to multiply the product of the factors (KxS) to obtain the value of G as a measure of the potential risk of water erosion on the arable land.

Due to the local variability of the factors L, C and/or P, this rule of thumb cannot, of course, be applied to individual plots. Therefore, the cadastral territory (a historical municipality territory) was chosen as the smallest unit for cartographic representation. The areal percentage of different VSEU within a cadastral territory was found for each such territory and the average value of the product (KxS) was estimated as an average of (KxS) for individual VSEUs, using their areas as weighting factors.

Wind Erosion

Previous results (Pasák and Janeek, 1971b) were applied to delimit the areas of susceptibility to wind erosion. First, a map of the climatic erosion factor C was created in order to quantify the effect of climatic conditions, i.e. wind speed and soil moisture content, on wind erosion.

The original relation for determination of the climatic erosion factor, formulated by Chepil (1956), was modified into:

\[ C = 100 \times (3 \times v^3 \times (Jz + 60)^{-2} \]

where:
- \( v \) - average annual wind speed at the standard height of 9 m, in m/s
- \( Jz \) - index of landscape wetness according to Konéek (1956).

To calculate the climatic erosion factor from the frequency of occurrence of winds > 50 Bf, the formula was modified as follows:

\[ C = 100 \times (6 + 0.52 \dot{e})^3 \times (Jz + 60)^2 \]

where: \( \dot{e} \) - frequency of occurrence of winds > 50 Bf in per cent per year.

The values of C = 20 and 40 were taken as boundaries between zones of different wind erosion risk. Isolines of these values were plotted on the map of the Czech Republic. To allow for the fact that various textural classes of soils show different susceptibility to wind erosion, a relationship of the soil erodibility by wind to the percentage of soil particles < 0.01 mm, derived by Pasák (1966), was used. By applying the two criteria simultaneously, the arable lands in the Czech Republic can be divided into six categories (Table 1).
Table 1: Erodibility of arable soils in the Czech Republic.

<table>
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<tr>
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<th>Climatic erosion factor C</th>
<th>% of particles &lt; 0.01 mm</th>
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<td>&lt; 20</td>
<td>any</td>
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<tr>
<td>II</td>
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<td>20 - 40</td>
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<td>III</td>
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<td>20 - 40</td>
<td>20 - 30</td>
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<tr>
<td>IV</td>
<td>medium</td>
<td>&gt; 40</td>
<td>0 - 20</td>
</tr>
<tr>
<td>V</td>
<td>high</td>
<td>&gt; 40</td>
<td>20 - 30</td>
</tr>
<tr>
<td>VI</td>
<td>very high</td>
<td>&gt; 40</td>
<td>0 - 20</td>
</tr>
</tbody>
</table>

Results

Water Erosion

Using the VSEU characteristics and the information about areal extent of VSEU, stored in the database of the Integrated Soil Information System, each cadastral territory identifier was assigned an average value of the product (KxS). This was done in the form of a map layer in the ARC/INFO geographic information system. In this way, the average degree of potential water erosion was determined for individual cadastral territories – see Figure 1.

Such a generalization, particularly if two or more extremely different categories of VSEU are present within the same cadastral territory, cannot, of course, describe a real situation in detail. It only characterizes a cadastral territory as a whole. Despite that, the resulting set of maps for individual districts (Figure 1), as well as a general map for the whole of the Czech Republic (Figure 2), provide a good overview. The potential water erosion in particular cadastres can be evaluated qualitatively using a scale of six degrees – see Figures 1 and 2. The soils were classed as potentially extremely erodible in 1,626 cadastres, weakly erodible in 2,930 and very weakly erodible or not erodible in 349 cadastres, while for the remaining 229 cadastres (non-agricultural land or land belonging to military zones) the information is lacking.

The relative area occupied by agricultural land obviously varies from one cadastral to another. Therefore, beside the map showing the average degree of potential erosion risk per unit area of agricultural soil in a cadastral territory, another map was prepared indicating the average potential soil loss per hectare of biologically exploited soil (including forests). This map distinctly delimits the regions where more detailed investigation is necessary into the susceptibility of individual plots to water erosion. It was produced by applying all factors of the unabridged Universal Soil Loss Equation, and it was recommended that the corresponding organizational, agronomic or technical erosion-control measures.

Wind Erosion

Using the pedological database of RISWC (the soil texture maps at scale 1:50,000) and the map of the climatic factor C, the maps of soil erodibility by wind for individual districts were constructed, showing separately the forested areas – see Figure 3, as well as a synoptic map of the Czech Republic – see Figure 4.

Discussion and conclusion

The regionalization of soil erosion is a relatively difficult task, more difficult than the regionalization of other physico-geographic phenomena (Stehlík, 1971). Direct observations of soil erosion and measurements of its intensity are not yet done regularly and systematically in the Czech Republic. The above-mentioned maps are a further step in a series of attempts to characterize the danger of the soil erosion processes in the country. The procedures described are to some extent similar to those used by Stehlík (1970) and Oeadlík and Urban (1980) or, among foreign authors, Vold et al. (1985). The availability of necessary software and hardware in RISWC made it possible to use GIS for these purposes. The data for individual cadastral territories have been stored on disk and are available for further interpretations. They can easily be used to document the need for erosion-control measures and, in particular, the need for an areal expansion of permanent types of vegetation cover (forests, meadows, pastures) in particular...
cadastral territories of the Czech Republic. Such need may well arise in connection with the expected reduction of agricultural production and in order to improve the level of protection of one of the most basic components of the environment – the soil.

References


Figure 1. Map showing the average degree of potential risk of water erosion on agricultural lands for individual cadastres in the Hodonín district. Explanation of scale (from top to bottom): (1) not evaluated, (2) very weak risk, < 1.5 t/ha/y, (3) weak risk, 1.6 to 3 t/ha/y, (4) medium risk, 3.1 to 4.5 t/ha/y, (5) high risk, 4.6 to 6 t/ha/y, (6) very high risk, 6.1 to 7.5 t/ha/y, (7) extreme risk, > 7.5 t/ha/y.
Figure 2. Map showing the average degree of potential risk of water erosion on agricultural lands for individual cadaster territories in the Czech Republic. Explanation of the scale: the same as in Figure 1.
Figure 3. Map of the potential soil erodibility by wind for the Hodonín district. Explanation of the scale (from top to bottom): (1) not evaluated, (2) none or very low erodibility, (3) low erodibility, (4) medium erodibility, (5) high erodibility, (6) very high erodibility, (7) forested areas, (8) open water surfaces.
Figure 4. Map of the potential soil erodibility by wind for the Czech Republic. Explanation of the scale: as in Figure 3.
The soil information tool SOPIC can also be used for the coupling and steering of process models. The UVF authority currently employs two models: spatial interpolation of measurements (weighted and unweighted) and simulation of the soil water regime.

Introduction

The public discussion about soil protection has caused an increasing demand for pedological data, and for area data in particular (BMU, 1987). In many counties of Germany, soil information has become an integral part of landscape planning and soil protection (Heineke et al., 1988, Oelkers and Vinken, 1988). This trend will be supported by the increasing availability of digital soil data describing the total area of single counties. The Preventive Environmental Atlas of the UVF (Umlandverband Frankfurt 1996) gives such an example.

Practical applications in planning and environmental protection need information on soil properties and soil functions. A wide interpretation of soil data or soil maps by planners or other non-geoscientific users may lead to misinterpretations, therefore prepared information about soil functions is needed rather than classical soil maps.

This enables wider use to be made of soil data which have been acquired by geological surveys at great expense, but requires new kinds of soil mapping, data preparation and data interpretation. Simply digitizing existing soil maps will not fulfill the demand for specific information about different soil functions. Instead, a system including such site data as climate, relief and land use data will be the way forward. The integration of information about land use is one central point in the administration and presentation of soil data.

On one hand, tools for the creation of soil maps in quantity are needed for the daily work of a geological survey. On the other hand we need versatile interactive GIS tools which allow the creation of complex expert maps which will include information about soil functions, soil properties, soil valuation and aims of soil protection and soil quality.

Since 1992, the Geological Survey of Hesse, Wiesbaden, and the regional planning authority UVF, Frankfurt, have been developing a tool based on the commercial GIS package ARC/INFO for the interactive query and visualization of spatial soil data (Pagenkopf, 1992). The program evaluates basic soil data for planning purposes and environmental studies.
Main properties of SOPIC

The soil information tool SOPIC (Solum pictum) is an interactive tool for selective interrogation and visualisation of digital soil data. It can also be used as a comprehensive soil information system.

The Geological Survey of Hesse and the UVF use a database of soil units at 1:25,000 to 1:50,000 scale. The last database for Hesse will be completed in 1997/1998. The soil units are described by information about soil properties. In addition, the UVF uses a soil condition register and geological units at 1:25,000 scale. Information about soil monitoring, relief, topography, climate and water regime complete the system.

One of the most important tasks of SOPIC is the data inquiry. The system has to enable all kinds of interactive selections concerning graphical and descriptive aspects. For example, all soil units with available water capacity greater than 200 mm and groundwater level less than 80 cm below surface can be visualized. The method of presentation may either be free, or may use standard shadesets (colour-, hatch- or signature set), according to the theme-related look-up tables.

Another task of the soil information tool is the steering of methods and process models. This function is not urgent because the visualization of existing information has priority, but visualizing data and steering processes by the use of just one tool is rather effective.

Main tasks of SOPIC

- Visualisation of database extracts (e.g.: soil properties, soil water regime, etc.)
- Creation of maps for selected themes and areas
- Creation of maps with different supplementary background information
- Steering of methods and process models
- Analytical methods (statistics).

If an interactive application saves time and is comfortable to use, it will be accepted by potential users. SOPIC therefore comprises nearly all the visualizing functions of ARC/INFO, it is easy to handle and macro developments are not necessary. The tool has been developed for geoscientific use with data processing knowledge to save time when creating complex expert maps.

The special tasks of SOPIC are in particular:

- administration and visualisation of covers, libraries and images (with a large amount of data) without fixed tiling boundaries
- area selection by tiles, landscapes or geographic co-ordinates
- visualization at any scale
- simultaneous visualization of several scientific and background themes (e.g. topography)
- interactive choice by attribute selection
- automatic plotting with standard layout and corresponding legend
- viewing and plotting of non-rectangular views
- automatic generating of insularity covers
- visualisation of information (thematic database query) related to geometric objects (polygons, lines, points)
- steering of methods and process models and subsequent visualization of the modelled data
- expanding of the tool by adding new ARC/INFO functions
- exchanging attribute data with external SQL databases
- saving the results of viewing sessions. Pre-fixed themes are available.

System structure of SOPIC

SOPIC is an ARC/INFO application working as a steering system for sifting information in context with points or areas. It consists of different elements: steering software (amls), geometric data (raster, polygon, line and point data), attribute data (database), methods and process models (Figure 1).

Basic data

The database is divided into geometric data and descriptive data (attributes). Many of the attributes refer to only a few geometric data, therefore this separation makes sense. Furthermore, this separation in data storage minimizes the data preservation.

Geometric data

The basic soil data are differentiated according to land use. They are stored in an unfixed tiling system using the ARC/INFO tool Librarian. Furthermore, geological and groundwater data are available both in the Geological survey and the UVF. The topographic background consists of scans of
topographic maps at different scales, of the ATKIS Digital Landscape model or of UVF-specific land-use data. The geometric objects are related to a relational database and can be handled independently from the tiling system.

**Descriptive data**

Descriptive data are stored and presented in an external database. Specific database procedures deliver interpretations derived from basic soil data. These data are also stored in INFO files to enable GIS access. After completion of the corresponding polygon database (Spies et al., 1998), these descriptive data will also be available in special ORACLE 7 views.

The soil units are described as soil forms under generalized land use (arable land, grassland, forestry). Relations exist to

- primary soil unit data
- site data depending on land use
- soil horizon data.

Several methods (Umlandverband Frankfurt, 1996) enable the derivation of numerous soil characteristics such as:

- soil water regime (fc, awc, saturated hydraulic conductivity, etc.)
- soil profile pH status
- soil acidification risk
- risk of nitrate leaching
- potential of heavy metal adsorption by soil and risk of ground water pollution.

Furthermore the UVF is provided with a soil quality register (soil condition register).

**Documenting the working process and presenting themes**

All thematic and geographic approaches can be saved during a single view session. The stored interpretations can be continued at any time. Furthermore, standardized themes with fixed geographic and thematic settings can be saved. When selecting a standardized theme, attributes and presentation will be adjusted automatically. For example, when selecting the theme group ‘primary soil unit data’, the theme ‘soil unit’ will be adjusted together with layout configurations.

**Application components**

**Standard elements of the SOPIC shell**

The SOPIC opening view consists of four components:

- main menu with view administration
- map display window
- menu for cover selection and plot file generating
- menu for selecting and editing of up to 11 simultaneously-displayed themes.

The most important menu functions of SOPIC are shown hierarchically in Figure 2.

**Start and main menu**

The start and main menu opens (and saves) data environment files (*.prefs) and view files (*.bv) and calls the modelling tools. Upon starting SOPIC, user-specific variables with information about workspace, database (libraries, covers, etc.), specific monitor layout and pre-fixed themes will be adjusted. According to the selected workspace, existing views can be presented. The views contain selected themes, map extracts and plotting parameters. They can be displayed on the monitor or sent to a plotter. Furthermore, the main menu contains buttons to call the editing menu ARCTOOLS or the integrated modelling tools (INTERPOL – model for interpolation, SIWA – hydrological modelling, FEEFLOW – ground water modelling).

**Theme presentation and data selection**

The SOPIC theme menu enables the user to display up to eleven simultaneous themes within one view. When selecting a data source (e.g. soil map, land-use specific soil data or soil horizon data), the individual themes will be presented with pre-fixed visualization parameters. Changing a theme leads to a corresponding change of these parameters. For data query, all themes can be varied quickly. This enables the comfortable use of all available data. For example, any available geometric or descriptive data can be incorporated as new themes. The parameters necessary for handling a new theme can also be adjusted by hand. When the user calls a new theme, a standard look-up table for visualization will be presented. It can be edited interactively by the user.

The SOPIC theme menu enables the selection and display of special geometric objects, areas and descriptive parameters. Statistical analysis of the selected parameters can be carried out. The menu for interactive attribute selection is shown in Figure 3. Data selection can be applied to every visualized theme.
and to all available incorporated geometries and attributes.

The selection of special map extracts (e.g.: topographic map, boundaries of communities) is done by the input of geographic co-ordinates or scales, or by zooming in or out. Geometric data stored in libraries are presented in corresponding tiles. Every tile can also be selected individually.

**Visualisation tools**

For soil units, site specific data and horizon data, pre-fixed standard shade sets (colour-, hatch- or signature set) can be used corresponding to the lookup tables of the single themes. Relations between geometric and descriptive data will be adjusted automatically. A selection menu enables interactive colour and signature changes. In addition, numerous specialist tools are available, e.g. to inscribe label points.

**Querying object data**

The querying of object data corresponds to the actually selected theme. The complete descriptive database of one or more selected geometric objects will be displayed or even printed. A standard query on horizon data is shown in Figure 4, as well as a profile constructed of horizon-related attribute values.

**Generating plot files**

The editing and generating of a standard plot file depends on the plot parameters of the chosen view. The map displayed on the monitor will be transformed into a plot file with standardized layout. Using the plot menu, information about author, project and administration can be included in the plot file. Depending on the selected map extract (e.g.: topographic map boundaries), the map frame may be rectangular or trapezoid. Data amount and map complexity are only restricted by the resources of the hardware system used.

**Conclusion**

The soil information tool SOPIC enables the interactive interrogation, visualization and plotting of spatial soil data. As it is modular in design, it can easily be upgraded by adding new tasks. SOPIC enables the creation of complex expert systems in a very time-saving way. It comprises most of the visualizing functions of the GIS software ARC/INFO and is only restricted by the hardware system used. In comparison with the ARC/INFO application ArcView, there are no limits in handling large data amounts and complex maps.

**References**


**SOPIC**

Application Shell

**Geometrical Data**
- soil map (differenciated by landuse)
- geological map
- map of soil analyses points (soil register)
- maps of interpolated heavy metal concentrations

**Descriptive Data**
(relation attribut tables)
- soil characteristics (soil map)
- relief data (soil map)
- modelled hydrological data (soil map)
- soil analyses data (soil register)

**Methods & Modelling Tools**
- Database Methods for calculation of soil characteristics (field capacity, hydraulic cond., etc.)
- Modelling tools for interpolation and time related process simulation
  - spatial interpolation (INTEROL)
  - hydrological model (SIWA)
  - groundwater model (FEFLOW)
### Bodeneinheit: 105 / Nutzung: 1

#### Horizontdaten

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<th>Mörl</th>
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#### Diagramm

- **Bodeneinheit:** 105
- **Nutzung:** 1

- **Bodenart:** Tiefenreiche-Parabraunerde
- **Näherung:** 1

Diagramm zeigt die Verteilung von pH-Werten, Lagerungsdichten, Lagerungsvolumina, und Nützlichen Hektarzahlen im Bodenprofil.
Pedo-regional representativeness of site-specific data from small-scale soil maps

Summary

Laws aimed at country-wide soil protection are currently being drafted in federal Germany. In this context, increasing efforts are being made to collect all soil data that are available at the various federal state institutions in order to screen them for inherent (lithogenic-pedogenic) and human (anthropogenic) background values (e.g. contamination). Subsequent country-wide application of these site-specific soil data requires, however, that the sampled sites are adequately representative with regard to soil substrate and land use.

In order to determine the pedo-regional representativeness of the available soil site data, the analytical results (including heavy metal contents) of 1,812 identically sampled topsoils are used. Since the derivation of background values primarily requires detailed knowledge of the soils’ substrate, an existing small-scale (1:1,000,000) digital map of soil parent materials (MPM) was compiled as a base map. In addition to parent material, available information about soil textures is used for the spatial extrapolation of the site-specific soil data.

The approach pursued is based on the spatial differentiation of the legend units of the MPM and the representativeness of the site data in accordance with the content of legend units. The pedo-regional representativeness of the site data, as derived from the combination of these two approaches, is illustrated for Germany as a whole. Further spatial (regional) and thematic (land use) differentiations are also discussed with regard to their effect on sampling requirements. As a result of the pedo-regional representativeness study, an enormous need for more data harmonized with respect to soil coring and analysis is evident.

Introduction

Against the background of the federal efforts running in Germany to establish a uniform soil protection law, increased efforts have been made in the recent past to create a country-wide compilation of available data for the purpose of evaluating background values for inorganic and organic substances in soils. This paper refers to the inorganic background values of soils, made up of their basic geogenic content and the distribution of ubiquitous substances as a consequence of diffuse entry into the soil.

The results of the country-wide evaluation compiled by the Joint Federal States Working Group for Soil Protection (LABO AK4, 1995) revealed that there is only a little site-specific data suitable for answering this type of question at a small, country-wide scale. The accurate extrapolation of the existing site-specific data to areal information requires that the sample sites are sufficiently representative with respect to the scale, substrate and land use.

Geostatistical analysis of the soil site data (involving soils derived from bedrock only) revealed autocorrelation lengths of less than 500 metres (Hindel et al., 1995). Given the limited data density, geostatistical approaches thus do not seem appropriate for determining the country-wide pedo-regional representativeness of site data.

Hence, an alternative, more pragmatic approach is pursued that is based on the spatial differentiation of the legend units of a parent material map (MPM).
and the representativeness of the site-specific data in accordance with the content of the legend units. The mainly methodologically-oriented work undertaken with the site and spatial data base components of BGR’s Soil Information System (SIS BGR) are aimed at evaluating and depicting the pedo-regional representativeness of profiles (in the sense of the regular distribution of soils) to derive background values at a country-wide scale (1:1,000,000). Against the background of optimizing the sampling and analysis effort, another question in this context is whether an improved land use and/or regionally-based spatial differentiation would be possible or sensible to derive background values at this scale.

Databases

Site-specific information

Site-specific data sets are evaluated for the pedo-regional representativeness analysis, which were i) available country-wide and ii) investigated using federally agreed methods. In total, information was available on 1,987 locations, of which 1,812 met the minimum demands with respect to site co-ordinates, soil parent material, soil type, soil texture, land use and heavy metal content. Heavy metal analyses in the form of total digestion (HF + HNO₃ pressure digestion, X-ray diffraction) were available for all of the samples used. 526 profiles (all from the former West Germany) originated from a research project set up to derive background values (Hindel and Fleige, 1989) and were supplemented by intensive investigations at a very local scale on five parent substrates (claystones, limestones, basic igneous and metamorphic rocks, sandstones and loess) intended amongst other things, for geostatistical purposes (Hindel et al., 1995), as well as other surveys from parts of the new federal German states (Hindel et al., 1996).

Figure 1 depicts the location of the 1,812 profiles. This clearly shows that the data sets used provide only very patchy coverage. The deficits are mainly in the new federal states, but also in part in the old federal states. As regards the scale problem, the site-specific data used in the representativeness study reveal sampling distances from a minimum of 10 m to a dimension of 10 km to 100 km.

Spatial database

According to LABO (1995), drawing up valid background values for inorganic compounds requires a hierarchical classification system with the reference parameter “substrate” (parent material, soil texture) on the first level, due to its dominant influence on both the geogenic content and the metal binding strength of soils. Additional reference parameters like “land use” and “regional type” are to be categorized below this level. Hence, studies on the representativeness of site-specific data should primarily refer to information on substrate and subsequently be differentiated with respect to land use and/or regional types.

Against this background, the pedo-regional representativeness assessment of profiles to derive background values first requires a country-wide small-scale map of the soil parent material (MPM) covering the Federal Republic of Germany. This map was compiled at a scale of 1:1,000,000 and is known as MPM 1000. The base map for MPM 1000 is the soil survey map 1:1,000,000 (BÜK 1000, Hartwich et al., 1995) with a total of 72 legend units (LU) containing the information required on soil parent material. Against the background of drawing up heavy metal reference values for topsoils, the 72 LUs of BÜK 1000 were classified and grouped according to pedo-lithogenic properties into a total of 15 LUs in MPM 1000. Because the current data situation does not yet allow reliable, statistically verified substrate differentiation to derive background values for top-soils, MPM 1000 actually represents a preliminary stage in the work.

Local differentiations of soil parent materials are partially lost in the small-scale maps at a federal level (≤1:200,000). If one uses the soil texture as an additional coupling element when extrapolating from a specific site to a regional level, it is possible to retain the substrate information of the site data even in the small-scale soil parent material classifications. In a further step, each LU of MPM 1000 was assigned soil texture groups that complied with German soil taxonomy (KA4) (AG Boden, 1994) according to the areal occurrence in the LU, by referring back to the legend contents of BÜK 1000. Thus both the soil parent material and the soil texture form the interface between site-specific and area information for the pedo-regional representativeness analysis.

Table 1 lists the legend units of the parent material map (MPM 1000), its relative cover with
respect to the total area of the Federal Republic of Germany, and the spectrum of soil texture classes in each LU of MPM 1000, differentiated according to their areal dominance. The soil texture classes according to German soil taxonomy (AG Boden, 1994) are ranked with increasing clay content. This clearly shows that the LUs of MPM 1000 have very different content heterogeneity with respect to the soil texture classes. Sands for example (flood plain sands, valley sands, aeolian sands, littoral sands (LU 4)) are primarily composed of pure sands and subordinate loamy and silty sands, whereas the grain size spectrum of LU 1, 2 or 10, more or less extends over the whole range of soil texture classes. Because the site and area information are coupled via the legend units “parent material” and “soil texture”, the heterogeneity of the LU content is an important criterion in the evaluation of the pedo-regional representativeness of profiles for the derivation of background values.

Fig. 1: Location of the 1812 profiles for the derivation of background values

Procedure and results of the pedo-regional representativeness study

The main objectives of a country-wide pedo-regional representativeness study are regional evaluations. Local differentiations of the background values, e.g. in urban areas, are only possible to a very limited extent because of the scale. Referring to the area type differentiation of LABO AK4 (1995) the following statements are therefore more directly related to rural regions (area type III). Moreover, the representativeness study does not differentiate according to land use, because this type of differentiation at a federal scale is not considered to be able to provide any additional information for the main aspects looked at here, namely, the methodological aspects of the representativeness study. Estimations of the amount of data required to evaluate “land use differentiated” area information from a representativeness point of view rapidly led to the conclusion that this requires much more detailed data sets than are currently available at a federal level.
Table 1: Soil parent material (grouped according to soil survey map (BÜK 1000)) and soil texture classes (according to AG Boden, 1994)

<table>
<thead>
<tr>
<th>Number</th>
<th>Parent Material</th>
<th>relative cover of MPM [%]</th>
<th>sand</th>
<th>loamy sand</th>
<th>silty sand</th>
<th>sandy silt</th>
<th>loamy silt</th>
<th>clayey silt</th>
<th>sandy loam</th>
<th>loam</th>
<th>clayey loam</th>
<th>silty clay</th>
<th>loamy clay</th>
<th>peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>marine, brackish, tidal sediments</td>
<td>1,7</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>fluvisols</td>
<td>6,5</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>river-terrace deposits</td>
<td>2,6</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>sands</td>
<td>19,2</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>sandy sediments overlying boulder loam (clay)</td>
<td>2,1</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>boulder loam (clay)</td>
<td>9,4</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>loess</td>
<td>17,2</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>limestones</td>
<td>7,8</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>claystones</td>
<td>12</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>sandstones</td>
<td>9,2</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>basic igneous and metamorphic rocks</td>
<td>1</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>tuffs rich in bases</td>
<td>0,1</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>acid igneous and metamorphic rocks</td>
<td>5,5</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>fens/bogs</td>
<td>4,1</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>anthrosols (cities, open cast mines)</td>
<td>1,5</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
</tbody>
</table>

Areal cover of the LU ⇒ • 1-10% •• 11-30% ••• 31-50% ■ 51-70% ■■ 71-90% ■■■ >90%
Figure 2: Procedure to evaluate the pedo-regional representativeness of soil profiles with regard to the map of parent material 1:1,000,000 (MPM 1000)

**Map of parent material MPM 1000**
- 15 legend units (LU) with information on parent material (PM) & soil texture (ST)

**Soil profiles for evaluation of background values**
- (n = 1812)

**Comparison of site-specific soil types with parent material (PM) and soil texture (ST) of LU of MPM 1000 (identical/different)**
- PM + ST
- Only PM
- None

**Content representativeness of soil profiles in accordance with LU of MPM 1000**
- EC 1 ⇒ PM + ST (n ≥ 20), distribution index ≥ 0,75
- EC 2 ⇒ PM + ST (n ≥ 20), distribution index ≥ 0,5 and < 0,75
- EC 3 ⇒ PM + ST (n ≥ 20), distribution index < 0,5
- EC 4 ⇒ any other case with n < 20

**Spatial differentiation of LU of the MPM 1000**
- EC 1 ⇒ little
- EC 2 ⇒ medium
- EC 3 ⇒ high

**Spatial differentiation of the LU**
- area of the LU [km²]
- spatial distribution of the LU [km²]

**Derivation of evaluation classes (EC) according to the 33 & 66 percentil values**

**Linking spatial differentiation of the LU of MPM 1000 with representativeness of soil profiles according to the LU of MPM 1000**

**Pedo-regional representativeness of soil profiles for evaluation of heavy metal background values**
- EC 1 - representative
- EC 2 - partly representative
- EC 3 - hardly representative

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365
The pedo-regional representativeness study is based on an evaluation algorithm, which on the one hand is based on the map of parent material and soil texture at 1:1,000,000 scale (MPM 1000), and on the other hand takes into consideration the topsoil data from 1,812 profiles derived from the above mentioned sources. The flow diagram in Figure 2 shows the basic procedure followed in the study.

In the first step (left side of the flow diagram, Figure 2) the LU of MPM 1000 is evaluated according to the following two criteria with respect to their spatial differentiation in the sense of spatial distribution and subdivision:

- spatial distribution of LU in Germany (ARC/INFO-area scale)
- total area of the LU

This step is taken because it is considered that the increasing subdivision and distribution of the LUs over the area covered by the Federal Republic of Germany will require an increasing number of profiles in order to provide an adequate level of representativeness. The spatial differentiation (SD) of LUs is calculated as follows:

$$SD = \frac{\text{spatial distribution LU} [\text{km}^2]}{\text{total area of LU} [\text{km}^2]}$$

Figure 3 shows in schematic form how the spatial differentiation of LUs is calculated. An LU comprising 4 sub-areas is considered where the length of each sub-area is 1. The lowest spatial differentiation of the LU is reached when the rectangle (as a measure of the spatial distribution) encompassing all of the sub-areas is also the total area of the LU (example 1). Increasing spatial distribution of the sub-areas of the LU raises the spatial differentiation (with constant total area of the LU). The maximum spatial differentiation in the case presented here is reached when the 4 sub-areas under consideration lie at the maximum distance from one another (example 3).

Figure 3.: Schematic diagram for exemplary calculation of the spatial differentiation of an LU (see text for explanation)
The analogously determined SD values of the 15 LU of MPM 1000 were divided into three classes using the 33 and 66 percentile of the cumulative frequency distribution as the class boundaries. This gave rise to a three-step evaluation of the LU with respect to its spatial differentiation (EC 1 ⇒ little, EC 2 ⇒ medium, EC 3 ⇒ high spatial differentiation). The evaluation of spatial differentiation thus provides a relative measure with a validity clearly limited to the analysed map at the given scale and the differentiation of the content. The results of the evaluation of LUs from MPM 1000 with respect to their spatial differentiation are summarised in Table 2.

According to this, and based on the described evaluation procedure, most of the area covered by the Federal Republic of Germany has low to medium spatial differentiation at a scale of 1:1,000,000.

According to the definition, spatially highly differentiated (EC 3) legend units are those which have low areal cover and are dispersed over wide areas of the Federal Republic of Germany. This is the case with flood plain soils, fluvial and melt water deposits, sandstones, basic igneous and metamorphic rocks, bog, and anthropogenic deposits. On the other hand, relatively localised soil parent material such as loess (LU 7) or tuffs (LU 12) are assigned relatively low spatial differentiations.

The second step (cf. right hand flow diagram, Figure 2) involves testing the extent to which the contents of profiles used to derive background values are representative of the areas (LU) in MPM 1000, whereby they are directly aligned with their geographic co-ordinates (x and y values). As a result of this comparison, profiles can be assigned to one of the following three attributes:

- “PM +ST” ⇒ profile reflects the soil parent material (PM) and one of the soil textures (ST) occurring in the LU
- “PM” ⇒ profile only reflects the parent material (PM) of the LU in MPM 1000
- “neither PM nor ST” ⇒ profile reflects neither the parent material “PM” nor the soil texture “ST” of the LU in MPM 1000

If the profiles initially considered to be non-representative (“false MPM”) lie within a radius of ≤ 1000 m (reflecting the spatial inaccuracy of the LU) to a neighbouring LU, they are then analogously aligned in another step with the content of the neighbouring LU in MPM 1000 and, if necessary, re-evaluated according to their representativeness.

The result of this site-specific testing of content representativeness revealed that 80% (1,441) of the total of 1,812 profiles accurately reflect the parent material as well as one of the soil texture classes occurring in the LU. In 6% of cases, only the parent material but not the soil texture class were correct, and in 14% of all profiles neither the parent material nor the soil texture class were correct.

Beside the aspect of content representativeness the statistically based derivation of heavy metal background values requires in addition a specific minimum number of samples for each LU, which with respect to the existing evaluations of LABO AK4 (1995) in a first approximation was set down as n = 20. On the basis of this minimum sampling value a distribution index (DI) related to the areal dominance of the texture classes for each LU was calculated. To this end, the minimum sampling rate was distributed among the soil texture classes occurring in an LU (Table 1) according to their areal cover expressed as a percentage. The distribution index can assume a value between 1 and 0. The distribution index has a value of 1

---

Table 2: Spatial differentiation of the legend units of MPM 1000

<table>
<thead>
<tr>
<th>Spatial Differentiation of the Legend Units of MPM 1000</th>
<th>Legend Units of MPM 1000</th>
<th>Areal Cover of MPM 1000 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>low (EC 1)</td>
<td>1, 4, 7, 9, 12</td>
<td>50.1</td>
</tr>
<tr>
<td>medium (EC 2)</td>
<td>5, 6, 8, 13</td>
<td>24.7</td>
</tr>
<tr>
<td>high (EC 3)</td>
<td>2, 3, 10, 11, 14, 15</td>
<td>25.2</td>
</tr>
</tbody>
</table>

1) Numbers referring to legend units in Table 1
if every soil texture class of an LU is covered by the spatial cover minimum value (1-20). As an example, Table 3 shows the calculation of the distribution index for the parent materials: basic igneous and metamorphic rocks (LU 11). Although this is a legend unit with a relatively high total number of samples (n = 322), the distribution index is only 0.6 because 40% of the total area is not covered by the minimum number of sample sites that is required.

Table 3: Distribution index calculation as a measure of the representativeness of the LU in MPM 1000 using LU 11 (basic igneous and metamorphic rocks) as an example.

<table>
<thead>
<tr>
<th>soil texture</th>
<th>areal cover [%]</th>
<th>minimum number of samples</th>
<th>actual number of samples</th>
<th>distribution index DI</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy silt</td>
<td>40</td>
<td>8</td>
<td>217</td>
<td>0.4</td>
</tr>
<tr>
<td>clayey silt</td>
<td>20</td>
<td>4</td>
<td>102</td>
<td>0.2</td>
</tr>
<tr>
<td>sandy loam</td>
<td>20</td>
<td>4</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>loam</td>
<td>20</td>
<td>4</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>100</td>
<td>20</td>
<td>322</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The distribution index was divided into three classes (DI < 0.5; 0.5 ≤ DI < 0.75; DI ≥ 0.75) to evaluate the content representativeness of the LU in MPM 1000. With respect to the LU of MPM 1000, this gives rise to the following four evaluation classes (cf. right hand side of flow diagram in Figure 2) for the representativeness of the profiles to derive background values:

- **EC 1** ⇒ high representativeness (PM+ST (n ≥ 20), distribution index ≥ 0.75)
- **EC 2** ⇒ medium representativeness (PM+ST (n ≥ 20), distribution index ≥ 0, 5 and < 0.75)
- **EC 3** ⇒ little representativeness (PM+ST (n ≥ 20), distribution index < 0.5)
- **EC 4** ⇒ very little representativeness (any other case with n ≤ 20).

Table 4 presents the results of the representativeness evaluation with respect to the LUs in the parent material and soil texture map. Most of the LUs (80%) are assigned to evaluation classes 1 to 3, i.e. these areas have a minimum of 20 locations with information on parent material and soil texture in the top-soil corresponding to the LUs of MPM 1000. The four LUs of evaluation class 1 (highly representative) represent more than half of the total area of the Federal Republic of Germany.

Table 6 shows the result of the country-wide pedo-regional representativeness evaluation. Of the total of 15 LUs of MPM 1000, 4 LUs are considered to be representative, 1 LU partly representative, and 10 LUs hardly representative on the basis of the developed evaluation method. The five adequately representative LUs cover more than 65% of the total area of the Federal Republic of Germany.

The actual target figure of the representativeness study carried out is the pedo-regional representativeness of profiles to derive background values compared to MPM 1000. This is determined by intersecting the evaluation results on spatial differentiation of the LUs of MPM 1000, with the content representativeness of profiles according to LUs in MPM 1000 (Figure 2). The ordinally scaled evaluation classes assigned to each LU for both aspects of the representativeness evaluation are determined from the association matrix shown in Table 5.

The pedo-regional background representativeness is ordinarily graduated into three evaluation classes as follows:

- **EC 1** ⇒ high (representative),
- **EC 2** ⇒ medium (partly representative),
- **EC 3** ⇒ little (hardly representative)

The contents of the base maps are assigned equal importance in the intersection procedure used to evaluate pedo-regional representativeness of the background value profiles related to the contents of MPM 1000. For this result of the representativeness evaluation – which should be considered along the lines of a methodological study because of the limited data base – either the association of the profiles to the LU is the vital factor, or the intrinsic spatial differentiation of the LU itself can be definitive.
Table 4: Content representativeness of soil profiles (topsoils) in accordance to LU of MPM 1000

<table>
<thead>
<tr>
<th>representativeness of soil profiles in accord. to LU of MPM 1000</th>
<th>legend units(^1) of MPM 1000</th>
<th>areal cover of MPM 1000 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC 1 (high)</td>
<td>4, 7, 8, 10</td>
<td>55,0</td>
</tr>
<tr>
<td>EC 2 (medium)</td>
<td>2, 9, 11,</td>
<td>19,5</td>
</tr>
<tr>
<td>EC 3 (little)</td>
<td>13</td>
<td>5,5</td>
</tr>
<tr>
<td>EC 4 (very little)</td>
<td>1, 3, 5, 6, 12, 14, 15</td>
<td>20,0</td>
</tr>
</tbody>
</table>

1) numbers referring to legend units in table 1

Of note is the partial or inadequate representativeness of LUs with relatively high sampling rates, such as sandstone (LU 10) or basic igneous and metamorphic rocks (LU 11). In both cases, these are LUs with high spatial differentiation. Despite high levels of representativeness (sandstones) only sub-optimal pedo-regional representativeness can be achieved here. The spatial differentiation, and the pedo-regional representativeness can only be improved in this case through a more regionalised assessment. In the case of the basic igneous and metamorphic rocks, the low content representativeness is also the cause of the poor overall result. The quality of the representativeness assessment depends on the precision with which the soil textures are estimated in the field, and the accuracy of the information in MPM 1000. Comparative assessments of measured and estimated soil textures confirm a relatively high level of uncertainty in determining soil texture (Hindel et al., 1995). Because the grain size class has probably been wrongly assessed for some of the sites investigated, one can assume that the actual pedo-regional representativeness achieved in the case of LU 11 can be classified at least as partly representative.

Table 5: Connective matrix to determine the pedo-regional representativeness of the site-specific data from the evaluation classes for spatial differentiation of LU of MPM 1000 and content representativeness of the top-soil data

<table>
<thead>
<tr>
<th>representativeness of soil profiles in accord. to LU of MPM 1000</th>
<th>spatial differentiation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EC 1</td>
</tr>
<tr>
<td>EC 1</td>
<td>1</td>
</tr>
<tr>
<td>EC 2</td>
<td>1</td>
</tr>
<tr>
<td>EC 3</td>
<td>2</td>
</tr>
<tr>
<td>EC 4</td>
<td>3</td>
</tr>
</tbody>
</table>

369
Table 6: Pedo-regional representativeness of site-specific data referring to MPM 1000 for the purpose of evaluating heavy metal background values in top-soils

<table>
<thead>
<tr>
<th>pedo-regional representativeness referring to MPM 1000</th>
<th>legend units(^1) of MPM 1000</th>
<th>areal cover of MPM 1000 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>representative (EC 1)</td>
<td>4, 7, 8, 9</td>
<td>56,1</td>
</tr>
<tr>
<td>partly representative (EC 2)</td>
<td>10</td>
<td>9,2</td>
</tr>
<tr>
<td>hardly representative (EC 3)</td>
<td>1, 2, 3, 5, 6, 11, 12, 13, 14, 15</td>
<td>34,7</td>
</tr>
</tbody>
</table>

\(^1\) numbers referring to legend units in table 1

The derivation and country-wide depiction of background values in top-soils requires an additional differentiation of the LU with respect to land use (LABO AK4, 1995), which was initially ignored in the pedo-regional representativeness assessment. In order to provide a rough guide to the amount of data which would be needed for the country-wide derivation of background values for the whole of Germany, Table 7 lists the background value profiles used in the above mentioned evaluation, differentiated according to type of land use, for the parent material and soil texture map LUs.

If, in an analogous way to the representativeness verification (Figure 2), one assumes a minimum sample number of \( n \geq 20 \) for each of the 45 feasible legend/land use units, this would give a high representativeness (PM + ST, \( n \geq 20 \)) assuming a distribution index \( \geq 0.75 \) in 14 cases, i.e. a third of all legend / land use units.

Because the anthropogenically caused proportion of heavy metal background values is also dependent on the regional emission levels, one must assume that the previous country-wide assessed LUs of the parent material map have to be at least in part evaluated on a regional basis. Whether, and to what extent, such differentiation makes sense can only be element specifically and substrate specifically tested by a statistical analysis of an appropriately large data set.

Independent of regional emission levels, regionalised evaluations should be carried out for those legend units characterised by high levels of spatial differentiation. A regionally differentiated representativeness study will enhance the total amount of data required country-wide considerably because of the increasing number of LUs to be filled.

Conclusions

- From a methodological point of view, the method developed is suitable for evaluating the pedo-regional representativeness of soil profiles for the purpose of deriving background values at a country-wide scale.
- A more strongly differentiated derivation of background values reflecting regional aspects can lead to a considerable increase in the amount of data required. The extent to which such subdivision makes sense can be element-specifically and substrate-specifically evaluated on the basis of a detailed statistical analysis of the data. It is indispensable here to harmonize the background level data stocks in each federal state and to incorporate them into a country-wide evaluation.
Table 7: Land use-related distribution (number of sites) of the background value profiles in the parent material classes.

<table>
<thead>
<tr>
<th>LU-Nr.</th>
<th>soil parent material</th>
<th>arable land</th>
<th>grassland</th>
<th>forest</th>
<th>other landuse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MPM + ST&lt;sup&gt;1&lt;/sup&gt;</td>
<td>MPM&lt;sup&gt;2&lt;/sup&gt;</td>
<td>MPM + ST&lt;sup&gt;1&lt;/sup&gt;</td>
<td>MPM&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>marine, brackish, tidal sediments</td>
<td></td>
<td>16</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>fluvisols</td>
<td>10</td>
<td>16</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>river terrace deposits</td>
<td>36</td>
<td>7</td>
<td>64</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>sands</td>
<td>19</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>sandy sediments overlying boulder loam (clay)</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>loess</td>
<td>57</td>
<td>3</td>
<td>33</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>limestones</td>
<td>7</td>
<td>7</td>
<td>188</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>claystones</td>
<td>57</td>
<td>131</td>
<td>1</td>
<td>81</td>
</tr>
<tr>
<td>9</td>
<td>sandstones</td>
<td>48</td>
<td>14</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>basic igneous and metamorphic rocks</td>
<td>127</td>
<td>3</td>
<td>105</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>tuffs rich in bases</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>acid igneous and metamorphic rocks</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>fens/bogs</td>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>anthrosols (cities and open cast mines)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>377</td>
<td>22</td>
<td>321</td>
<td>17</td>
</tr>
</tbody>
</table>

<sup>1</sup> PM + ST: in coincidence with parent material and soil texture classes of LU of MPM 1000
<sup>2</sup> PM: in coincidence with parent material of LU of MPM 1000

References


A Land Information System for the application of sewage sludge in Greece

Summary
A land information system has been developed for use in Greece to assist with decisions on land suitability for sewage application. The overall objective is to identify areas most suited to the disposal of sewage. Such land and soil parameters as slope, stoniness, ponding, soil depth, presence of impermeable layer, permeability, structure, SAR, electrical conductivity, pH, CEC, and salt content are considered in order to classify land automatically into Suitability Classes (S1, S2, S3, N1, N2) for sewage sludge application.

For each land mapping unit, the rate and the duration of sewage sludge application are determined by the characteristics of the sewage sludge and the levels of heavy metals in relation to EU regulations. A Land Information System has been developed using databases and GIS. Land data were coded and input to dBASE or MS Access and into Laser-Scan or Intergraph GIS combined with ORACLE. Routines have been developed and used both in Stirling and Athens, based on Boolean algebraic logic in order to process soil and land data automatically and plot land suitability maps for sewage sludge application. Such maps have been produced for many areas of Greece.

Apart from automatically printing land suitability maps for sewage sludge application, the system can also be used and evaluated for storage of soil and land data, and monitoring and predicting the long-term environmental impacts of sewage sludge application on agricultural land, physical and chemical properties of the soil, and the spatial distribution of the heavy metals and potential pollutants in the soil.

Introduction
In almost all large cities of Greece, plants which process waste waters and produce treated sewage sludge are either under construction or in operation. This sludge has to be disposed of somewhere, at minimal cost, without detriment to the human and natural environment. Apart from the lack of alternatives, there are many reasons for disposing of sewage sludge on to agricultural land, the overwhelming one being its potential nutritional value.

Soil and land data have to be considered in combination with bioclimatic conditions and management practices in order to develop a system for assessing land suitability. Such data already exist in soil survey reports or in other database systems. A Geographical Information System is necessary to guide the application of sewage sludge to agricultural land because of the importance of spatial accuracy in the application. Also, it is necessary to include information on land, soil and sludge properties, processes and composition; climate variability; land use and management; and possible environmental risks.

Soils can filter pollutants and nutrients from sludge in the solid state. Pollutants can be absorbed/adsorbed through electrochemical reactions with soil colloids, and the decomposition of organic pollutants can be enhanced through soil microbial populations (Berglund et al., 1984); Hall, 1992; MAFF, Dept. of Environment, 1989). The liquid pollutants or the solids in solution may reach the groundwater through lateral or
vertical water movement. So the ultimate goal is to apply sewage sludge to agricultural land such that the soil either filters the potential toxic elements effectively, or electrochemically absorbs them or decomposes them in order that a clean solution passes through the soil body. The soil must maintain its absorption capacity to ensure a sustainable system.

In this paper, a system for spatially manipulating soil and land data to match land suitability requirements, to produce a classification for the suitability of land to accept sewage sludge. Such an approach is necessary not only in Greece but in many countries where sewage sludge is produced in large quantities at present and where there will be future major problems of land disposal in the future. Future development possibilities are indicated.

**The land information system**

**Background**

The Land Resource Information System has been designed and developed for the Viotia area of Central Greece where a soil survey had been completed project (Theocharopoulos, 1992). This system was developed in Laser-Scan software on a micro VAX II with Sigmex 6000 graphic terminal, in Stirling, by Davidson et al., (1994) and Theocharopoulos et al., (1995). The system adopted the soil survey methodology used in the original project. Each mapping unit was categorised according to the following: polygon type (mapped, not mapped, lake, sea), drainage class, (assessed from profile morphology), texture (classes and for 3 depths i.e. 0-25 cm, 25-75 cm and 75-150 cm), gravel (classes), slope (classes), erosion (classes), calcium carbonate (classes), soil order, suborder and great group, irrigability (availability of water for irrigation), variability class and limitations, rainfall, and geology of the parent material. Also in some mapping units infiltration rate, and the presence and depth of the impermeable layer was recorded. In each mapping unit, analytical data from profile samples or auger sampling and for each horizon were also stored. The following properties were analysed: sand, silt and clay % throughout the profile, electrical conductivity (mmhos cm⁻¹), salt content (%), pH, calcium carbonate (%), organic matter (%), cation exchange capacity (meq 100g⁻¹). Also where salts were detected then additional data are produced for sodium absorption ratio (SAR), base saturation, water soluble and exchangeable sodium, etc.

Soil and land data were also derived from SOILDB (Theocharopoulos et al., 1990), which is a soil database developed in the mid-1980s before GIS was widely used in Greece. SOILDB was developed to standardize, code, store, edit, manipulate and use existing soil survey data. This soil data system was developed using dBASE III and has recently upgraded using Access 2 for Windows. Existing soil and land data from soil survey reports, mapping units, soil auger bores, profiles and soil horizons are stored, updated, corrected, edited, printed and manipulated through the QUERY language of dBASE. This offers the possibility for data to be extracted and generated as inputs to the Intergraph Corporation Modular GIS Environment System Nucleus (MGE/SX), supported by the ORACLE relational database. Land suitability maps for sewage sludge application were then produced using the Land Information System developed at the Soil Science Institute of Athens, using data from the above database with the routines and system commands that had been developed.

**Sewage sludge application system**

Sewage sludge can be applied to agricultural land in a number of ways: surface application, surface application with incorporation, subsurface application or injection. The capacity of the soil as far as its capacity to absorb heavy metals is concerned must be much higher than the amounts added by the sludge application.

The huge amount and diversity of the data and the necessary manipulations require the flexibility of the Geographical Information System of Natural Resources as described and discussed by Davidson (1992). The Land Information system for application of sewage sludge to agricultural land has to consider location, geology, physiography, geomorphology, hydrogeology, land use, soil structure, texture, water permeability, coefficient of hydraulic conductivity (saturated or unsaturated), porosity, presence and depth of impermeable soil layers. Also it is necessary to include soil chemical properties such as macronutrients content, pH, CEC, CaCO₃ content, organic matter content, heavy metal content (e.g. Cd, Cu, Ni, Zn, Pb, Hg, Cr, Mn, Mo), toxic elements contents (e.g. Se,
As, B, F) residues of herbicides and pesticides. If it is possible, organic compounds such humic and fulvic acids have to be considered. Soil fauna and flora should also be studied (sensitivity, population dynamics), before, during and after application in order to ensure soil sustainability and to avoid soil pollution by heavy metals.

Sewage sludge should also be analyzed in terms of macronutrient content, pH, CEC, CaCO$_3$ content, organic matter content, heavy metal contents (Cd, Cu, Ni, Zn, Pb, Hg, Cr, Mn, Mo), toxic element content (Se, As, B, F) residues of herbicides, pesticides, organic compound content such as humic and fulvic acids, COD (Chemical Oxygen Demand), BOD (Biological Oxygen Demand), aliphatic and polycyclic aromatic carbohydrates, and phenolic and alogenic compounds.

The system has to be built up in the following steps (Figure 1). Firstly, soils with the potential to receive sewage sludge are identified. Secondly, the rate of annual sewage sludge application is determined taking into account the maximum permitted levels of potentially toxic elements as defined by the European Community (EC Council Directive 86/278) and Greek laws. For the third step, the annual rate and timing of applications in relation to crop management has to be determined. This is defined by the annual rainfall rate, intensity and distribution throughout the year and the temperature, in relation to water balance, soil properties and processes, and microbial activity and sludge decomposition. The fourth step is monitoring the impact of sewage sludge application to soil on ground water and the environment under the specific bioclimatic conditions of the Greek areas being treated.

**Principles**

The system is based on the philosophy of the UN Food and Agriculture Organization’s 1976 Soils Bulletin, “A framework for land evaluation” (FAO, 1976) as far as its structure, nomenclature and definitions are concerned. The criteria are based on published guides of other Scientific Organizations (MAFF, Dept. of Environment, 1989; Soil Science Society of America (1986) for assessing the suitability of soil for different kinds of use and experience of soil properties and seasonal variability of soil processes gained in the field. The system allocates soil map units to Suitability Orders (S for suitable and N for unsuitable) and Suitability Classes according to the degree of their limitations (S1 for slight, S2 for moderate and S3 for severe limitations; N1 for currently not suitable and N2 for permanently not suitable for sewage sludge application. These criteria are presented in Table 1.

The system as described in detail by Theocharopoulos et al. (1994) has the following specifications:

a) is adopted to Greek bioclimatic conditions,
b) is general and can be used throughout Greece,
c) incorporates soil behaviour,
d) incorporates all or most of the principles of other countries e)

e) is based on velocity of water movement, soil map interpretation and on the combination of limiting factors and downwards water movement.

The most efficient way to produce a single-factor soil map or a land evaluation map for sewage sludge application is to write a macro routine or command file. This specifies the selection criteria that are required to produce the land suitability map. The mapping unit and/or sample points are then interrogated to determine if they meet those required conditions. The fundamental process in the whole system, in order to evaluate for sewage sludge application, is the comparison or matching of land use requirements (Table 1) with the attributes of the land mapping units, data are evaluated.
Figure 1: A land information system for sewage sludge application to agricultural land
**Table 1: Criteria for land suitability for sewage sludge application.**

<table>
<thead>
<tr>
<th>Property</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>N1</th>
<th>N2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td>never</td>
<td>seldom</td>
<td>often</td>
<td>always</td>
<td>as N1</td>
</tr>
<tr>
<td>Depth to bedrock (cm)</td>
<td>&gt;300</td>
<td>&gt;180</td>
<td>100-180</td>
<td>&lt;100</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Depth to impermeable layer (cm)</td>
<td>&gt;200</td>
<td>&gt;180</td>
<td>100-180</td>
<td>&lt;100</td>
<td>&lt;50</td>
</tr>
<tr>
<td>coverage with water</td>
<td>never</td>
<td>never</td>
<td>seldom</td>
<td>often</td>
<td>always</td>
</tr>
<tr>
<td>Groundwater level (cm)</td>
<td>&gt;300</td>
<td>&gt;180</td>
<td>100-180</td>
<td>&lt;100</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Infiltration rate cm/h</td>
<td>2-6.5</td>
<td>0.5-6.5</td>
<td>0.5&lt;, &gt;6.5</td>
<td>0.5&lt;, &gt;6.5</td>
<td>as N1</td>
</tr>
<tr>
<td>Slope %</td>
<td>&lt;3</td>
<td>3-8</td>
<td>8-12</td>
<td>&gt;12</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Stones % (&gt;7.5 cm)</td>
<td>&lt;20</td>
<td>&lt;35</td>
<td>&gt;35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>all except CL,SC,SiCL, SiC,C.S,S or with gravels</td>
<td>all except C or with gravels</td>
<td>Clay (vertisols)</td>
<td>as N1</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>granular blocky or platy or compacted</td>
<td>massive</td>
<td>vertic</td>
<td>as N1</td>
<td></td>
</tr>
<tr>
<td>SAR</td>
<td>&lt;12</td>
<td>&lt;12</td>
<td>&gt;12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.3-8.4</td>
<td>6.6-7.3</td>
<td>5.6-6.5</td>
<td>&lt;5.6</td>
<td>as N1</td>
</tr>
<tr>
<td>EC mmhos/cm</td>
<td>&lt;16</td>
<td>&lt;16</td>
<td>&gt;16</td>
<td>&gt;16</td>
<td>&gt;24</td>
</tr>
<tr>
<td>CEC meq/100g</td>
<td>&gt;16</td>
<td>8-16</td>
<td>&lt;8</td>
<td>&lt;8</td>
<td></td>
</tr>
<tr>
<td>Salt %</td>
<td>&lt;0.09</td>
<td>0.09-0.16</td>
<td>0.16-0.26</td>
<td>0.16-0.41</td>
<td>&gt;0.41</td>
</tr>
</tbody>
</table>

**Results and discussion**

Using the steps illustrated in Figure 1 and the land information system described above, land suitability maps for sewage sludge application were produced for Viotia’s total acreage of 141,974 ha, (Figure 2) and for other areas in Greece where it is planned to apply sewage sludge (Figure 3).

Table 2 presents the data on the seven mapping units for the Thive-Bagia region of Viotia. Also given are the maximum permitted quantities of sewage sludge that should be applied, the years of application based on maximum annual application rates of Cd and maximum permissible values of Cd content in soils (EC Council Directive 86/278).

The system has been used for evaluating land near sewage treatment plants and suitability maps were produced. Variation in suitability classes for the different mapping units was investigated whilst the results were validated for field assessment. This approach is being adopted in other areas such as Aliveri, Xalkis, Sparta, etc. The system was also evaluated in experimental fields set up to gauge plant response and the nutritional effect of sludge application in areas where sludge is traditionally applied by farmers. From monitoring the nitrogen content in two experimental fields under maize in suitability class S1/S2 in the Thessaloniki area, it was found that adding 4000 Kg sewage sludge per ha (i.e. 140 kg-N/ha) did not increase the amount of residual nitrogen in the soil (Theocharopoulos et al., 1994). The addition of a much higher quantity of sewage sludge (20,000 kg per ha, i.e. 700 kg-N/ha) increased the residual nitrogen in the top 30 cm of soil.
Figure 2: Sample of Land Suitability map for sewage sludge application of Thiva-Bagia area (Viotia). Sampling point for heavy metal analyses.

Figure 3: Sample of Land Suitability map for sewage sludge application of Evia area.
Conclusions

The system as developed offers a tool to identify those soils in Greece that are suitable for sewage sludge application. The ability to print land suitability maps for sewage sludge application automatically, along with estimating levels and timing of these applications is beneficial for policy-makers, local planners, agronomists, farmers and other parties concerned with sustainable agriculture and maintenance of soil quality. Further research, such as that by Theocharopoulos et al., (1996), is investigating the development, use and evaluation of the system in order to design and develop models for predicting the fate of PTE and soil degradation.

Table 2: Estimated maximum permitted sludge added based on maximum limiting values for Cd addition and the limiting value of Cd content in soil.

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>mapping unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>244</td>
</tr>
<tr>
<td>Sand %</td>
<td>50.2</td>
</tr>
<tr>
<td>Silt %</td>
<td>19.0</td>
</tr>
<tr>
<td>Clay %</td>
<td>30.8</td>
</tr>
<tr>
<td>pH</td>
<td>7.99</td>
</tr>
<tr>
<td>EC mmhos/cm</td>
<td>877</td>
</tr>
<tr>
<td>CaCO3 %</td>
<td>3.5</td>
</tr>
<tr>
<td>O. M. %</td>
<td>1.3</td>
</tr>
<tr>
<td>N %</td>
<td>0.2</td>
</tr>
<tr>
<td>P mg/kg</td>
<td>42.6</td>
</tr>
<tr>
<td>K meq/100g</td>
<td>0.2</td>
</tr>
<tr>
<td>Cu ppm</td>
<td>14.0</td>
</tr>
<tr>
<td>Zn ppm</td>
<td>29.6</td>
</tr>
<tr>
<td>Cd ppm</td>
<td>0.2</td>
</tr>
<tr>
<td>Limiting maximum quantity allowed to be added Kg-Cd/ha/year</td>
<td>0.15</td>
</tr>
<tr>
<td>Cd in the sludge (ppm)</td>
<td>1.89</td>
</tr>
<tr>
<td>Permitted maximum sludge (dry weight/kg /ha)</td>
<td>79,365</td>
</tr>
<tr>
<td>Years of permitted application</td>
<td>19</td>
</tr>
</tbody>
</table>

Acknowledgements

The authors would like to thank all the staff of the Soil Science Institutes who helped in any way with this work. Sincere thanks are also expressed to George Papadimos and Nikos Papadopoulos for developing the SOILDB. Thanks are also due to Prof. D Tseles and George Galanos for improving and transforming SOILDB from dBASE to Access 2 for Windows. We are also grateful to Mr. N. Kandidis of SSI, Thesaloniki, for permitting access to his experimental results.
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COUNCIL DIRECTIVE 86/278, EC. On the protection of the Environment and in particular soil when sewage sludge is used in agriculture.


Esplan – software for engineering assessment of soils in Italy

Summary

The ESPLAN (Engineering Soil Planning) software is an application of some Conversion Tables to soil assessment for engineering uses.

The assessment is done taking into account the limitation degree for different uses (shallow foundations; playgrounds; local roads and streets; paths and trails; embankments, dikes and levees; sanitary landfill by trench; soil reconstruction material for drastically disturbed areas) which are determined by soil and topography characters and qualities. These data are commonly obtained from modern soil maps. Two Tables for evaluating the risk of corrosion potential of soil for uncoated steel and concrete are also presented.

ESPLAN, an original Clipper-based software for MS-DOS personal computer, was prepared to derive a soil technical classification in three suitability classes: “optimal”, “marginal” and “poor”.

At first the program needs the input of a list of Land Units. They are grouped into Land Unit Classes and identified by a 6-character code. Then the requested input data are the values of the different Properties which characterize the Conversion Tables.

It is possible to choose the evaluation for a particular Land Use or for all the 9 proposed Land Uses. The evaluation output is stored into a file and is available on screen, printer or text file. It is also possible to print all the 9 Conversion Tables used by the program.

Introduction

From the beginning of the sixties there has been an increasing use of information derived from soil maps for engineering land planning all over the world (Bartelli, 1978; Olson, 1981; Haans and Westerveld, 1970; Murtha and Reid, 1976; Soil Survey Staff, 1975, 1983; De La Rosa and Davidson, 1980; Davidson, 1992; Bridges and Davidson, 1982; Jarvis and Mackney, 1979; etc).

Jarvis (1982) validates this “interpretation” of the soil, observing that the survey of soil properties is able to give information about strength, consistence, ease of compaction, consolidation, shrinkage, potential frost action, permeability, corrosiveness, which can be of great interest for civil and geotechnical engineers. These information can be used for preliminary engineering land planning: e.g. planning of urban and industrial development, waste disposal, local roads and playground localization, etc.

Methods for engineering assessment of soils has been proposed in Italy by Magaldi et al. (1983); Magaldi (1983); Regione Toscana (1983); Magaldi et al. (1988). The suitability of soil is normally put into practice from “Conversion Tables”, where physical and chemical properties, together with climatic and morphological characteristics, are grouped according to their matching specific engineering requirements.

Most of these Tables have been prepared by Soil Survey Staff of USDA (1979, 1983) and by Olson (1974). Very good examples can be found also in the experience of the Dutch Soil Survey (Haans and Westerveld, 1970).

Some Conversion Tables have been used for several years in Italy for engineering soil assessment on the base of information taken from Italian
soil maps, along with comparison, where possible, with real situations. Testing foreign methods for soil assessment gave the opportunity of modifying and updating the Tables to make them more suitable to Italian situations and to the availability of climatic, morphological and pedological basic data.

This report deals with the explanation of these new tables, discussion on criteria for their use in Italy and presentation of ESPLAN software.

Conversion tables and engineering uses of soil

Some Conversion Tables have been selected and modified in order to relate them to the 9 engineering uses here described. The Tables are shown in their complete form in Table 1.

1) Shallow foundations. One of the first applications of the results of soil survey involved projects of urban expansion in agricultural or natural (wild) areas (e.g. in the USA, in Australia, in many developing countries and also in countries like Holland that almost yearly increases its territorial extension due to the polder phenomenon).

The Conversion Table has been prepared to evaluate the soil suitability for the excavation of shallow foundations (normally not deeper than 2m, used for low buildings). The considered properties refer to strength of soil and to ease of excavation, and thus to the low cost of the foundations. It is opportune to note that shallow coherent rock is considered, in contrast with geotechnical principles, a limiting factor because it hinders the deepening of foundations and therefore increases the costs.

Another property considered is the potential frost action: as is well-known, frost can cause dangerous under-pressures resulting in sinking of structures. The proposed Table, unlike the original, evaluates mechanical soil properties directly from the texture and from the coefficient of linear expansion (COLE), according to the relations among soil classification of the Unified System, the Atterberg limits, COLE and textural classes of the Soil Survey Manual of USDA (Soil Survey Staff, 1951).

2) Playgrounds represent one of the non-agricultural land uses in which applied soil science assumes a great importance. Under the term ‘playgrounds’ we consider all the wide extensions with grass used to play soccer, baseball, volleyball, basketball and outdoor athletics.

The characteristics considered refer to properties that make possible:
- easy and quick movement of persons on the ground surface (flat or slightly steep surface or moderate rolling surface, absence of big stones, soil not too hard nor too soft);
- good soil drainage and soil not prone to compaction due to excessive trampling;
- continuous growing of grass, which is indispensable for good-quality playgrounds.

It is opportune that, in temporary or permanent absence of grass covering, dry soil should not produce dust and therefore excessively silty textures are “penalized”. Most characteristics refer to soil surface (normally down to 30-40cm depth).

3) Local roads and streets. In these cases soil is used as foundation for road-bed and asphalt (or other materials) superficial cover. Related properties of these soils are: ease of excavation, rapid drainage, capability to sustain vehicular traffic. Also in this case it could be necessary to have further information about underground hydrogeological characteristics.

4) Paths and trails. The localization of paths and trails, usually in protected areas, should consider the morphological and soil conditions which facilitate walking or riding, without damaging the soils. The proposed evaluation table is nevertheless not particularly severe, except in excluding zones which are too stony, too marshy and prone to erosion.

5) Embankments, dykes and levées. These works are made to protect alluvial plains from floods and to construct small water reservoirs. Soil material is normally used for the main work structure; in dykes and embankments it is used to form the waterproof nucleus, which is then protected and strengthened with stones and, sometimes, bituminous materials.

Soil properties, obviously referring to the whole reworked and mixed soil profile, should prevent water filtration, piping, edge and side erosion of the structure.
and should allow easy excavation and working. Often the sides of the structure, generally formed by artificial slopes, must be covered by natural or planted vegetation; therefore the used material should permit slight water percolation and the formation of a suitable soil structure.

6) **Sanitary landfill by trench.** In this type of waste disposal, suggested by the Soil Survey Staff of USDA (1983), urban solid rubbish is spread in layers, in excavated trenches deeper than 5m. Waste is usually compacted and covered daily with a thin layer of soil. Geological knowledge of the subsoil has great importance in preventing and limiting the risk of contamination of ground water by seepage.

The Table is based on those soil characteristics which condition the risk of ground water pollution: ease of excavation, possibility of covering the worked-out dump with soil and plants, risk of subsidence or of differential sinking of stored material. Obviously this type of soil use requires not only soil knowledge but also awareness of geological, geomorphological, hydrogeological, landscape and socio-economic factors.

7) **Soil recontruction for drastically disturbed areas.** Drastically disturbed areas, such as quarries and open pits, should when worked out be restored to prevent damage to landscape. For this reason these areas should be filled or remodelled and covered with vegetation. Therefore it is necessary to cover the site with a soil material with high capability for supporting vegetation. The characteristics of these soils, which sometimes have to be examined separately for each soil horizon, are of agronomic type: texture, available water capacity, etc. The new soil will remain initially uncovered, so it is important to know the water erosion hazard of the upper soil horizons.

In addition to these, two other Conversion Tables for the evaluation of soil corrosion potential were prepared.

8) **Risk of corrosion potential of soil for uncoated steel.** When uncoated steel is placed underground, it is damaged by corrosion due to the solution of iron in water. Corrosion is aided by permanent water stagnation and by water acidity and salinity. Soil solutions cause charge movements from anodic zones (iron and unaltered steel) to cathodic ones (corroded zones) where dissolved iron deposits (ferrous hydroxide) after oxidation, accumulate (ferric hydroxide). If the solution is particularly rich in sodium chloride, e.g. in some salty soils, corrosion is accelerated by concomitant action of chlorine and sodium on the hydroxide formation.

Among soil characteristics reported in the Conversion Table there is also “exchangeable acidity” (H+, Al+++). This property is more definitive than pH, which can nevertheless be used in absence of data on exchangeable acidity.

9) **Risk of corrosion potential of soil for concrete.** As known, the corrosion risk of a cement material placed under or on the ground mostly depends on acidity from circulating solutions, which react with calcium hydroxide. Furthermore, solutions containing considerable quantities of sulphate ions, which may be present in salty soils and in marine water, are aggressive. These solutions react to form calcium sulpho aluminate (ettringite), which, because of volume expansion, dis charges cement.

The presence of chlorides is also harmful to concrete structures. Chlorides, although not damaging to cement, are particularly dangerous for reinforcement bars, particularly for pre-stressed reinforced concrete, in which steel bar corrosion may cause sudden collapse.

The deterioration process is related to the duration of soil-solution contact and then to internal soil drainage quality. Furthermore, soil frost action, which favours mechanical disaggregation processes, facilitates the penetration of elements harmful to cement durability.

**Evaluation method**

The properties considered have been grouped into the qualitative and quantitative classes reported in Table 2, most of them already proposed and discussed by Magaldi *et al.* (1992).

As is already known, the land unit suitability assessment is done by the examination of properties related to a specific land use; the result is a technical classification for each land unit property.
according to one of three suitability classes: “optimal”, “marginal” or “poor”.

In only a few cases does a land unit have the same suitability class for all properties (e.g. all “marginal”); otherwise the problem is to determine the method for making a final judgement on the specific use of the land unit.

Generally there are two methods. The most common is to attribute the most negative resulting evaluation to the land unit: e.g. even if only one single property is “marginal” or “poor”, the whole land unit is considered so. This method is obviously very extreme, even if it can be applied immediately.

Another method is to consider the number and quality of the different properties in order to apply a weighted judgement. The concept of the “Soil Potential Index” (SPI) proposed by Soil Survey Staff (1993) allows this method. The SPI is based on the cost estimate to minimize or reduce the limitations for a specific use. This approach is of great practical interest, but strictly connected to the socio-economic conditions of the area in which the aptitude classification is executed, and also considerably related to the moment in which the assessment is done.

A new method is now proposed to simplify the use of the Conversion Tables regardless of socio-economic conditions and the moment of evaluation.

This new method for final evaluation is based on the number of land unit properties respectively classified as “optimal”, “marginal” or “poor”. The flow diagram of the classification algorithm is shown in Figure 1.

If a land unit has no properties classified as “poor”, then if the number of “marginal” properties is less than 20% of the total, the final judgement is “optimal”; otherwise it is “marginal”. The final judgement is still “marginal” if the number of “poor” properties is less or equal to 20% of all properties; otherwise it is “poor”.

This method has been tested on various soil maps of different Italian regions and at different scales: the results of classification agreed with map evidence and direct knowledge of local conditions and characteristics.

**Esplan software**

The proposed method for engineering assessment of land units has been coded in the original software ESPLAN, Engineering, Soil, Planning, written by one of the authors (G.L. Ricciardulli) in xBASE programming language and compiled with Clipper v.5.2c.

The software, running under MS-DOS, is designed to store basic information about all the Land Units (LU) and the global evaluation of each LU for several Engineering Uses (EU). Evaluations are calculated from the values of the single Land Unit Properties (LUP), according to those showed in Table 2.

The program flow mainly considers three groups of actions:

a) managing LU basic data: input, delete, modify, group into LU Classes;

b) managing LUP data: input, modify;

c) calculation and displaying of EU evaluation results.

Besides these primary functions ESPLAN has some utilities:

d) managing the output to file or printer;

e) controlling properties input data;

f) printing Conversion Tables;

g) program configuration.

Land Units are identified by a six-character name and are grouped into Land Unit Classes (LUC); LUC are shown according to the user-defined order (which is modifiable) while LU are always shown alphabetically.

ESPLAN uses three archive files: one for the LUC, one for the LU and one for LUP values and final EU evaluations. When properties are being input it is possible to choose an evaluation type for a single EU or for all 9 EUs. Afterwards, for each LU the user has to input values for the properties described in the Conversion Table. If a property has already been used for another EU, the user must confirm the previous value or input a new one; in this case all related EUs are again evaluated automatically.

Printing options include: a list of LU grouped into LUC, EU evaluation results, LUP list of values and Conversion Tables. The output is previewed on display and then sent to a printer or to file (with printer control characters or a simple ASCII file).

To receive a licensed copy of ESPLAN software, please contact DISAT Department: Professor D. Magaldi; eng. G. L. Ricciardulli, e-mail riccig@disat.ing.univaq.it – or fax DISAT at (+39) 862 434548.

**Conclusions**

ESPLAN will facilitate the evaluation and comparison of different Land Units for several
engineering land uses. The applications supported by ESPLAN allow the users to select the most suitable land (map) units for settled uses; meanwhile very limiting properties for soil suitability can be detected from the comparison between Conversion Tables and LUP values, in order to reduce their effects (e.g. site steepness, soil drainage, salinity, etc.).

The land suitability assessment accomplished by such a method further proves that the legend of soil maps for applied purposes should express the status and soil information in a quantitative or at least semi-quantitative form.

Figure 1: Flow diagram of classification algorithm.

Figure 2: ESPLAN: program flow and data structure.
Table 1: - Conversion Tables

**Shallow foundations**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Optimal</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
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<td>***0.06</td>
<td>&gt; 0.06</td>
<td>&gt; 0.09</td>
</tr>
<tr>
<td>Internal soil drainage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(frequency)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excessively drained</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well drained</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately well drained</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imperfectly drained</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poorly drained</td>
<td></td>
<td></td>
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<tr>
<td>Very poorly drained</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
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<td>&gt; 10%</td>
</tr>
<tr>
<td>Internal stoniness (5 cm)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(frequency)</td>
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<tr>
<td>&gt; 10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth to hard bedrock</td>
<td>&gt; 200 cm</td>
<td>&gt; 100 cm</td>
<td>***100 cm</td>
</tr>
<tr>
<td>Flooding</td>
<td>none</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Potential frost action</td>
<td>none</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Rockiness (occupied area)</td>
<td>&lt; 2%</td>
<td>***2%</td>
<td>&gt; 10%</td>
</tr>
<tr>
<td>Detailed texture classes between 25 and 150 cm</td>
<td>s, ls, sl, scl, sc</td>
<td>l, st, s, cl</td>
<td>sil, sic</td>
</tr>
</tbody>
</table>

**Playgrounds**

<table>
<thead>
<tr>
<th>Feature</th>
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<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface stoniness &lt;10 cm</td>
<td></td>
<td>***0.01%</td>
<td>&gt; 0.1%</td>
</tr>
<tr>
<td>(frequency)</td>
<td></td>
<td>***0.1%</td>
<td></td>
</tr>
<tr>
<td>Surface stoniness &gt;10 cm</td>
<td>***3%</td>
<td>&gt; 3%</td>
<td>&gt; 15%</td>
</tr>
<tr>
<td>(frequency)</td>
<td></td>
<td>***15%</td>
<td></td>
</tr>
<tr>
<td>Alkalinity (ESP)</td>
<td>0***15%</td>
<td>-</td>
<td>15***100%</td>
</tr>
<tr>
<td>Geotechnical classification</td>
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<td>-</td>
<td>Pt</td>
</tr>
<tr>
<td>Internal soil drainage</td>
<td>well drained</td>
<td>moderately well drained</td>
<td>imperfectly drained</td>
</tr>
<tr>
<td>Depth to hard bedrock</td>
<td>&gt; 100 cm</td>
<td>***50 cm</td>
<td>***100 cm</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>&gt; 2 cm/h</td>
<td>***0.1 cm/h</td>
<td>&lt; 0.1 cm/h</td>
</tr>
<tr>
<td>Depth to cemented pans</td>
<td>&gt; 100 cm</td>
<td>***50 cm</td>
<td>***100 cm</td>
</tr>
<tr>
<td>Reaction (pH)</td>
<td>pH 4.5</td>
<td>***4.5</td>
<td>pH &lt; 4.5</td>
</tr>
<tr>
<td>Potential frost action</td>
<td>none</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Flooding</td>
<td>none</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Salinity (conductability at 25°C)</td>
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<td>&gt; 4 dS/m</td>
<td>&gt; 8 dS/m</td>
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<td>scl, cl, sic</td>
<td>l, st, l, st, s</td>
<td>s, sc, sic</td>
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### Local roads and streets

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<th>MARGINAL</th>
<th>POOR</th>
</tr>
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<tbody>
<tr>
<td>GW, GP, GM, GC, SW, SP, SM</td>
<td>SC, ML, CL, CH</td>
<td>OL, MH, OH, Pt</td>
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</tr>
</tbody>
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<table>
<thead>
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<th>POOR</th>
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</thead>
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<tr>
<td>COLE</td>
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<td>&gt;0.06</td>
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<tr>
<td>Slope</td>
<td>###10%</td>
<td>&gt;10%</td>
<td>&gt;20%</td>
</tr>
<tr>
<td>Internalstoniness (frequency)</td>
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<td>&gt;25%</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>Ground water</td>
<td>&gt;100 cm</td>
<td>50 ###100 cm</td>
<td>&lt;50 cm</td>
</tr>
<tr>
<td>Depth to hard bedrock</td>
<td>&gt;100 cm</td>
<td>###50 cm</td>
<td>###100 cm</td>
</tr>
<tr>
<td>Potential frost action</td>
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<td>high</td>
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### Paths and trails

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<tr>
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<td>Pt</td>
</tr>
<tr>
<td>Water erodibility (K)</td>
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<td>-</td>
<td>&gt;0.35</td>
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<tr>
<td>Slope</td>
<td>###10%</td>
<td>&gt;10%</td>
<td>&gt;20%</td>
</tr>
<tr>
<td>Internalstoniness (frequency)</td>
<td>###3%</td>
<td>&gt;3%</td>
<td>&gt;15%</td>
</tr>
<tr>
<td>Ground water</td>
<td>&gt;100 cm</td>
<td>50 ###100 cm</td>
<td>&lt;50 cm</td>
</tr>
<tr>
<td>Flooding</td>
<td>none</td>
<td>moderate</td>
<td>-</td>
</tr>
<tr>
<td>Detailed texture classes between 25 and 150 cm</td>
<td>s, ls, sl, scl</td>
<td>l, sil, sc, sicl</td>
<td>c, cl, sic, si</td>
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### Embankments, dykes and levées

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<th>POOR</th>
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<tbody>
<tr>
<td>Alkalinity (ESP)</td>
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<td>-</td>
<td>&gt;15%###</td>
</tr>
<tr>
<td>Geotechnical classification</td>
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<td>GM, CL</td>
<td>GW, GP, SW, SP, SM, ML, OL, MH, CH, OH, Pt</td>
</tr>
<tr>
<td>Internalstoniness (frequency)</td>
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<td>&gt;10%</td>
<td>&gt;25%</td>
</tr>
<tr>
<td>Soil depth</td>
<td>&gt;150 cm</td>
<td>&gt;100 cm</td>
<td>###100 cm</td>
</tr>
<tr>
<td>Ground water</td>
<td>&gt;100 cm</td>
<td>50 ###100 cm</td>
<td>&lt;50 cm</td>
</tr>
<tr>
<td>Salinity (conductibility at 25°)</td>
<td>###8 dS/m</td>
<td>&gt;8 dS/m</td>
<td>&gt;15 dS/m</td>
</tr>
</tbody>
</table>
**Sanitary landfill by trench**

<table>
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<tr>
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<th>OPTIMAL</th>
<th>MARGINAL</th>
<th>POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (ESP)</td>
<td>&lt;=###15%</td>
<td>-</td>
<td>&gt;15###</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>natric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>halic</td>
</tr>
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<td></td>
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<td>alkaline phases</td>
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<td>Geotechnical classification</td>
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<td>-</td>
<td>OL, OH, Pt</td>
</tr>
<tr>
<td>Infiltration rate</td>
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<td>&gt;5 cm/h</td>
</tr>
<tr>
<td>Slope</td>
<td>###10%</td>
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<td>&gt;20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>###20%</td>
</tr>
<tr>
<td>Interna stoniness (frequency)</td>
<td>###10%</td>
<td>&gt;10%</td>
<td>&gt;25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>###25%</td>
</tr>
<tr>
<td>Ground water</td>
<td>&gt;100 cm</td>
<td>-</td>
<td>###100 cm</td>
</tr>
<tr>
<td>Depth to cemented pans</td>
<td>&gt;200 cm</td>
<td>-</td>
<td>###200 cm</td>
</tr>
<tr>
<td>Depth to hard bedrock</td>
<td>&gt;200 cm</td>
<td>-</td>
<td>###200 cm</td>
</tr>
<tr>
<td>Reaction (pH)</td>
<td>pH ###4.5</td>
<td>-</td>
<td>pH &lt;4.5</td>
</tr>
<tr>
<td>Flooding</td>
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<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Salinity (conductibility at 25')</td>
<td>###15 dS/m</td>
<td>-</td>
<td>&gt;15 dS/m</td>
</tr>
<tr>
<td>Detailed texture classes between 25 and 150 cm</td>
<td>sl, l, sil, si, scl</td>
<td>ls, cl, sicl, sc</td>
<td>s, sic, c</td>
</tr>
</tbody>
</table>

**Soil reconstruction material for drastically disturbed areas**

<table>
<thead>
<tr>
<th></th>
<th>OPTIMAL</th>
<th>MARGINAL</th>
<th>POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (ESP)</td>
<td>&lt;###10%</td>
<td>10###15%</td>
<td>&gt;15###</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>natric</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>alkaline phases</td>
</tr>
<tr>
<td>Available Water Capacity</td>
<td>&gt;1 mm/cm</td>
<td>0.5###1 mm/cm</td>
<td>&lt;0.5 mm/cm</td>
</tr>
<tr>
<td>Toxic elements content</td>
<td>low</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Water erodibility (K)</td>
<td>###0.35</td>
<td>&gt;0.35</td>
<td></td>
</tr>
<tr>
<td>Wind erodibility (WEG)</td>
<td>###2</td>
<td>-</td>
<td>&gt;2</td>
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<tr>
<td>Surface stoniness &lt;10cm (frequency)</td>
<td>###15%</td>
<td>-</td>
<td>&gt;15%</td>
</tr>
<tr>
<td>Surface stoniness &gt;10cm (frequency)</td>
<td>###3%</td>
<td>&gt;3%</td>
<td>&gt;15%</td>
</tr>
<tr>
<td>Reaction (pH)</td>
<td>pH &gt;5.5</td>
<td>pH ###7.5</td>
<td>pH &gt;8.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.6&lt;pH ###8.5</td>
<td></td>
</tr>
<tr>
<td>Salinity (conductibility at 25')</td>
<td>###8 dS/m</td>
<td>8-15 dS/m</td>
<td>&gt;15 dS/m</td>
</tr>
<tr>
<td>Detailed texture classes between 25 and 150 cm</td>
<td>sl, l, sil, si</td>
<td>ls, scl, cl, sicl</td>
<td>s, sic, c</td>
</tr>
</tbody>
</table>

**Risk of corrosion potential of soil for uncoated steel (for soils deeper than 1 m )**

<table>
<thead>
<tr>
<th></th>
<th>OPTIMAL</th>
<th>MARGINAL</th>
<th>POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchangeable acidity or pH</td>
<td>0###10 cmol(+)/kg</td>
<td>25 cmol(+)/kg</td>
<td>&gt;25 cmol(+)/kg</td>
</tr>
<tr>
<td></td>
<td>6.5&lt;pH ###8.5</td>
<td>7.6&lt;pH ###8.5</td>
<td>pH &gt;8.5</td>
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<tr>
<td>Internal soil drainage</td>
<td>excessively drained</td>
<td>well drained</td>
<td>imperfectly drained</td>
</tr>
<tr>
<td></td>
<td>moderately well drained</td>
<td>poorly drained</td>
<td>very poorly drained</td>
</tr>
<tr>
<td>Salinity (conductibility at 25')</td>
<td>&lt;1 dS/m</td>
<td>###1 dS/m</td>
<td>&gt;4 dS/m</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</tr>
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</table>

388
### Risk of corrosion potential of soil for concrete

<table>
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<th>MARGINAL</th>
<th>POOR</th>
</tr>
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<tr>
<td>NaCl content</td>
<td>&lt;2000 ppm</td>
<td>2000###10000 ppm</td>
<td>&gt;10000 ppm</td>
</tr>
<tr>
<td>Na or Mg sulphate content</td>
<td>&lt;1000 ppm</td>
<td>1000###7000 ppm</td>
<td>&gt;7000 ppm</td>
</tr>
<tr>
<td>Internal soil drainage</td>
<td>excessively drained</td>
<td>well drained</td>
<td>poorly drained</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moderately well drained</td>
<td>imperfectly drained</td>
</tr>
<tr>
<td>Potential frost action</td>
<td>none</td>
<td>moderate</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>low</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Reaction (pH)</td>
<td>pH &gt;6.5</td>
<td>5.5 &lt; pH ###6.5</td>
<td>pH ###5.6</td>
</tr>
</tbody>
</table>

**Table 2. - Property values**

#### Exchangeable acidity

<table>
<thead>
<tr>
<th>Exchangeable acidity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 cmol(+)/kg</td>
<td></td>
</tr>
<tr>
<td>5 ### 10 cmol(+)/kg</td>
<td></td>
</tr>
<tr>
<td>10 ### 25 cmol(+)/kg</td>
<td></td>
</tr>
<tr>
<td>25 ### 50 cmol(+)/kg</td>
<td></td>
</tr>
<tr>
<td>&gt; 50 cmol(+)/kg</td>
<td></td>
</tr>
</tbody>
</table>

#### Alkalinity

<table>
<thead>
<tr>
<th>Alkalinity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP &lt; 5%</td>
<td></td>
</tr>
<tr>
<td>ESP 5% ### 10%</td>
<td></td>
</tr>
<tr>
<td>ESP 10% ### 15%</td>
<td></td>
</tr>
<tr>
<td>ESP 15% ### 20%</td>
<td></td>
</tr>
<tr>
<td>ESP &gt; 20%</td>
<td></td>
</tr>
<tr>
<td>Natric</td>
<td></td>
</tr>
<tr>
<td>Halic</td>
<td></td>
</tr>
<tr>
<td>Alkaline phases</td>
<td></td>
</tr>
</tbody>
</table>

#### Available Water Capacity

<table>
<thead>
<tr>
<th>Available Water Capacity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low: &lt; 0.5 mm/cm</td>
<td></td>
</tr>
<tr>
<td>Medium: 0.5 ### 1 mm/cm</td>
<td></td>
</tr>
<tr>
<td>High: &gt; 1 mm/cm</td>
<td></td>
</tr>
</tbody>
</table>

#### Geotechnical classification

<table>
<thead>
<tr>
<th>Geotechnical classification</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GW - Well graded gravels</td>
<td></td>
</tr>
<tr>
<td>GP - Poorly graded gravels</td>
<td></td>
</tr>
<tr>
<td>GM - Silty gravels</td>
<td></td>
</tr>
<tr>
<td>GC - Clayed gravels</td>
<td></td>
</tr>
<tr>
<td>SW - Well graded sands</td>
<td></td>
</tr>
<tr>
<td>SP - Poorly graded sands</td>
<td></td>
</tr>
<tr>
<td>SM - Silty sands</td>
<td></td>
</tr>
<tr>
<td>SC - Clayed sands</td>
<td></td>
</tr>
<tr>
<td>ML - Inorganic silts and very fine sands</td>
<td></td>
</tr>
<tr>
<td>CL - Inorganic clays of low to medium plasticity</td>
<td></td>
</tr>
<tr>
<td>OL - Organic silts and organic siltclays of low plasticity</td>
<td></td>
</tr>
<tr>
<td>MH - Inorganic silts</td>
<td></td>
</tr>
<tr>
<td>CH - Inorganic clays of high plasticity</td>
<td></td>
</tr>
<tr>
<td>OH - Organic clays of medium to high plasticity</td>
<td></td>
</tr>
<tr>
<td>Pt - Peat and other highly organic soils</td>
<td></td>
</tr>
</tbody>
</table>

#### COLE

<table>
<thead>
<tr>
<th>COLE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>COLE &lt; 0.03</td>
</tr>
<tr>
<td>Medium</td>
<td>0.03 ### COLE ### 0.06</td>
</tr>
<tr>
<td>High</td>
<td>0.06 &lt; COLE ### 0.09</td>
</tr>
<tr>
<td>Very high</td>
<td>COLE &lt; 0.09</td>
</tr>
</tbody>
</table>

#### Toxic elements content

<table>
<thead>
<tr>
<th>Toxic elements content</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>
### NaCl content

<table>
<thead>
<tr>
<th>Level</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 2000 ppm</td>
</tr>
<tr>
<td>Medium</td>
<td>2000-10,000 ppm</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 10,000 ppm</td>
</tr>
</tbody>
</table>

### Na or Mg sulphate content

<table>
<thead>
<tr>
<th>Level</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 1000 ppm</td>
</tr>
<tr>
<td>Medium</td>
<td>1000-7000 ppm</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 7000 ppm</td>
</tr>
</tbody>
</table>

### Internal soil drainage

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very poorly drained</td>
<td>Imperfectly drained</td>
</tr>
<tr>
<td>Poorly drained</td>
<td>Moderately well drained</td>
</tr>
<tr>
<td>Well drained</td>
<td>Excessively drained</td>
</tr>
</tbody>
</table>

### Water erodibility (K)

<table>
<thead>
<tr>
<th>Level</th>
<th>K Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.35</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 0.35</td>
</tr>
</tbody>
</table>

### Wind erodibility (WEG)

<table>
<thead>
<tr>
<th>Level</th>
<th>WEG Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 2</td>
</tr>
</tbody>
</table>

### Slope

<table>
<thead>
<tr>
<th>Level</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0%</td>
</tr>
<tr>
<td>Very low</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Low</td>
<td>2%</td>
</tr>
<tr>
<td>Moderate</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Strong</td>
<td>5%</td>
</tr>
<tr>
<td>Very strong</td>
<td>&gt; 5%</td>
</tr>
</tbody>
</table>

### Infiltration rate

<table>
<thead>
<tr>
<th>Type</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very slow</td>
<td>K &lt; 0.1 cm/h</td>
</tr>
<tr>
<td>Slow</td>
<td>0.1-0.5 cm/h</td>
</tr>
<tr>
<td>Moderately slow</td>
<td>0.5-2 cm/h</td>
</tr>
<tr>
<td>Moderate</td>
<td>2-6 cm/h</td>
</tr>
<tr>
<td>Moderately rapid</td>
<td>6-12 cm/h</td>
</tr>
<tr>
<td>Rapid</td>
<td>12-25 cm/h</td>
</tr>
<tr>
<td>Very rapid</td>
<td>K &gt; 25 cm/h</td>
</tr>
</tbody>
</table>

### Internal stoniness (frequency)

<table>
<thead>
<tr>
<th>Level</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>P.i. &lt; 2%</td>
</tr>
<tr>
<td>Few</td>
<td>2% - 5% P.i.</td>
</tr>
<tr>
<td>Common</td>
<td>5% - 10% P.i.</td>
</tr>
<tr>
<td>Frequent</td>
<td>10% - 25% P.i.</td>
</tr>
<tr>
<td>Abundant</td>
<td>25% - 50% P.i.</td>
</tr>
<tr>
<td>Dominant</td>
<td>&gt; 50% P.i.</td>
</tr>
</tbody>
</table>

### Surface stoniness <10cm (frequency)

<table>
<thead>
<tr>
<th>Level</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>P.s. &lt; 0.01%</td>
</tr>
<tr>
<td>Few</td>
<td>0.01% - 0.1% P.s.</td>
</tr>
<tr>
<td>Common</td>
<td>0.1% - 3% P.s.</td>
</tr>
<tr>
<td>Frequent</td>
<td>3% - 15% P.s.</td>
</tr>
<tr>
<td>Abundant</td>
<td>&gt; 15% P.s.</td>
</tr>
<tr>
<td>Dominant</td>
<td>&gt; 90% P.s.</td>
</tr>
</tbody>
</table>

### Surface stoniness >10cm (frequency)

<table>
<thead>
<tr>
<th>Level</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>P.s. &lt; 0.01%</td>
</tr>
<tr>
<td>Few</td>
<td>0.01% - 0.1% P.s.</td>
</tr>
<tr>
<td>Common</td>
<td>0.1% - 3% P.s.</td>
</tr>
<tr>
<td>Frequent</td>
<td>3% - 15% P.s.</td>
</tr>
<tr>
<td>Abundant</td>
<td>&gt; 15% P.s.</td>
</tr>
<tr>
<td>Very abundant</td>
<td>&gt; 90% P.s.</td>
</tr>
</tbody>
</table>

### Soil depth

<table>
<thead>
<tr>
<th>Level</th>
<th>Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very shallow</td>
<td>h &lt; 25 cm</td>
</tr>
<tr>
<td>Shallow</td>
<td>25 - 50 cm</td>
</tr>
<tr>
<td>Moderately deep</td>
<td>50 - 150 cm</td>
</tr>
<tr>
<td>Deep</td>
<td>&gt; 150 cm</td>
</tr>
</tbody>
</table>

### Ground water

<table>
<thead>
<tr>
<th>Level</th>
<th>Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>&lt; 50 cm</td>
</tr>
<tr>
<td>Moderately deep</td>
<td>50 - 100 cm</td>
</tr>
<tr>
<td>Deep</td>
<td>&gt; 100 cm</td>
</tr>
</tbody>
</table>

### Depth to cemented pans

<table>
<thead>
<tr>
<th>Level</th>
<th>Distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>h &lt; 50 cm</td>
</tr>
<tr>
<td>Moderately deep</td>
<td>50 - 100 cm</td>
</tr>
<tr>
<td>Deep</td>
<td>&gt; 100 cm</td>
</tr>
<tr>
<td>Very deep</td>
<td>h &gt; 200 cm</td>
</tr>
</tbody>
</table>
## Depth to hard bedrock

<table>
<thead>
<tr>
<th>Depth</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>h &lt; 50 cm</td>
</tr>
<tr>
<td>Moderately deep</td>
<td>50 cm</td>
</tr>
<tr>
<td>Deep</td>
<td>100 &lt; h</td>
</tr>
<tr>
<td>Very deep</td>
<td>h &gt; 200 cm</td>
</tr>
</tbody>
</table>

## Depth to soft bedrock

<table>
<thead>
<tr>
<th>Depth</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>50 cm</td>
</tr>
<tr>
<td>Deep</td>
<td>&gt; 50 cm</td>
</tr>
</tbody>
</table>

## Reaction (pH)

<table>
<thead>
<tr>
<th>Reaction</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very acid</td>
<td>&lt; 4.5</td>
</tr>
<tr>
<td>Acid</td>
<td>4.5 &lt; pH</td>
</tr>
<tr>
<td>Subacid</td>
<td>5.5 &lt; pH</td>
</tr>
<tr>
<td>Neutral</td>
<td>6.5 &lt; pH</td>
</tr>
<tr>
<td>Alkaline</td>
<td>7.5 &lt; pH</td>
</tr>
<tr>
<td>Very alkaline</td>
<td>pH &gt;</td>
</tr>
</tbody>
</table>

## Potential frost action

<table>
<thead>
<tr>
<th>Frost action</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

## Flooding

<table>
<thead>
<tr>
<th>Flooding</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>: less than once every 10 years</td>
</tr>
<tr>
<td>Moderate</td>
<td>: from once to 5 times every 10 years</td>
</tr>
<tr>
<td>High</td>
<td>: more than once every 5 years</td>
</tr>
</tbody>
</table>

## Rockiness (occupied area)

<table>
<thead>
<tr>
<th>Rockiness</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>Scarce</td>
<td>2% &lt; R</td>
</tr>
<tr>
<td>Common</td>
<td>10% &lt; R</td>
</tr>
<tr>
<td>Frequent</td>
<td>25% &lt; R</td>
</tr>
<tr>
<td>Very frequent</td>
<td>50% &lt; R</td>
</tr>
<tr>
<td>Rock outcrop</td>
<td>R &gt; 90%</td>
</tr>
</tbody>
</table>

## Salinity (conductibility at 25°)

<table>
<thead>
<tr>
<th>Salinity</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 1 dS/m</td>
</tr>
<tr>
<td>Scarce</td>
<td>1 &lt; S</td>
</tr>
<tr>
<td>Medium</td>
<td>4 &lt; S</td>
</tr>
<tr>
<td>Moderate</td>
<td>8 &lt; S</td>
</tr>
<tr>
<td>Strong</td>
<td>S &gt; 15 dS/m</td>
</tr>
</tbody>
</table>

## Sensitivity

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>Medium</td>
<td>4</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 8</td>
</tr>
</tbody>
</table>

## General texture classes

<table>
<thead>
<tr>
<th>Texture</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td></td>
</tr>
<tr>
<td>Moderately coarse</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Moderately fine</td>
<td></td>
</tr>
<tr>
<td>Fine</td>
<td></td>
</tr>
</tbody>
</table>

## Detailed texture classes between 25 and 150 cm

<table>
<thead>
<tr>
<th>Texture</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>s - Sand</td>
<td></td>
</tr>
<tr>
<td>ls - Loamy sand</td>
<td></td>
</tr>
<tr>
<td>sl - Sandy loam</td>
<td></td>
</tr>
<tr>
<td>l - Loam</td>
<td></td>
</tr>
<tr>
<td>sil - Silt loam</td>
<td></td>
</tr>
<tr>
<td>s - Silt</td>
<td></td>
</tr>
<tr>
<td>scl - Sandy clay loam</td>
<td></td>
</tr>
<tr>
<td>cl - Clay loam</td>
<td></td>
</tr>
<tr>
<td>scl - Silty clay loam</td>
<td></td>
</tr>
<tr>
<td>sc - Sandy clay</td>
<td></td>
</tr>
<tr>
<td>sic - Silty clay</td>
<td></td>
</tr>
<tr>
<td>c - Clay</td>
<td></td>
</tr>
</tbody>
</table>
References


Introduction

Heavy metals are chemical elements, common to all kinds of soils, and their abundance ranks between percentage (Fe only) and parts per million. The very low general level of their content in soils and plants, as well as the biological role of most of these chemical elements, has led to them being grouped under the generic name of “microelements”. When the soil has very high contents of such chemical elements, the term “heavy metal pollution” is used.

In some areas, the contents of these elements in soil are higher than the maximum concentration which has a beneficent or harmless effect on vegetation.

The content of heavy metals in soil can reach levels that inhibit the normal growth and development process of plants, and cause functional disturbance in other environmental components. These very high contents may be of geogenic or anthropogenic nature.

The negative effect of heavy metals depends on the percentage weight of their concentration as well as on a series of physical and chemical soil specific characteristics, such as: texture, organic matter content, pH, redox potential, etc.

In order to interpret the level of soil heavy metals, only their content values have been initially considered: values analytically determined both in normal soils not affected by anthropic impact, and in affected soils. Then values representing the maximum allowable limits (MAL) of concentration of heavy metals in soils have been established, mainly applicable to growth and development of plants. Such MAL have been established by Kloke (1980) in Germany, according to the results obtained from laboratory, greenhouse and field experiments (Table 1). Later, some of these thresholds were changed (Kloke and Einkmann, 1991, quoted by Kabata-Pendias, 1995), some of them being decreased (Cd - 2 ppm, Cu - 50 ppm) and others being increased (Cr - 200 ppm, Pb - 500 ppm). The maximum allowable limits established by Kloke (1980) are still used in several countries, including Romania.

The same principle has been used for determining and standardizing values of the maximum allowable limits in other countries (Great Britain, Austria, Poland, Canada, Japan, Switzerland, etc.) (Table 2). Both similarities and differences among figures can be noted. The differences are greater when the element induces a higher toxicity level. Generally, it is being noticed that countries facing more severe pollution (Great Britain, Germany) have established lower values of the maximum admissible levels for some of these chemical elements (Cd) than those accepted in countries that have been less exposed to such phenomena (Austria, Canada).

A step to improve the interpretation of soil heavy metal pollution level was made in Poland, by distinguishing several pollution classes, taking into account soil texture and reaction. For soils with high organic matter content, this component was also taken into consideration (Kabata-Pendias, 1993, in Kabata-Pendias, 1995). However, the ranking of the five pollution classes – from unpolluted to excessively polluted soils – was made without directly using the above-mentioned specific characteristics (pH, organic matter and clay content) for the calculation of the limits between classes.
In Holland, the so-called interpretation classes, types A, B and C, were established, which, in fact, represent: level of the reference values (A), level of the maximum allowable limits (B) and level of the values calling for soil decontamination measures (C) (Table 3). Canada has also adopted this system for interpretation of the analytical data. In the Dutch system, the reference value (A) is not a constant of a heavy metal for all soil types. The authors of this system provide mathematical formulae to determine the reference values specific to each sample, taking into account also the content of organic matter and clay less than 0.002 mm (Table 3).

Not all methods for interpreting the content of heavy metals in soil relate the significance of values obtained in direct relationship with intrinsic soil features – even if some of them group the interpretation values according to these features, as Kabata-Pendias (1993) did. A method aiming at this goal is presented below.

**Materials and Methods**

Data for illustrating the proposed method were taken from the papers concerning research activities carried out in the Baia Mare area polluted with heavy metals due to emissions from two metallurgical factories processing complex sulphides, mostly mined within this area (Lăcătusu et al., 1993 and 1994).

Samples were collected from the topsoils (0-20 cm) of agricultural soils. The main soils from the studied area are: Argillic Brown soils, Albic Luvisols, Brown Luvic soils, Brown Forest soils and – on smaller areas – Alluvial soils.

The total content of heavy metals was measured using atomic absorption spectrometry, the flame atomisation method. Soil digestion was carried out by using a mixture of concentrated HClO₄ and HNO₃ at a 2:1 ratio; then, by dissolving the precipitate in HCl 0.5 n, a solution was obtained in which spectrometric measurements were made.

**Results and discussion**

As clay and organic matter directly influence the other physical and chemical soil characteristics, the maximum soil capacity for heavy metals was adjusted according to these macro-constituents.

Starting with the calculation formulae for the reference values, taken from the Dutch system, a method for calculating and interpreting the obtained values was elaborated. This method permits calculations of an index to place a sample within the contamination range or the soil pollution range.

In this view, the term “soil contamination” defines the content interval within which any measured value of heavy metals, linked to the texture and organic matter content, has not or will not have immediate negative effects on plant growth and development or on other environmental components. The term “soil pollution” defines the content interval within which any measured value induces negative effects on some or all of the environmental components.

When soil contamination continues to increase, there is the possibility that it will exceed the soil capacity to fix chemical elements (by the well-known phenomena of colloidal absorption and complexing) and also the possibility of inducing negative effects on soil functions; thus, the pollution phenomenon starts off. Of course, continuous severe and very severe contamination will always carry the possibility of soil pollution.

A distinction between soil contamination range and soil pollution range is established by means of contamination/pollution index (C/p). This index represents the ratio between the heavy metal content effectively measured in soil by chemical analysis, and the reference value of contamination obtained by calculation for each sample, using the formulae of the Dutch system.

Values of the contamination/pollution index higher than 1 define the pollution range and those lower than 1 define the contamination range. The two ranges were divided into intervals of values that define a very slight, slight, medium, severe and very severe contamination, and a very slight, slight, medium, severe and very severe or excessive pollution, respectively. The tentative values of the limits of these intervals are presented in Table 4.

The index values defining only the pollution range can be totalled, obtaining, in this case, the values of multiple pollution with heavy metals; this is also interpreted according to the scheme presented in Table 4.

The illustration of the contamination/pollution index calculation was made taking into
account the analytical data on samples collected from the Baia Mare polluted area. The numerical and symbolical representation of the contamination/pollution degree of some of these samples is presented in Table 5.

The distinction between the pollution classes was established according to the effect of pollution on vegetation habitus and its content of heavy metals.

The spatial distribution of the contamination/pollution index values \( (C/p) \) allows the delineation of certain areas with different degrees of pollution or contamination with heavy metals and, finally, obtaining some maps concerning the level of contamination or pollution with heavy metals of soils within an area (total pollution or individual chemical element pollution). Representations of such maps, characteristic for the Baia Mare area, are presented in Figures 1-3. Areas differently contaminated or polluted with Cr or Pb are observed. The map of global pollution with heavy metals is slightly different from the maps specific to each chemical element. But the spatial distribution of areas uniformly contamination or polluted corresponds to the spreading directions of the pollutant emissions released by the two major polluting factories – S.C. Phönix S.A. and S.C. Romplumb S.A. – directions determined by the local geomorphological and climatic conditions.

It has to be mentioned that the map of soil contamination and pollution with Pb (Figure 2), a pollutant element specific to this area, prepared having in view this index of contamination/pollution, presents another image as compared to a previous interpretation taking into account only the maximum allowable limit value (100 ppm) established by Kloke (1980). The difference, as compared to the previous map, consists of including within the category of severely to slightly contaminated soils of the areas situated in the south and south-western part of the studied zone, even though, within these areas, Pb contents exceeding or near the maximum allowable limit were detected. However, this time, the correction, made by using values of the organic matter and clay content, changed the image initially created only taking into account the Pb analytical values.

By totalling the contamination/pollution index values specific to the pollution range for all the analysed chemical elements, the real representation of heavy metal pollution within the area can be obtained. The pollution is ranked into five categories (classes), and the prevailing intervals are those from moderate to excessive pollution (Figure 3).

### Conclusions

1. The level of soil contamination with one or more heavy metals represents any concentration of these chemical elements that has no negative effect on soils, plants or other environmental components. On the contrary, the pollution level means any concentration that has harmful effect on these components.

2. In order to make a distinction between the two levels, the method defines and suggests the calculation of the contamination/pollution index \( (C/p) \). This represents the ratio between a heavy metal content, analytically determined in soil, and its reference value, respectively the value of the reference contamination determined by calculation, according to the formulae of the Dutch system (values A from the ABC series).

3. The contamination/pollution index values lower than 1 characterise the soil contamination range, and values higher than 1 characterise the pollution range. Each range was divided into intervals that define: a very slight \( (C/p<0.1) \), slight \( (0.1-0.25) \), moderate \( (0.26-0.50) \), severe \( (0.51-0.75) \) and very severe contamination \( (0.76-1.00) \), and a slight \( (1.1-2.0) \), moderate \( (2.1-4.0) \), severe \( (4.1-8.0) \), very severe \( (8.1-16.0) \) and excessive pollution \( (>16.0) \), respectively.

4. The values of the index that define only the pollution range may be totalled, thus obtaining the value of the total pollution with heavy metals which is interpreted by the proposed scheme.

5. The contamination/pollution index values and the contamination/pollution degree values, respectively, may be schematically represented by a table or may be used for preparing maps concerning contamination or pollution of an area, for delineation of the areas contaminated or polluted with heavy metals.

6. The paper also presents the procedure to calculate and interpret the contamination/pollution index values concerning the Baia Mare area affected by heavy metals.
References


LACATUSU, R., RAUTA, C., DUMITRU, M., RISNOVEANU, I., TAINA, S., KOVACSOVIC, B., LUNGU, M., RIZEA, N. and CIOBANU C., Poluarea cu metale grele a solurilor si vegetatiei din pasunile si fanetele zonei Baia Mare, Report, Arhiva I.C.P.A.

Table 1: Normal content intervals and maximum allowable limits of heavy metals in soils (after Kloke, 1980)

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>Normal content interval</th>
<th>Maximum allowable limits (M.A.L.) mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0.1 - 1.0</td>
<td>3</td>
</tr>
<tr>
<td>Co</td>
<td>1 - 10</td>
<td>50</td>
</tr>
<tr>
<td>Cr</td>
<td>2 - 50</td>
<td>100</td>
</tr>
<tr>
<td>Cu</td>
<td>1 - 20</td>
<td>100</td>
</tr>
<tr>
<td>Ni</td>
<td>2 - 5</td>
<td>50</td>
</tr>
<tr>
<td>Pb</td>
<td>0.1 - 20</td>
<td>100</td>
</tr>
<tr>
<td>Zn</td>
<td>3 - 50</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 2: Values of maximum allowable limits (M.A.L.) for heavy metals in soil (mg/kg) used in different countries (in KABATA-PENDIAS, 1995)

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>Austria</th>
<th>Canada</th>
<th>Poland</th>
<th>Japan</th>
<th>Great Britain</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Cd</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Co</td>
<td>50</td>
<td>25</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cr</td>
<td>100</td>
<td>75</td>
<td>100</td>
<td>-</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Cu</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>125</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Ni</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Pb</td>
<td>100</td>
<td>200</td>
<td>100</td>
<td>400</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Zn</td>
<td>300</td>
<td>400</td>
<td>300</td>
<td>250</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>
Table 3: Interpretation values of heavy metals content in soil (from Dutch standard - 1988, quoted by EWERS, 1991)

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>A values mg/kg</th>
<th>B values mg/kg</th>
<th>C values mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>0.4 + 0.007 (A* + 3MO**)</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Co</td>
<td>20</td>
<td>50</td>
<td>300</td>
</tr>
<tr>
<td>Cr</td>
<td>50 + 2A</td>
<td>250</td>
<td>800</td>
</tr>
<tr>
<td>Cu</td>
<td>15 + 0.6 (A + MO)</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Ni</td>
<td>10 + A</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Pb</td>
<td>50 + A + MO</td>
<td>150</td>
<td>600</td>
</tr>
<tr>
<td>Zn</td>
<td>50 + 1.5 (2A + MO)</td>
<td>500</td>
<td>3000</td>
</tr>
</tbody>
</table>

*) clay smaller than 0.002 mm (%)    ***) organic matter (%)

Table 4: Significance of intervals of contamination/pollution index (C/p)

<table>
<thead>
<tr>
<th>Cl/p</th>
<th>Significance</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.1</td>
<td>Very slight contamination</td>
<td>v.s.l.</td>
</tr>
<tr>
<td>0.10 - 0.25</td>
<td>Slight contamination</td>
<td>s.l.</td>
</tr>
<tr>
<td>0.26 - 0.50</td>
<td>Moderate contamination</td>
<td>m.l.</td>
</tr>
<tr>
<td>0.51 - 0.75</td>
<td>Severe contamination</td>
<td>st.l.</td>
</tr>
<tr>
<td>0.76 - 1.00</td>
<td>Very severe contamination</td>
<td>v.st.l.</td>
</tr>
<tr>
<td>1.1 - 2.0</td>
<td>Slight pollution</td>
<td>s.p.</td>
</tr>
<tr>
<td>2.1 - 4.0</td>
<td>Moderate pollution</td>
<td>m.p.</td>
</tr>
<tr>
<td>4.1 - 8.0</td>
<td>Severe pollution</td>
<td>st.p.</td>
</tr>
<tr>
<td>8.1 - 16.0</td>
<td>Very severe pollution</td>
<td>v.st.p.</td>
</tr>
<tr>
<td>&gt; 16.0</td>
<td>Excessive pollution</td>
<td>e.p.</td>
</tr>
</tbody>
</table>
Table 5: Schematic presentation of contamination or pollution degrees with heavy metals of some soils within the Baia Mare area

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Contamination</th>
<th>Individual pollution</th>
<th>Multiple pollution (p) with heavy metals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>v.s.</td>
<td>s.</td>
<td>m.</td>
</tr>
<tr>
<td>139</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>144</td>
<td>Cr</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>61 (e.p.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>146</td>
<td>Cu</td>
<td>0.15</td>
<td>Ni</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1 (s.p.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>Cr</td>
<td>0.20</td>
<td>Ni</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.4 (sv.p.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>161</td>
<td>Cr</td>
<td>0.25</td>
<td>Ni</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28.1 (e.p.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

v.s. - very slight
s. - slight
m. - moderate
sv. - severe
v.sv. - very severe
e. - excessive
Figure 1: Cr loading map of soils (0-20 cm) within the BAIA MARE area (scale 1:200,000)

Figure 1: Cr contamination map of soils (0-20 cm) within the Baia Mare area (scale 1:200,000)

very low loading
slight loading
moderate loading

locality

Bozinta Mioă
Figure 2: Pb contamination and pollution of soils (0-20 cm) within the Baia Mare area (scale 1:200,000)
Figure 3: Heavy metals pollution (Cd, Co, Cu, Ni, Pb, Zn) map of soils (0-20 cm) within the Baia Mare area (scale 1:200,000)
Spatial Information Systems for Environmental Impact Assessment in the UK

Summary

This paper describes the development of spatial systems that use soil and related information for environmental impact assessment in the UK. Over the past 17 years, the Soil Survey and Land Research Centre (SSLRC) has developed a computerised land information system, LandIS, that has spawned a number of stand-alone applications targeted at environmental protection. These address the risks of pollutant transfer, ground instability, and corrosion.

Other applications also exist for assessing suitability for alternative crops, abatement strategies, and planning the sustainable management of land.

CatchIS, the Catchment Information System, was developed for assessing the vulnerability of ground and surface water to contamination from a range of commonly used pesticides. It is now operational with one of the largest water supply companies in the UK, which has also shared the development costs of the system. LEACS is a system for evaluating the risk of soil-based corrosion to underground assets (pipe networks) and as such provides a framework for asset management in both the water and utilities industries. INSURE is a geotechnical application for assessing environmental risks (subsidence, flood and storm) for the construction and finance industries. All three applications operate as stand-alone systems, but they all rely directly on the provision of data from the central database (LandIS).

Introduction

The Soil Survey and Land Research Centre (SSLRC) has been collecting information on soils for over 50 years. The Centre has been responsible for developing a comprehensive soil classification system, collecting soil samples and subjecting them to physical and chemical analysis, and mapping the distribution of the different soil types. SSLRC has also developed the computerised Land Information System; LandIS, for storing all the data collected during survey work (Ragg and Proctor, 1983; Hallett et al., 1996). Development of LandIS commenced during the 1980s, and SSLRC is currently engaged on a four-year programme, funded by the Ministry of Agriculture, Fisheries and Food (MAFF), to re-engineer the software and hardware platforms to take account of current industry standards (Proctor et al., 1998).

LandIS

LandIS is one of the most comprehensive computerised land information systems of its kind in Europe. It allows groups and organisations in environmental, engineering, and agricultural fields to access valuable information and expertise that would otherwise need to be extracted from paper maps and log books.

- A key database in LandIS is NATMAP: a 100m x 100m resolution raster version of the 1:250 000 scale National Soil Map of England and Wales, published in six sheets (Soil Survey Staff, 1983). The 1:250 000 scale National Soil Map was originally digitised in vector format, but until

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recently, versions of NATMAP in raster format have been used in most applications. Summaries of NATMAP at 1km and 5km resolution have also been compiled, and are stored in LandIS as separate databases.

- The 100m resolution data has one map unit code for each unique Easting and Northing (map coordinates). The map unit code represents an association of soils; a group of soil series that are associated in a related pattern within the landscape. The system also holds information from the National Soil Map legend; for example, the percentage of each soil series in a map unit, where a soil series is the basic level of soil classification (Clayden and Hollis, 1984).

A number of Geographical Information Systems (GIS) projects have been developed using LandIS data. These assess environmental risks such as pollutant transfer, ground movement, and corrosion. They have been designed as Decision Support Systems (DSS), operating on UNIX workstations or PCs, to address specific business problems that cannot be solved using LandIS alone. These systems include:

- CatchIS - Catchment Information System
- LEACS - Land Evaluation for the Assessment of Corrosion and Subsidence
- INSURE - Information System for Underwriting Risk Evaluation

A fourth system SEISMIC, Spatial Environmental Information System for Monitoring the Impact of Chemicals has been developed for PC. It is a product developed for commercial sale with funding from the Pesticide Safety Division; an Agency of the UK Ministry of Agriculture, Fisheries and Food, and the British Agrochemicals Association (BAA). SEISMIC is described in detail by Hallett et al. (1995).

**CatchIS**

CatchIS, the Catchment Information System, is a spatial application developed in association with Severn Trent Water (STW) Ltd. CatchIS was originally developed in 1994 (Breach et al., 1994) as a research tool for assessing the vulnerability of ground and surface water to contamination from a range of commonly used pesticides. This is achieved by simulating the attenuation of these compounds in the natural environment using the logical and intuitive graphical user interface (GUI) presented in Figure 1. The results are presented as thematic maps and as statistical tables, which could be used to support business decisions. The system has been used as an operational tool since 1995.

STW is one of the largest water supply companies in the UK and is responsible for the operational management of the water resources in an area of central England, serving more than 8 million people. Water resources in this area are under considerable threat from pollution by industry, agriculture (particularly agrochemicals), transport, and waste disposal (both agricultural and industrial). CatchIS was developed largely to support the work of the Water Quality and Planning Department of STW and contains data on soils, climate, water resources, and basic spatial features such as transport networks and administrative boundaries. These data sets can be used for navigational as well as modelling purposes. Provided the appropriate data are incorporated, CatchIS can be used to support the management of water supplies in any other region in the UK or Europe.

Figure 2 presents a thematic overview of CatchIS which shows the modular structure of the system. This modular approach enables enhancements and conversions to be incorporated with maximum efficiency.
Figure 1: The CatchIS Environment.
Since it was commissioned in 1994, CatchIS has been operated on an IBM/RS6000 RISC workstation running the AIX (UNIX) operating system. The data sets are manipulated using the object oriented APIC spatial development environment produced by APIC S.A. (Timms, 1992). APIC possesses powerful spatial object data modelling capabilities (APIC, 1994a; 1994b; 1994c), and is particularly appropriate for spatial environmental information systems such as CatchIS. Despite the complex hardware and sophisticated underlying software platforms, CatchIS has been developed as a comprehensive solution to a specific business requirement, to deliver clean water to the public, in such a way that the user of the system does not have to be an expert in UNIX or GIS.

**CatchIS Models.**

Two environmental fate and behaviour models are encapsulated in CatchIS. These are SWAT; Surface Water Artenuation model, and AQUAT; Aquifer Artenuation model, (Hollis et al., 1993). These models have been developed to predict the leaching and surface run-off, respectively, of applied organic compounds such as pesticides. AQUAT is based on the work of Rao et al., (1985) and Leonard and Knisel, (1988), and calculates the attenuation factor; the fraction of applied pesticide in recharge water, corresponding to the amount of pesticide impacting the groundwater surface for specific pesticide, soil and climate parameters. This factor is used to estimate the likely annual average concentration of pesticide in recharge waters, based on the crop-specific pesticide application rate, with adjustments to take into account any likely crop interception and the average annual volume of recharge.

---

**Figure 2:** Thematic overview of the CatchIS application.
Figure 3: Runoff vulnerability for the Bow Brook sub-catchment.

The SWAT model is a further development of the concepts encapsulated by AQUAT, and estimates the average pesticide concentration likely to enter streams during peak drainage from fields following the first rainfall event after pesticide application that initiates run-off. By combining the vulnerability of soils to pollution by pesticide compounds with land use data, the actual risk for any given region can be estimated. Therefore, it is possible for users to visualise the potential for resource pollution, and the areas where this potential is likely to be realised.

CatchIS also incorporates soil-based interpretations such as pesticide run-off potential classes that can be thematically mapped as well as vulnerability assessments from AQUAT and SWAT. Figure 3 presents an example of such an interpretation as a thematic map.

CatchIS Data

The core databases of the CatchIS system include a regional soil map derived from the 100 m resolution NATMAP data set stored in LandIS. Associated data include: soil attributes, agroclimate, land use, aquifer, catchment and sub-catchment boundaries, river networks, surface and groundwater abstraction point data, administrative boundaries, and pesticide-compound data. The digital soil and climate data sets are derived from LandIS. Other
digital data sets include Ordnance Survey Strategi data. Figure 4 presents a typical report comprising data held at any given point both in terms of agroclimatic variables and spatial location. In addition raster maps at scales of 1:50 000 and 1:250 000 are included. Thematic maps may be overlaid on these data sets to create maps of use in the field or in the office.

Potential Uses and Users

The CatchIS system can be customised to cover any area in the UK for which the appropriate spatial databases exist.

<table>
<thead>
<tr>
<th>Report for Selected Point: Grid Reference: sj76503844</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate:</td>
</tr>
<tr>
<td>Field Capacity Days : 198</td>
</tr>
<tr>
<td>Excess Winter Rainfall : 0310</td>
</tr>
<tr>
<td>Return to Field Capacity : -79</td>
</tr>
<tr>
<td>Soil:</td>
</tr>
<tr>
<td>Soil Association : 551a</td>
</tr>
<tr>
<td>Rank Series Code % Leaching Runoff</td>
</tr>
<tr>
<td>1  BRIDGNORTH 0144  50.00   H2do  S4v</td>
</tr>
<tr>
<td>2  BROMSGROVE 0149  20.00   H2do  S4v</td>
</tr>
<tr>
<td>3  NEWPORT 1310  10.00   H2mo  S5v</td>
</tr>
<tr>
<td>4  CUCKNEY 0282  15.00   H2do  S4v</td>
</tr>
<tr>
<td>Characterisation:</td>
</tr>
<tr>
<td>The following describe the properties of the dominant series (Bridgnorth)</td>
</tr>
<tr>
<td>Leaching Potential Sandy soil with low organic matter over soft sandstone with deep groundwater</td>
</tr>
<tr>
<td>Runoff Potential Soils with low run-off potential but very low adsorption potential</td>
</tr>
<tr>
<td>Landuse:</td>
</tr>
<tr>
<td>Currently selected Landuse Group: Grass : 5.40%</td>
</tr>
<tr>
<td>Category % set-aside 5.40</td>
</tr>
<tr>
<td>Miscellaneous Spatial Features:</td>
</tr>
<tr>
<td>Point falls in Catchment : Upper Severn</td>
</tr>
<tr>
<td>Point falls in Subcatchment : Tern and Roden</td>
</tr>
<tr>
<td>Point falls in Water Supply District : ST</td>
</tr>
<tr>
<td>Point falls in Water Supply Zone : ST15B</td>
</tr>
<tr>
<td>Point falls in District Health Authority : North Staffordshire</td>
</tr>
<tr>
<td>Point falls in Local Authority : Newcastle-under-Lyme</td>
</tr>
<tr>
<td>Point falls in Nitrate Sensitive Area (NSA) : Wellings</td>
</tr>
<tr>
<td>Point falls in Nitrate Vulnerable Zone (NVZ) : Swynnerton A (G)</td>
</tr>
</tbody>
</table>

Figure 4: Sample CatchIS data.

Potential users of the CatchIS system include the following:
- The Water Industry
- Water Regulators
- Public Utilities
- The Agrochemical Industry
- Contract Laboratories
- Environmental and Agricultural Consultancies
- Government Departments and Agencies
- Universities, Colleges and other Educational establishments
- Research Institutes
Further Developments

CatchIS is under continuous development and is currently installed at STW as version 3.4. Future enhancements will include the introduction of a vector format 1:250 000 scale National Soil Map, to supersede the raster based NATMAP described in this paper. CatchIS is also in the process of being ported to run on an HP platform running under the HP-UX operating system. The system may also be further developed to include the assessment of other hazards to water supplies such as farm waste disposal.

LEACS

LEACS; Land Evaluation Assessment for Corrosion and Subsidence, is a system evaluating the risk of corrosion or fracture to underground pipe networks. It is of particular interest to the water industry. Mechanical failures in the water distribution network are a major problem to many water companies and the costs of amelioration are high. LEACS uses the relationship between soil characteristics and failures to predict areas where the mains pipes and other underground assets are liable to fail. The results from the system allow water industry users to establish protocols to facilitate the repair and replacement of buried assets. There are a number of soil characteristics that can cause corrosion. These are described in the sections below.

Soil Corrosivity Potential

The corrosion of metal in soil is a complex electrochemical process and it is difficult to identify all the contributing factors. There is no national standard for assessing the corrosivity of soil, although there are standards for some individual tests, and standards produced by interested organisations. However, the soil properties that are considered to be the most important in having a significant effect on the corrosion of buried metal pipes are presented in Figure 5.

![Soil Corrosivity Factors](image)

**Figure 5:** Corrosivity factors modelled.
Soil Fracture Potential

Clay particles occur in most kinds of soil, but they only begin to exert a strong influence on the behaviour of the whole soil where there is in excess of 35% clay-sized (< 2µm) material present. Since clay particles are very small and commonly platy in shape, there is an immense surface area to which water can be attracted relative to the total volume of the soil material. In their natural undisturbed condition, the moisture content of clays does not change greatly, and consequently there are no changes in volume leading to soil fracture. However, the situation is very different when clays are exposed at or near the ground surface, especially if vegetation is rooting in them.

When rainfall is small, and is exceeded by evapotranspiration, a soil moisture deficits occur. This leads to a reduction in soil volume, and the consequent shrinkage causes stress in the soil materials, and on the structures that are resting in the soil. These structures may then move, thus causing damage.

LEACS Data

The basic soil data are derived from the 100m resolution NATMAP data set stored in LandIS. Using these data, two soil characteristics - soil corrosivity and soil fracture potential, that have a significant effect on the failure of underground assets, can be modelled spatially.

Two types of failure data are collected by the water companies, both of which are spatially referenced to the Ordnance Survey National Grid. The data sets are:

- Pipe Mains - geometric data on the location of underground water mains.
- Pipe Bursts - georeferences of the locations of known pipe bursts.

For a given section of pipe mains, there is a considerable chance that the pipe will fall within different soil types, with different soil characteristics (Figure 6). It is therefore, important to know which portions of the pipe mains will be more susceptible to failure due to the effect upon the pipe of the soil characteristics.

Figure 6: Spatial distribution of soils with different characteristics.
Assessment of Potential Risks

Six soil corrosivity classes are identified, with two additional classes, water and unclassified, to account for non-soil data. These categories are presented in Table 1.

Table 1: Soil corrosivity potential.

<table>
<thead>
<tr>
<th>Class</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Aggressive</td>
<td>NoA</td>
</tr>
<tr>
<td>Slightly Aggressive</td>
<td>SA</td>
</tr>
<tr>
<td>Moderately Aggressive</td>
<td>MoA</td>
</tr>
<tr>
<td>Highly Aggressive</td>
<td>HA</td>
</tr>
<tr>
<td>Very Highly Aggressive</td>
<td>VHA</td>
</tr>
<tr>
<td>Rock</td>
<td>R</td>
</tr>
<tr>
<td>Unclassified</td>
<td>Un</td>
</tr>
<tr>
<td>Water</td>
<td>H2O</td>
</tr>
</tbody>
</table>

Results

The results of the LEACS analysis can be expressed as a function of mains length per modelled risk class, or as a function of burst occurrences per modelled risk class. More importantly, these two results can be combined to produce a burst index (burst rate), which normalises results on a uniform ratio scale. Intra-comparison of these normalised results can be achieved in this way. The burst index is produced by dividing the number of bursts observed within a given class by the mains length (in km) within that class. This provides a figure for the number of bursts per kilometre of mains pipes:

\[ \text{Burst Index} = \frac{\text{Number of Bursts in class}}{\text{Mains Length in class}} \]

Based on a study which was carried out for North East Water (unpub), using a simplified soil corrosivity scheme, it has been shown that there is a direct link between soil corrosivity and pipe mains failure. As a function of corrosivity class, Table 3 shows that there is a marked increase in the burst rate, and hence pipe susceptibility between the slightly and moderately aggressive soil types. In this instance, no pipes occurred within the highly aggressive soils.

Table 3: Soil corrosivity analysis (corrosivity class).

<table>
<thead>
<tr>
<th>Soil Corrosivity Potential Class</th>
<th>Burst Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slightly Aggressive</td>
<td>0.24</td>
</tr>
<tr>
<td>Moderately Aggressive</td>
<td>0.78</td>
</tr>
<tr>
<td>Highly Aggressive</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 2: Soil fracture potential.

<table>
<thead>
<tr>
<th>Class</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>VL</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
</tr>
<tr>
<td>Moderate</td>
<td>M</td>
</tr>
<tr>
<td>High</td>
<td>H</td>
</tr>
<tr>
<td>Very High</td>
<td>VH</td>
</tr>
<tr>
<td>High* (Alluvial)</td>
<td>H*</td>
</tr>
<tr>
<td>Unclassified</td>
<td>Un</td>
</tr>
<tr>
<td>Water</td>
<td>H2O</td>
</tr>
</tbody>
</table>

*Alluvial soils are treated separately

Table 4: Soil corrosivity analysis (pipe type).

<table>
<thead>
<tr>
<th>Pipe Type Class</th>
<th>Burst Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>1.12</td>
</tr>
<tr>
<td>Lead</td>
<td>0.60</td>
</tr>
<tr>
<td>PVC</td>
<td>0.33</td>
</tr>
</tbody>
</table>
As a function of pipe type Table 4 shows that pipe mains constructed of cast iron are more susceptible to failure than other metal (lead) pipes, and that plastic (PVC) pipes are the least susceptible to failure.

### Table 5: Soil corrosivity analysis (pipe type within corrosivity class).

<table>
<thead>
<tr>
<th>Pipe Type</th>
<th>Soil Corrosivity Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Iron</td>
<td>Slightly Aggressive: 0.15</td>
</tr>
<tr>
<td>Lead</td>
<td>Slightly Aggressive: 0.07</td>
</tr>
<tr>
<td>PVC</td>
<td>Slightly Aggressive: 0.02</td>
</tr>
</tbody>
</table>

As a function of pipe type within soil corrosivity class, Table 5 shows that the marked increase in burst susceptibility affects all pipe types, but that cast iron pipes have nearly double the burst rate of lead pipes, and nearly five times the burst rate of PVC pipes, within the moderately aggressive soil types. No pipes occurred within the highly aggressive soils.

Similar studies for a major water company in Southern Britain confirmed the trends established in the North East Water LEACS analysis. The LEACS analysis was extended to include the effect of soil corrosivity on burst susceptibility of pipes with different diameters. It was shown that pipes of smaller diameters were more susceptible to failure in all soil corrosivity classes. In addition, the effect of soil fracture potential was investigated, and it was shown that pipes located in soils of higher fracture potential were more susceptible to failure than pipes located in soils of lower fracture potential (the precise results of this LEACS analysis can not be included, for reasons of commercial confidentiality).

It has been shown that soil data can be interpreted to identify corrosion risk and in practice these predictions correlate closely with the actual occurrences of pipe bursts and failures where such data are available. The corrosivity classification has been shown to be a good first approximation for identifying areas of land aggressive to buried ferrous pipes, confirming a relationship of soil type to mains bursts (Jarvis and Hedges, 1994).

Furthermore, it is clear that spatial soil data at 1:250 000 scale (NATMAP) can broadly discriminate areas of risk of pipe bursts, although inevitably a proportion of corrosive interaction will not be identified because corrosive soils can be of very limited extent and therefore not easily delineated at this scale. The soil classification system used by SSLRC, with its most precisely defined unit the soil series, allows a rapid appraisal of any area in England and Wales where soil maps exist. It also ensures that there is a consistent national approach to the assessment of soil corrosivity.

**INSURE**

The *In*formation System for *Un*derwriting *R*isk *E*valuation, INSURE, is a geo-technical application developed for the UK insurance industry for assessing the risk of subsidence, flood and storm. The background to the system is described by Hallett *et al.* (1994). It was developed on an IBM RS/6000 UNIX workstation, using the APIC *object-oriented* development environment. The subsidence risk assessment module is based on the type of soil (*e.g.* the potential to shrink and swell, SSWELL, or the origin of the parent material), and the climate (*e.g.* the potential soil moisture deficit; PSMD). The flood risk assessment module is based on the origin and type of the soil parent material. Alluvial areas delineate the extent of floodable land and these are the areas most at risk. The storm exposure risk assessment module classifies risk, based on wind exposure, in which average wind speeds, and field survey information are taken into account. INSURE is fully geo-referenced, using the Ordnance Survey National Grid Reference and the Royal Mail Post Code resolved down to Unit level.
Subsidence

Soil-related building subsidence is the result of ground movement. The kinds of soil materials directly associated with ground movement and their effects (Jarvis, 1993) are listed below:

- Clay shrinkage and swelling
- Sand and erosion
- Peat and shrinkage
- Silts and frost heave
- Soft soils and compressibility

With its current configuration, INSURE predicts subsidence risks caused primarily by Shrink-swell (SSWELL) of clays. It can also identify the occurrence of sands, silts, soft (alluvial) soils and peat soils, but clay shrink-swell is by far the most extensive cause of subsidence in England and Wales. Other natural mechanisms associated with and/or causing ground movement include mining subsidence, landslips and the formation of swallow holes, but these are not assessed by INSURE.

Clay-related subsidence

Cracking caused by shrinking soils is not uncommon in summer months; it is particularly noticeable in soils with high clay content. The exact amount of shrinking and cracking depends upon the soil type, density, and field conditions (Hall et al., 1977). The shrink-swell potential of the soil has been determined from direct measurements of shrinkage and an understanding of the mineralogy of soil clays. Cracking affects structural development (Reeve and Hall, 1978; Reeve et al., 1980) and this knowledge has been used to classify each of the national soil series on the basis of its potential to shrink and swell (SSWELL) when moisture is expelled and absorbed.

Shrinkage is the reduction in volume of a soil when moisture is expelled through drainage, evaporation and transpiration. It depends on the amount of clay and the type of clay minerals present. Measurements have been made under specific conditions...
and the soil Shrink-Swell (SSWELL) potential at 1m depth has been made for all nationally important soil series portrayed on the National Soil Map of the UK. Five classes of SSWELL are recognised on the basis of predicted volumetric shrinkage between 5 and 1500 kPa, expressed as a percentage of the volume at 5 kPa.

In some parts of Britain, particularly in the South and East, summer rainfall is relatively low, and is exceeded by evapotranspiration. At this time of year water reserves are not replenished by rainfall, and soil moisture deficits occur. The water being removed from the soil by the plants leads to reduction in soil volume, and the consequent shrinkage causes stress in the soil materials, leading in turn to stress on foundations that are resting in the soil. The foundations themselves may then move and thus cause damage to building structures. This problem can be exacerbated by the fact that the soil beneath the structure may not dry out uniformly, so that any lateral pressure exerted on the building foundation is made effectively greater.

In predicting subsidence risk for clay shrinkage, it is important to know the cycle of wetting and drying in soil at different locations in the country. Using rainfall and evapotranspiration data, the cycle of wetting and drying can be expressed in terms of the potential soil moisture deficit; PSMD (Smith, 1967; Jones and Thomasson, 1985).

\[ \text{PSMD} = \sum (R - PT), \text{expressed in mm} \]

The PSMD is accumulated over a season and represents the excess of evapotranspiration (PT) over rainfall in that season. Average values, expressed in mm rainfall equivalent, are combined with SSWELL data for assessing clay-related subsidence risk. Data are included representing 15 years of measurements of weather parameters collected from field meteorological stations, representing the full range of conditions expected in England and Wales. Data at a resolution of 5km x 5km from the agroclimatic databank (Jones and Thomasson, 1985; Ragg et al., 1988) are used in this study.

INSURE uses the mean maximum PSMD which represents the maximum deficit under a short green crop such as grass. This is a conservative estimate because where large trees with deep roots occur, the maximum PSMD can be significantly greater than under grass.

**Other Soil-Related Subsidence**

There are other soil properties which can cause ground movement (Jones et al., 1995). Sandy soils do not shrink when moisture is abstracted, and are generally non-compressible. However, if a water pipe buried in loose sandy material bursts, severe erosion can occur below ground and cavities can form, posing a danger to buildings founded in such material. Many insurance claims for subsidence damage in the UK are preceded by bursts in the water pipes proximate to the property.

The heaving of silty soils under frosty conditions can also lead to significant damage to building structures. Silty soils often form platy structures, and in moist conditions, water is held against gravity in the pores between grains and on the surfaces of the plates. Heave is caused by migration of this water to sites in the soil subjected to sub-zero temperatures. The subsequent freezing causes expansion, particularly in the vertical dimension.

Peats are subject to a considerable degree of shrinkage when they are drained, and thus buildings located on such materials are vulnerable to subsidence. Peat is also soft and very compressible and consequently there is an increased risk of subsidence when such land is loaded by building structures.

Soft soil material, e.g. sands, silts and clays, deposited in rivers, lakes, and seas as lacustrine, riverine and marine alluvium, are weakly consolidated. Such materials have very low bulk densities (< 1.0gcm\(^{-3}\)) and are compressed when subjected to loads. The weight of building structures is such that, in many cases, the vertical stress exerted is greater than the bearing strength of the soft soil material and this can lead to consolidation and subsidence. Areas most at risk from this kind of subsidence are largely confined to the floodplains of rivers and streams, the coastal flats underlain by marine alluvium, and areas covered by lacustrine deposits and peat (Jones et al., 1995).

**INSURE Data**

The INSURE system integrates a number of discrete data types. These data are brought together and manipulated by the risk models encapsulated within the system. The principal data types include soil data, climatic data and geo-referencing/cadastral data. Figure 8 presents a thematic overview of INSURE showing the modular structure of the system.
Developed to run on a UNIX workstation, INSURE uses 100m resolution NATMAP soil data derived from LandIS, which means that subsidence risk can be identified in the UK at Postcode Unit level (typically representing groups of 15 - 50 residential properties).

All spatial data in the INSURE system are geo-referenced through the Ordnance Survey National Grid system, allowing direct comparison of differing data types. INSURE data can also be accessed geo-spatially through the Royal Mail Postcode system (Chorley, 1987). The Postcode system offers a common reference for locating properties and linking with the exposure-to-subsidence-risk data. In its core implementation, INSURE works at all Postcode levels: Areas, Districts, Sectors, and Units. INSURE also retains the National Grid referencing system for accessing and manipulating the spatial data as an alternative to the Postcode data sets. For navigation, INSURE is capable of supporting both vector and raster overlay information, such as the Ordnance Survey ‘Strategi’ and 1:50,000 scale Landranger map data (roads, railways, canals, major and minor settlements etc.).

**Figure 8:** Thematic overview of the INSURE application.

**INSURE in the Finance sector**

INSURE provides a decision support system for underwriters in the UK Insurance industry. It uses the best available data on the soil material directly in contact with the foundations of most domestic housing. It uniquely overlays climatic data, thus giving the best measure of the realisation of the potential risk of shrinkage and swelling in soils. INSURE also contains information on the origin and nature of soil parent materials. This information is used to assess the risk of subsidence caused by compressibility of soft soils and
also to identify the area of floodable land.

One of the advantages of INSURE is that it uses soil data that specifically relate to the nature of the material present at the surface and to a depth of 1.5m depth, and not only to the geological deposits from which some surface materials derive. The soil data in LandIS therefore more accurately reflect the thin superficial drift deposits, resulting from alluviation and glaciation, that commonly overlie the solid geology in many parts of Britain.

The object orientated framework of INSURE integrates a powerful object modelling capability with rapid data visualisation within a single comprehensive application package. INSURE is now available as a commercial product under the name of VENTECH.

**Overall Conclusions**

This paper describes spatial applications developments relevant to the real world, that are soundly based on comprehensive digital soil and land data (from LandIS). These applications illustrate the importance and the benefits that can be gained from using spatial data from a secure central source. The use of soil and related data has moved on from the traditional areas of research into agricultural productivity of land and land capability to the protection of the soil itself and the natural environment as a whole. The growing concern over the impact that everyday human activities, and particularly climate change, are having upon the environment has led to a marked increase in applications centred on environmental risk assessment.

The development of CatchIS has demonstrated how soil, climatic, and land use data can be combined in one system directed at the protection of water supplies from pesticide leaching and runoff. Not only can CatchIS act as a tool for assessing the potential risk, but it can also provide a platform, based on sound scientific principles, for reducing this risk.

LEACS is an application that addresses a major problem for the UK water industry: the leakage of underground water pipes through corrosion and fracture. Some water companies lose large amounts of potable water in this way and the industry is now striving to reduce these losses though pipe rehabilitation with the aid of the LEACS system.

In the case of INSURE, digital soil and climatic data, coupled with other spatially-referenced data such as national postcodes, are used to discriminate between groups of residential properties situated in areas of the country which have high as opposed to low risk of subsidence. In general, the growth in the availability of administrative data sets, such as UK Postcode and County boundaries, allows the financial institutions to manage their assets on the basis of the environmental risks that can now be identified by INSURE (VENTECH).

In planning environmental research during the next few years, it is important to remember data collection is an expensive process. However, experience shows that soil and land data, originally pertaining to the needs and requirements of the period when they were collected, have proved to be invaluable for tackling the environmental problems today.

**References**


Section 6: Land Evaluation
Section 6: Land Evaluation

Root zone capacity maps for Denmark based on the EU soil profile analytical database
N.H. Jensen, Th. Balstrøm, H. Breuning-Madsen

A soil information system as a tool for conservation and sustainable land use
A. Hagemeister, P. Meier, TH. Vorderbrügge

Using soil data to predict potential native woodland distribution in Scotland
W. Towers, D. C. Macmillan, S. Macleay
Introduction

The Soil Map of the European Communities at scale 1:1,000,000 (Commission of the European Communities, 1985) shows the distribution of soil types according to FAO-Unesco, 1974. More than 300 different map units are defined as combinations of various soil types. Each map unit is defined as a main soil type in combination with associations and inclusions.

Normally, the percentage share of the different soil types is listed, as well as the textural class and the slope classes of the main soil type in the associations. This soil map was originally digitized in 1986 as part of the CORINE project (Platou et al., 1989; Wiggins et al., 1985) in order to establish a geographical database system to assist environmental protection planning for the European Communities.

In 1986 a group of experts under the Computerization of Land Data Working Group was convened to advise the Commission on the establishment of a soil profile analytical database connected to the EU Soil Map (Madsen, 1991). The recommendations from that group formed the basis for the establishment of a soil profile analytical database, which was later defined by the Soil and GIS Support Group related to the MARS project (Madsen and Jones, 1995a).

The first step was to build a first-level database with analytical data describing the dominant soil types found on the EU Soil Map. Today, this Level 1 database covering most EU countries is available in two forms: one with standardized data for typical soil profiles (which may include estimated values according to common guidelines), and one with measured data. The standardized analytical database contains all the proposed information for the main soil types, whereas in the measured database some data can be missing. Data are given for farmland soils if agriculture existed on the main soil type.

According to the recommendations, the next step of the database development (called Level 2) will be to include data from soil types only present as associated soils. This work has now been completed for Denmark. Thus, it will be possible to produce thematic maps based on first-level information (main soil types within each mapping unit) only, or on second-level information.

This paper illustrates the difference in producing a root zone capacity (RZC) map of Denmark based on main soil types (first-level data) only, compared to including information from soil associations and inclusions as well (second level data).

The RZC is selected for this study because it is a function of important soil characteristics such as textural composition, organic matter and the structure of all horizons within the root depth. Furthermore, the RZC is important when assessing irrigation needs for Danish farmlands. During a typical Danish growing season, precipitation is normally less than the potential evapotranspiration. According to Madsen, Nørr and Holst (1992), the average precipitation deficit during a growing season (May to November 1956-1985) is between 16 mm and 131 mm for Denmark, depending upon the climatic conditions.
zone. Because of proper soil management, use of fertilizers and pesticides, the deficit of plant available water is the most important limiting factor to high yields on soils without shallow groundwater.

Methods and materials.

The EU soil map of Denmark.

In the decade after the elaboration of the first EU soil map of Denmark, extensive soil investigations have been carried out and recently a revised soil map has been elaborated (Madsen and Jensen, 1995; Madsen and Jensen, 1996). This soil map shown in Figure 1 is now part of the EU Soil Map. Its 16 map units are listed in Table 1 and the areal distribution of those is shown in Table 2.

Map unit 1 covers less than 1% of Denmark and is dominated by two large raised bogs in North Jutland and two bog areas on Zealand. Map unit 2 is the salt marsh areas in South-western Jutland and covers around 1%, too. Map unit 4 is found on younger marine forelands from the Litorina transgression era and on endiked areas. This map unit covers around 7%. Map units 5 to 11 are dominated by relatively well-drained clayey soils mainly found in the Weichsel glacial landscape in South-eastern Jutland and on the islands. They cover close to 43% of the area. Map unit 12 comprises soils in the clayey part of the Saale glaciation landscape in Western Jutland covering around 2%. Map units 13-15 are the sandy well-drained soils (40% of the total area). Map unit 13 is mainly situated on the outwash plains and on the sandy parts of the Saale glaciation landscape in Western Jutland west of the main stationary ice front during the Weichsel glaciation. Map unit 14 is mainly found in the Weichsel glaciation landscape in Northern Jutland. Map unit 15 is primarily located on the islands. Map unit 16 is found on coastal dunes (3%) and map unit 17 is found on seabottom sediments from the Yoldia transgression in Northern Jutland (2%).

EU soil profile analytical database for Denmark

With reference to the recommendations (Madsen and Jones, 1995a) the first level database should contain analytical data from the dominant soil types of the mapping units, only. The main soil types are also classified in relation to textural classes, so the data should be given for each soil type for each texture class. The data in the first level database should refer to soil types on agricultural land because the primary use is now to model and forecast yields of various crops. Only mapping units representing non-agricultural land should be given analytical data for non-arable conditions.

The composition of the map units covering Denmark is shown in Table 1. Here 16 map units dominated by 12 different main soil types are recognized: Od, Jeg-2/4, Ge-1, Be-2, Be-1, Lo-2, Lo-1, Lg-2, Ah-1, Po-1, Qc-1 and Rd-1. Analytical data from these main soil types are all available in the level 1 database. However, 15 of these map units have soil associations and inclusions which cover between 25 and 60% of the areas within the map units. Thus, beside the main soil types 17 additional soil types are represented as associations and inclusions: Oe, Gm-1, Gd-1, Re-1, Bg-2, Gm-2, Bk-2, Lg-1, Bg-1, Id-1, Ah-2, Dd-2, Gd-2, Dd-1, Bd-1, Ph-1 and Pg-1. Data from these profiles are included in the second level database, which is now ready for Denmark.

At this second level, data are given for soils on arable land where agriculture exists. The RZC-calculations made in this paper are based on information from soils with agricultural production except for soil types Rd-1 and Id-1.

An example of analytical data for a Danish soil profile is shown in Table 3.

Calculation of root zone capacity

To evaluate the differences between root zone capacity (RZC) for the various map units based on the first and second level databases, the plant available water content (PAW) within the effective rooting depth (ERD) was calculated for

1) the 16 map units found in Denmark based on the first-level database, which means that the main soil types represent the whole map unit;

2) the second-level data, which take into account the soil associations and inclusions and their areal share.

PAW was defined as the water content at 10 kPa (moisture content at field capacity) minus the water content at 1500 kPa (moisture content at the wilting point for most crops). RZC was
defined as the PAW within the ERD. Information about the water content at different tensions for each soil horizon and the ERD for winter wheat, spring barley and grass was all given in the analytical soil database as shown in the example, Table 2. Based on this information RZC was calculated for the first-level data (each dominant soil type on the EU soil map, Table 1). Afterwards RZC was calculated as a weighted sum in relation to the occurrence of associations and inclusions using the second-level information (table 1).

On soils with permanently high groundwater levels, it is assumed that the crops will be supplied with sufficient groundwater during the growing season to allow capillary rise. Therefore, RZC on these soils was set to 250 mm, which is the same level as the RZC found on relatively well-drained soils with the highest root zone capacity. Soil types with permanently high groundwater levels were the Histosols (Oe and Od) and the Gleysols (Gm, Gd and Ge) which cover approximately 7% of.

Results and discussion

Table 4 shows the RZC for each soil type found within the first- and second-level databases calculated for winter-sown wheat, spring-sown barley and grass. The highest root zone capacity is found for a winter-sown wheat on a Dystric Podzoluvisol and the lowest ones on a Dystric Regosol. Next to the soils with high groundwater level, the highest values are in general found in soils developed in the clayey morainic landscape. The lowest values were found in soils developed on glacial sand and soils on wind-blown sand.

In Table 5 the RZC values for winter wheat, spring-sown barley and grass have been calculated for each map unit according to the first- and second-level database information as a combination of Table 1 and Table 4. Furthermore, the absolute and relative differences between the first- and second-level calculations are shown in Table 5.

The largest deviation between the results from the two databases is found in map unit 5 for winter wheat, where the RZC based on the second-level database is 38 mm higher than that based on the first-level data. The highest deviations in percent are found on the mainly sandy map units, where deviations of more than 40% are found in 2 map units.

The average RZC for the whole country is 128 mm based on the Level 1 database and 136 mm based on Level 2. The average for all map units of the numeric difference between the two calculations is for winter wheat: 12 mm or 9%. The same difference for the map units with mainly sandy soils (map units 13-17) is 16 mm or 32%.

This overall tendency also holds true for the spring-sown barley, but for grass the RZC is clearly underestimated for most map units. As an example, Figures 2 and 3 show RZC for wheat calculated for Level 1 and Level 2 data respectively. Figure 4 shows the percentage relative difference for the RZC based on the Level 1 and Level 2 data.

Conclusion

From the results it can be concluded that the second-level database information gives a much more precise indication of the actual root zone capacity for each individual map unit within the EU Soil Map. Several map units dominated by sand will have a significantly larger root zone capacity when associations and inclusions of clayey soils and Histosols or Gleysols are used in the calculations.

The absolute differences between root zone capacity calculated for Level 1 versus Level 2 data were highest for winter wheat.

No doubt, from this point of view the second level data gives much more realistic values when calculating the actual available water content to plants for different soils. Therefore it is recommended that a second-level analytical soil database be compiled for all EU countries in the near future.
References:


Table 1: The definition of the 16 different map units on the revised EU Soil Map of Denmark.

<table>
<thead>
<tr>
<th>Map unit</th>
<th>Area in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:</td>
<td>Od (90%)</td>
</tr>
<tr>
<td></td>
<td>Oe (10%)</td>
</tr>
<tr>
<td>2:</td>
<td>Jeg-2/4 (100%)</td>
</tr>
<tr>
<td>4:</td>
<td>Ge-1 (40%)</td>
</tr>
<tr>
<td></td>
<td>Gm-1 (25%)</td>
</tr>
<tr>
<td></td>
<td>Gd-1 (25%)</td>
</tr>
<tr>
<td></td>
<td>Rd-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Re-1 (5%)</td>
</tr>
<tr>
<td>5:</td>
<td>Be-2 (50%)</td>
</tr>
<tr>
<td></td>
<td>Bg-2 (25%)</td>
</tr>
<tr>
<td></td>
<td>Qe-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Gm-2 (5%)</td>
</tr>
<tr>
<td></td>
<td>Lg-2 (10%)</td>
</tr>
<tr>
<td></td>
<td>Lo-2 (15%)</td>
</tr>
<tr>
<td></td>
<td>Bk-2 (10%)</td>
</tr>
<tr>
<td>6:</td>
<td>Be-1 (55%)</td>
</tr>
<tr>
<td></td>
<td>Lo-1 (20%)</td>
</tr>
<tr>
<td></td>
<td>Qc-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Gm-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Lg-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Bg-1 (10%)</td>
</tr>
<tr>
<td>7:</td>
<td>Lo-2 (50%)</td>
</tr>
<tr>
<td></td>
<td>Lg-2 (30%)</td>
</tr>
<tr>
<td></td>
<td>Qc-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Gm-2 (5%)</td>
</tr>
<tr>
<td></td>
<td>Be-2 (10%)</td>
</tr>
<tr>
<td>8:</td>
<td>Lo-1 (60%)</td>
</tr>
<tr>
<td></td>
<td>Lg-1 (20%)</td>
</tr>
<tr>
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<td>Qc-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Gm-1 (5%)</td>
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<tr>
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<td>Be-1 (10%)</td>
</tr>
<tr>
<td>9:</td>
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</tr>
<tr>
<td></td>
<td>Lg-2 (15%)</td>
</tr>
<tr>
<td></td>
<td>Id-1 (10%)</td>
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<tr>
<td></td>
<td>Qc-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Gm-2 (5%)</td>
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<tr>
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<td>Be-2 (5%)</td>
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<td>10:</td>
<td>Lg-2 (25%)</td>
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<td></td>
<td>Lo-2 (20%)</td>
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<tr>
<td></td>
<td>Ah-2 (15%)</td>
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<tr>
<td></td>
<td>Dd-2 (15%)</td>
</tr>
<tr>
<td></td>
<td>Be-2 (10%)</td>
</tr>
<tr>
<td></td>
<td>Gd-2 (10%)</td>
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<tr>
<td></td>
<td>Po-1 (5%)</td>
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<tr>
<td>11:</td>
<td>Lo-1 (25%)</td>
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<tr>
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<td>Lg-1 (20%)</td>
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<td>Ah-1 (15%)</td>
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<tr>
<td></td>
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<td></td>
<td>Gd-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Qc-1 (5%)</td>
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<tr>
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<td>Po-1 (5%)</td>
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<tr>
<td></td>
<td>Bg-1 (10%)</td>
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<td></td>
<td>Od (10%)</td>
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<tr>
<td></td>
<td>Po-1 (10%)</td>
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<tr>
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<td>Po-1 (45%)</td>
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<td></td>
<td>Ph-1 (30%)</td>
</tr>
<tr>
<td></td>
<td>Pg-1 (10%)</td>
</tr>
<tr>
<td></td>
<td>Qc-1 (10%)</td>
</tr>
<tr>
<td></td>
<td>Od (5%)</td>
</tr>
<tr>
<td>14:</td>
<td>Po-1 (50%)</td>
</tr>
<tr>
<td></td>
<td>Qc-1 (30%)</td>
</tr>
<tr>
<td></td>
<td>Pg-1 (10%)</td>
</tr>
<tr>
<td></td>
<td>Gd-1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Oe (5%)</td>
</tr>
<tr>
<td>15:</td>
<td>Qc-1 (80%)</td>
</tr>
<tr>
<td></td>
<td>Po-1 (15%)</td>
</tr>
<tr>
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<td>Ge-1 (5%)</td>
</tr>
<tr>
<td>16:</td>
<td>Rd-1 (90%)</td>
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<tr>
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<td>Re-1 (10%)</td>
</tr>
<tr>
<td>17:</td>
<td>Qc-1 (65%)</td>
</tr>
<tr>
<td></td>
<td>Po-1 (20%)</td>
</tr>
<tr>
<td></td>
<td>Od (10%)</td>
</tr>
<tr>
<td></td>
<td>Dd-1 (5%)</td>
</tr>
</tbody>
</table>

Table 2: Area distribution of the map units defined in table 1.

<table>
<thead>
<tr>
<th>Map unit</th>
<th>Area in %</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>6.7</td>
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<tr>
<td>5</td>
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<td>1.5</td>
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<td>7</td>
<td>23.0</td>
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<tr>
<td>8</td>
<td>5.0</td>
</tr>
<tr>
<td>9</td>
<td>0.1</td>
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<tr>
<td>10</td>
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<tr>
<td>13</td>
<td>20.8</td>
</tr>
<tr>
<td>14</td>
<td>14.1</td>
</tr>
<tr>
<td>15</td>
<td>5.2</td>
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<tr>
<td>16</td>
<td>2.9</td>
</tr>
<tr>
<td>17</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Table 3: Example of analytical data for a soil profile in Denmark extracted from the database.

Proforma I for Soil Analytical Data: Estimated

Soil name: Orthic Podzol
Country: Denmark
Groundwater level: Highest: 5 Lowest: 5 Landuse: Agriculture
Parent material: Outwash plain

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Texture</th>
<th>2-20</th>
<th>20-200</th>
<th>200-2000</th>
<th>Stones + Gravel</th>
<th>Structure</th>
<th>OM %</th>
<th>C %</th>
<th>CaCO3 %</th>
<th>Active CaCO3</th>
<th>pH(H2O)</th>
<th>EC</th>
<th>SAR</th>
<th>ESP</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-20</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>10</td>
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<td>5</td>
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<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.5</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>20-30</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>21</td>
<td>73</td>
<td>1</td>
<td>5</td>
<td>1.2</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.5</td>
<td>1</td>
</tr>
<tr>
<td>Els</td>
<td>30-50</td>
<td>2</td>
<td>4</td>
<td>34</td>
<td>57</td>
<td>1</td>
<td>1</td>
<td>1.9</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.1</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>50-200</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>39</td>
<td>58</td>
<td>1</td>
<td>0.2</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.0</td>
<td>1</td>
</tr>
</tbody>
</table>

Origin of Data

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Each Bases cmol +kg</th>
<th>Volumetric Water Content (%)</th>
<th>Total Porosity</th>
<th>Bulk Density</th>
<th>A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>3.0</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5-20</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5-50</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Origin of Data

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Crops</th>
<th>Winter-Sown Cereals</th>
<th>Spring-Sown Cereals</th>
<th>Short Grass</th>
<th>Bees</th>
<th>Olives</th>
<th>Maize</th>
<th>Cation</th>
<th>A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Effectiveness</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mean Total</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Root zone capacity (in mm) for the soil types shown on the EU-soil map of Denmark. The soil types are divided into those found as main soil types (Level 1 in the soil database) and those only found as associations or inclusions (included in Level 2 soil database).

Soil types included in the Level 1 database:

<table>
<thead>
<tr>
<th>Soil type</th>
<th>RZC, mm Winter wheat</th>
<th>RZC, mm Spring barley</th>
<th>RZC, mm Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Od</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Jeg 2-4</td>
<td>153</td>
<td>153</td>
<td>153</td>
</tr>
<tr>
<td>Ge-1</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Be-2</td>
<td>181</td>
<td>151</td>
<td>105</td>
</tr>
<tr>
<td>Be-1</td>
<td>157</td>
<td>119</td>
<td>83</td>
</tr>
<tr>
<td>Lo-2</td>
<td>189</td>
<td>159</td>
<td>114</td>
</tr>
<tr>
<td>Lo-1</td>
<td>168</td>
<td>136</td>
<td>88</td>
</tr>
<tr>
<td>Lg-2</td>
<td>208</td>
<td>174</td>
<td>123</td>
</tr>
<tr>
<td>Ah-1</td>
<td>152</td>
<td>120</td>
<td>73</td>
</tr>
<tr>
<td>Po-1</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Qc-1</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Rd-1</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

Additional soil types included in the Level 2 database:

<table>
<thead>
<tr>
<th>Soil type</th>
<th>RZC, mm Winter wheat</th>
<th>RZC, mm Spring barley</th>
<th>RZC, mm Grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oe</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Gm-1</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Gd-1</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Re-1</td>
<td>73</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>Bg-2</td>
<td>180</td>
<td>148</td>
<td>105</td>
</tr>
<tr>
<td>Gm-2</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Bk-2</td>
<td>187</td>
<td>155</td>
<td>107</td>
</tr>
<tr>
<td>Lg-1</td>
<td>201</td>
<td>167</td>
<td>118</td>
</tr>
<tr>
<td>Bg-1</td>
<td>186</td>
<td>154</td>
<td>122</td>
</tr>
<tr>
<td>Id-1</td>
<td>189</td>
<td>159</td>
<td>114</td>
</tr>
<tr>
<td>Ah-2</td>
<td>174</td>
<td>159</td>
<td>99</td>
</tr>
<tr>
<td>Dd-2</td>
<td>254</td>
<td>210</td>
<td>166</td>
</tr>
<tr>
<td>Gd-2</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Dd-1</td>
<td>148</td>
<td>120</td>
<td>92</td>
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<tr>
<td>Bd-1</td>
<td>162</td>
<td>134</td>
<td>101</td>
</tr>
<tr>
<td>Ph-1</td>
<td>70</td>
<td>70</td>
<td>70</td>
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<tr>
<td>Pg-1</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
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</table>
Table 5: The average root zone capacity (RZC) for each map unit in the EU-soil map of Denmark according to the Level 1 and Level 2 databases calculated from a combination of Table 1 and Table 3. Furthermore, the absolute difference calculated as the RZC, Level 1 minus RZC, Level 2. The difference in percent is calculated in relation to RZC, Level 1.

**Winter-sown wheat:**

<table>
<thead>
<tr>
<th>Map unit</th>
<th>Soil unit</th>
<th>RZC, mm Level 1</th>
<th>RZC, mm Level 2</th>
<th>abs. diff. mm</th>
<th>%diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Od</td>
<td>250</td>
<td>250</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2 Jeg-2/4</td>
<td>153</td>
<td>153</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4 Ge-1</td>
<td>250</td>
<td>230</td>
<td>-20</td>
<td>-8</td>
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</tr>
<tr>
<td>5 Be-2</td>
<td>181</td>
<td>219</td>
<td>38</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>6 Be-1</td>
<td>157</td>
<td>164</td>
<td>7</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>7 Lo-2</td>
<td>189</td>
<td>190</td>
<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>8 Lo-1</td>
<td>168</td>
<td>172</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>9 Lo-2</td>
<td>189</td>
<td>171</td>
<td>-18</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>10 Lg-2</td>
<td>208</td>
<td>199</td>
<td>-9</td>
<td>-4</td>
<td></td>
</tr>
<tr>
<td>11 Lo-1</td>
<td>168</td>
<td>161</td>
<td>-7</td>
<td>-4</td>
<td></td>
</tr>
<tr>
<td>12 Ah-1</td>
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<td>156</td>
<td>4</td>
<td>2</td>
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<tr>
<td>13 Po-1</td>
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<td>66</td>
<td>16</td>
<td>32</td>
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</tr>
<tr>
<td>14 Po-1</td>
<td>50</td>
<td>71</td>
<td>21</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>15 Qc-1</td>
<td>55</td>
<td>64</td>
<td>9</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>16 Rd-1</td>
<td>31</td>
<td>35</td>
<td>4</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>17 Qc-1</td>
<td>55</td>
<td>78</td>
<td>23</td>
<td>41</td>
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</tbody>
</table>

**Spring-sown barley:**

<table>
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<th>Map unit</th>
<th>Soil unit</th>
<th>RZC, mm Level 1</th>
<th>RZC, mm Level 2</th>
<th>abs. diff. mm</th>
<th>%diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Od</td>
<td>250</td>
<td>250</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2 Jeg-2/4</td>
<td>153</td>
<td>153</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4 Ge-1</td>
<td>250</td>
<td>230</td>
<td>-20</td>
<td>-8</td>
<td></td>
</tr>
<tr>
<td>5 Be-2</td>
<td>151</td>
<td>185</td>
<td>34</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>6 Be-1</td>
<td>119</td>
<td>131</td>
<td>12</td>
<td>10</td>
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<tr>
<td>7 Lo-2</td>
<td>159</td>
<td>162</td>
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<tr>
<td>8 Lo-1</td>
<td>136</td>
<td>142</td>
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<td>4</td>
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</tr>
<tr>
<td>9 Lo-2</td>
<td>159</td>
<td>146</td>
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<td>-8</td>
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</tr>
<tr>
<td>10 Lg-2</td>
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<tr>
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<td>-2</td>
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<tr>
<td>12 Ah-1</td>
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<td>132</td>
<td>12</td>
<td>10</td>
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</tr>
<tr>
<td>13 Po-1</td>
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<td>66</td>
<td>16</td>
<td>32</td>
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</tr>
<tr>
<td>14 Po-1</td>
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<td>71</td>
<td>21</td>
<td>42</td>
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<tr>
<td>15 Qc-1</td>
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<td>9</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>16 Rd-1</td>
<td>31</td>
<td>35</td>
<td>4</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>17 Qc-1</td>
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<td>77</td>
<td>22</td>
<td>40</td>
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</tbody>
</table>
**Grass:**

<table>
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<th>Soil unit</th>
<th>RZC, mm level 1</th>
<th>RZC, mm level 2</th>
<th>abs. diff. mm</th>
<th>%diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Od</td>
<td>250</td>
<td>250</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Jeg-2/4</td>
<td>153</td>
<td>153</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Ge-1</td>
<td>250</td>
<td>230</td>
<td>-20</td>
<td>-8</td>
</tr>
<tr>
<td>5</td>
<td>Be-2</td>
<td>105</td>
<td>134</td>
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<td>27</td>
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<tr>
<td>6</td>
<td>Be-1</td>
<td>83</td>
<td>97</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>Lo-2</td>
<td>114</td>
<td>120</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>Lo-1</td>
<td>88</td>
<td>100</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>Lo-2</td>
<td>114</td>
<td>110</td>
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<td>-3</td>
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<td>131</td>
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<td>6</td>
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<td>Po-1</td>
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<td>15</td>
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<td>64</td>
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</tr>
<tr>
<td>16</td>
<td>Rd-1</td>
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<td>35</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>Qc-1</td>
<td>55</td>
<td>75</td>
<td>20</td>
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</table>
Figure 1: The revised EU soil map of Denmark.
Figure 2: Root zone capacity for winter sown wheat based on Level 1 data.
Figure 3: Root zone capacity for winter sown wheat based on Level 2 data.
Figure 4: Relative difference in root zone capacity for winter-sown wheat (based on Figure 2 and Figure 3).
A soil information system as a tool for conservation and sustainable land use

Summary

As a result of the public discussion on soil protection, there has been an increasing demand for soil data, and availability of and access to the data now have increasing priority in earth science studies.

To meet this need, the Hessische Landesamt für Bodenforschung (Geological Survey of Hesse) has set up a Soil Information System for Hesse, called HESBIS (Hessisches Bodeninformationssystem). This is one of a number of branch geoinformation systems that includes geology, soils, hydrology etc.

The main areas of concern of the soil branch are:

- the analytical processing of pedological data (ground water recharge),
- the influence of changing land use from agricultural to grassland on the amount of ground water recharge,
- the idea of a soil condition register.

Introduction

Soil protection and different aspects of sustainable land use need information on the state of soil as one of the basic components of our environment as well as information on different consequences of regional planning activities.

By combining the information from soil maps and geological maps, data on land use, climate and relief, GIS technology allows the processing of relevant data for soil protection in different regions. Soil physical data (e.g. plant available water capacity in the rooting zone) and methods of analysis (e.g. estimating the rate of water leakage according to land use) as components of a soil information system enable us to give information on different functions of soil (e.g. influence on the rate of ground water recharge) for a whole region.

In the future, the most important task of a soil information system will be the estimation of the consequences of different planning activities on soil and its functions. Therefore, the consequences of a potential change of arable land into grassland on the rate of water leakage were explored by Hagemeister (1995) for a region on the topographical map at 1:25,000 scale, sheet 6216 (Gernsheim). For this work, he combined and analysed soil physical data and data on relief, land use (Landsat TM) and climate by using the GIS ARC/INFO. One of the consequences of changing arable land into grassland is a clearly reduced rate of ground water recharge.

For the same region, the data on the content of toxic agents (heavy metals and organic pollutants) in soil were analysed in terms of exceeding limiting values, published by Eikmann and Kloke (1991) and in the so-called Netherlands List (1994). Furthermore, background values had been published by LABO (Joint Federal Study Group for Soil Protection). This paper differentiates between background values according to land use, density of industry and population. Different systems for classifying the substratum in neighbouring states (Rhineland-Palatinate, Hesse) give different frequencies of exceeding the background values. The results of comparing measured data with background values according to these different systems are presented.

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Structure of the soil information system

At their meeting on 16-17 November 1989 the German Environment Ministers recommended that the proposal for setting up soil information systems prepared by the “Basic Information on Soil Protection” working group should be adopted by the individual federal state. Owing the complexity of the problem to be tackled, the soil information system as a part of the complex environmental information system (LABO, 1995a; Vinken, 1992), is to be subdivided as follows:

- basic geoscientific data
- anthropogenic impact on the soil
- nature and landscape protection.

The state Geological Survey is responsible for setting up an information system to provide basic geoscientific data. This system consists of a “steering system” (which records and controls the handling of methods and data) and information systems for the different geoscientific disciplines, called “branch information systems”.

The concept of handling databases and methods for soil protection by the branch information system pedology has been described by Heineke et al. (1995).

Database of branch information system pedology

The database is divided into spatial data and information about soil properties. The main sources are listed below (see also Figure 1).

- soil mapping at different scales (1:25,000, 1:50,000, 1:200,000)
- profile data from the investigation of the soil survey (point data)
- data from laboratory analysis
- data from the soil monitoring program

Two examples, marked in the above figure, the practical application ground water recharge and the Soil Condition Register of Gernsheim, as an integral part of the Hessian Soil Information System, will be discussed in detail later.

Geography of the test site and its main soil landscapes

The test site, defined by the topographical map 1:25,000 sheet 6216 Gernsheim, is located in the upper northern Rhine valley about 10 km north of Worms. The area, described by the digital “Bodenkarte 1:50,000 der nördlichen Oberheinebene” (Soil map at 1:50,000 scale of the northern Upper Rhine area) (Weidner 1990), can be separated into three different soil landscapes:

- the mountain area of the ‘Rheinhessisches Tafel- und Hügelland’ with soils on loess (very western part),
- the two pleistocene terraces with dominant sandy soils (‘Braunerde’ [Cambisol], and ‘Parabraunerde’ [Luvisol])
- a middle zone with hydromorphic soils such as ‘Niedermoor’ [Low bog soil],’ Auengley’ [Fluvio-Eutric Gleysol] and ‘Brauner Auenboden’ [Eutric Fluvisol] (see Map 1, Appendix).

The northern upper Rhine valley is characterized by a warm to very warm and dry climate with mild winter temperatures (0.9 °C in January) and summer temperatures of 19.3 °C in July. The average annual precipitation rate is about 667 mm, of which 65% falls during the summer months April to September.

The test site is a sparsely-populated rural district with predominantly agricultural land use. The main crops are cereals, maize, sugar beet, potatoe, onion, and on the west bank of the Rhine only, asparagus and grape.

The whole upper Rhine valley and especially the test site are outstandingly suitable for the exploitation of ground water which is pumped up from three main aquifers.

Examples of applications

Ground water recharge

The study of ground water recharge is a practical application of a soil information system as a tool for soil protection, sustainable land use and protection of the natural groundwater resource. At the same time this application demonstrates the necessity of combining a high number of input data from various geoscientific sources (pedology, geology, climatology, geomorphology, etc.) in models and methods that will fulfil the increasing demands of complex environmental information for planning purposes. Therefore, a soil information system requires not only a suitable database, complemented by so-called external geoscientific data, but also a method base in which methods, modules and algorithms...
are stored and documented in a uniform structure.

**Purpose of the investigation**

Spatial information concerning the ground water recharge for an extensive region are essential for the regional water management. This becomes clearly recognizable in relatively arid regions of Germany, like the upper Rhine valley, where negative climatic water balances are common. The high exploitation of ground water (for drinking water supply) in the upper Rhine valley results mainly from the huge demand from the urban agglomerations of the Rhine-Main region. If the exploitation of ground water exceeds the recharge rate for a longer period, it will lead to a lower ground water level which damages ecologically-important biotopes, like the low-lying bog-soil. Those low-lying bog-soil localities, mainly in ancient meander arcs, are called ‘Ried’ and once gave their name to the entire region.

![Figure 1. Structure of the Hessian Soil Information System](image)

*) Soil maps
Modelling and steps of data processing

A suitable numerical model for obtaining spatial information on ground water recharge at a medium planning scale of 1:50,000 is that of Renger and Strebel (1980). The following input data sets are combined in empirical equations:

- soil data set: storage capacity of the soil expressed by the total amount of plant available water in the rooting zone
- climate data set: regionalized precipitation and evapotranspiration
- land use data set
- relief data set: slope exposure (aspect) and slope angle.

However, some qualifications of the model have to be considered in such a way that the model is only applicable:

- on locations with flat relief where the surface run-off can be neglected,
- on locations without stagnant soil water conditions.

For locations under forest, the ground water recharge can only be approximated, because the soil-relevant parameter ‘total amount of plant available water’ is not considered in the algorithm. The yearly amount of soil water which leaves the rooting zone and penetrates through the unsaturated zone into the upper aquifer is simply described as a function of precipitation, evapotranspiration and the storage capacity of the soil. The parameters of relief, land use and vegetation cover modify the process, which is taken into account by three empirical equations differentiated between arable land, grassland and forest locations. Beyond that, a differentiation is made between the precipitation during the vegetation growth period and that during the winter period. This considers that the process of ground water recharge happens predominantly during the winter months October to March, when the soils under arable land are bare and consequently the evapotranspiration is low.

The individual steps of data processing are summarized in the following flowchart (Figure 2). All spatial operations are realized with the GRID module of ARC/Info 7.03. The geometric resolution of the grid cells is 30 by 30 m, fitting on the resolution of the remotely-sensed data from Landsat TM.

The modelling database

The spatial database can be divided into pedological data (left column of the flowchart), climatological data (right column of the flowchart), geomorphological and land use data (central part of the flowchart).

Pedological data

For the investigation of ground water recharge, the basic soil data consist exclusively of physical soil properties. These are: soil texture, soil type, bulk density, content of coarse soil, rock layer, peat type and content of organic matter. All soil properties exist for each horizon of each soil type. Some basic physical soil properties, like soil texture, horizon thickness, content of coarse soil, etc. were captured during the soil mapping itself. The more complex soil properties, like field capacity, plant available water, pore volume, depth of the rooting zone, etc. can be derived from those basic soil properties. All data are stored in related tables organized into a soil library, and can be connected with the geometry (polygons) of the soil map.

Climatological data

In general, climatic data can be provided from the DWD (Deutscher Wetterdienst, Offenbach) in point data quality. These point data must be extrapolated to spatial data using an appropriate geostatistical algorithm such as Kriging. Considering the high spatial variability of the precipitation and the sensitivity of this input variable within the model, this extrapolation has to be done very carefully. The potential evapotranspiration can be calculated by several formulae, from which the Penman formula is the preferred choice. The data storage is analogous to the soil database. For the present investigation, a data set covering a 30-year period from 1961 to 1990, from 17 meteorological stations situated in the upper Rhine valley, was available.

Geomorphological data

Most of the parameters determining the ground water recharge are directly relief correlated (e.g. precipitation and evapotranspiration rate, spatial distribution of soil types). Besides that, there are other interrelations between relief, surface run-off and ground water recharge. Therefore, the relief parameters slope angle and exposure (aspect) are very important and must be considered within the model. This was done by using a DEM (digital elevation model) with a geometrical resolution of 20 m x 20 m, published by the LVA Rhineland-Palatinate. The
The determination of the relief parameters was finally realized with the surface modelling module of ARC/Info based on a TIN (triangulated irregular network).

Land use data

Land use data are essential within the soil information system; they are necessary to take the specific evaporation of different land covers into account by simulating the water balance of the landscape. Generally, land use data can be extracted from remote sensing data (Map 2a, Appendix) or from ATKIS (Amtlich Topographisch-Kartographisches Informationssystem) (Map 2b, Appendix). One of the advantages of remote sensing data is their topicality and the ability to distinguish different crops within the class 'arable area', which represents about 70% of the entire test site area. On the other hand, the advantage of using vector-based ATKIS data is the precision of boundaries. In Map 2a (Appendix) the results of a land use classification from a Landsat TM scene using the conventional Maximum Likelihood Classifier are shown. Map 2b (Appendix) makes clear that ATKIS data are not yet available in some states of Germany.

The effect of different climatic conditions on the ground water recharge

To investigate the effects of the climate, three climatic scenarios were calculated:

- dry years with distinctly less precipitation (lower than average value minus standard-deviation);
- wet years with distinctly more precipitation (greater than average value plus standard-deviation).

For the dry period scenario the hydrological year 1976 was chosen. The year 1987 characterized a typical wet period.

Results

First and foremost the ground water recharge depends on the regional precipitation pattern which is extremely variable in space and time. The annual precipitation rate varies from 390 mm in the dry year 1976 to 720 mm in 1987, with an average of 617 mm according to ground water recharge rates of -59 mm in 1976, 197 mm in 1987 and an average rate of 123 mm (all values represent the spatial average of the entire test site). The results are summarized below (Table 1):
Table 1: Comparison of precipitation, evapotranspiration and ground water recharge

<table>
<thead>
<tr>
<th>Period / year</th>
<th>Precipitation</th>
<th>Evatranspiration</th>
<th>Ground water recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961 - 1990</td>
<td>617 mm</td>
<td>716 mm</td>
<td>123 mm</td>
</tr>
<tr>
<td>1976 (dry year)</td>
<td>390 mm</td>
<td>981 mm</td>
<td>-59 mm</td>
</tr>
<tr>
<td>1987 (wet year)</td>
<td>720 mm</td>
<td>548 mm</td>
<td>197 mm</td>
</tr>
</tbody>
</table>

Regarding the spatial variations, strongly south-north orientated zones with equal annual precipitation rates can be found. The local maximum is in the very eastern parts, the minimum in the very western parts of the test site. On average, the difference between both parts is about 120 mm/a (Map 3, Appendix). Concerning the evapotranspiration rate, only a temporal variability could be found (Table 1).

Besides that, the different soil landscapes within the test site contribute to a distinct spatial differentiation of the ground water recharge. In spite of the high average storage capacity of 190 mm, there are some soil types with distinctly higher permeability rates. These soils, represented by ‘Braunerden’ (Cambisols) on drift sand or ‘Parabraunerden’ (Luvisols), are predominantly found on the pleistocene terraces, where the ground water recharge reaches its maximum (east of the river Rhine). The lowest recharge rates are found under soils with capillary rise, like the low bog soils, situated in the ancient meander arcs of the river. Map 4a (Appendix) (left side) illustrates the results of a typical wet period represented by the year 1987 (positive climatic water balance of 172 mm). During extreme dry periods, for example 1976, with a strongly negative climatic water balance of -590 mm, most of the grid cells have negative values for the ground water recharge (Map 4a, appendix, right side). This is comparable to a loss of soil water to the atmosphere. The higher ground water recharge in the eastern zones of the test site can be attributed to the spatial gradient of the climatic water balance already discussed.

**The effect of a simulated change of land use**

At least the model enables the individual user to simulate different scenarios by changing the land use input data set. Due to the fact that the ground water recharge rate decreases in the order arable land > grassland > forest, extensive changes of land use pattern have outstanding effects on the regional water balance. An example of these effects is given by a simulated switch of only 1850 ha arable land to grassland. The longer duration of the vegetation period of grassland compared with tilled areas (bare soil during several months of the year) results in a significantly higher evapotranspiration rate and therefore a reduced ground water recharge rate. The loss of ground water recharge caused by such interference could amount to an average of 18 mm, equal to two million litres if projected over the entire test site. The sub-region where the land use was converted from arable land to grassland is marked by hatches (Map 4b, Appendix).

**The Gernsheim Soil Condition Register**

A Soil Condition Register is also an essential tool for the scientifically accurate processing, analysis and presentation of data relating to the current levels of pollution in different soils. The most recent data concerning pollution levels due to heavy metals and organic pollutants in the area (defined by the topographical map TK25 sheet 6216 Gernsheim) have been collated from technical reports, maps from the geological-pedological survey of the Federal state of Hesse and a diploma thesis. Given the scarcity of resources, only the introduction of a standardized data structure and the opportunity to examine data from several different projects permit the avoidance of overlapping projects, the identification of gaps in data collection and the development of strategies for sampling and analysis to meet situation-specific requirements. Indeed, the Hessian Soil Information System has as its aims not only the collation of analogous data and the assessment of existing methods of analysis, but also the continuous expansion and updating of its database.
Abbreviations used in the flowchart:
- GWN: ground water recharge
- nFK: available water capacity
- Wpfl: plant available water
- dB: depth of the rooting zone
- ta: period of capillary rise
- KR: rate of capillary rise (in mm/day)
- KA: total amount of capillary rise (in mm)
- Wpfl: plant available water
- ETP: potential evapotranspiration
- N\textsubscript{win}: precipitation during the winter period
- N\textsubscript{veg}: precipitation during vegetation period

(*) Parameter modified by

- \(\Theta\) increases GWN
- \(\bigcirc\) decreases GWN
- \(\bigodot\) modifies GWN
Extent of applicability of the data

When interpreting measurements of heavy metals and organic pollutants in soils, it must be borne in mind that all data are fundamentally site-specific. Plotting the sample sites (Maps 5a, 5b, 6a and 6b, Appendix) revealed great variability in sampling density. It will be seen that the sample density is higher in those parts of the study area which are in Hesse, due to their proximity to the HLFB (Geological Survey of Hesse). Within that segment there are specific concentrations resulting from particular surveys carried out in those localities.

In an attempt to extrapolate data over the entire area, the individual measurements were combined with topographical background information. However, taking into account the units identified by Weidner (1990) in his “Bodenkarte 1:50,000 der nördlichen Oberrheinebene” (Soil map at 1:50,000 scale of the northern Upper Rhine area), it became clear that the present state of the Gernsheim Soil Condition Register does not permit any conclusions to be drawn about levels of soil pollution over wider areas. One of the causes is the unhomogenous structure of the study area (as a result of the frequent changes of substrate in the meander systems of the river Rhine).

The use of listed values to assess the data

The readings for heavy metals (but not those for organic pollutants) were evaluated not only for their applicability but also in comparison with listed values from Eikmann and Kloke (1991), the Netherlands List (1994) and those from the LABO (Joint Federal Study Group for Soil Protection, 1995). Since the chosen map, TK 25 sheet 6216 Gernsheim, covers areas of similar size in both Rhineland-Palatinate and Hesse, it is particularly appropriate for highlighting the problems of background values specific to federal states and substrates, as can be seen from the application of the LABO values.

Comparison of the readings with reference and intervention values from the Netherlands List (1994)

Comparison of the readings for heavy metals with the reference and intervention values of the Netherlands List (1994) showed that 54 horizons exceed the reference value (‘S-Wert’) for at least one element. None of them exceeded the intervention value. As can be seen from Map 5b (Appendix), the profiles where the reference value is exceeded in one horizon, as well as many of those where it is exceeded in several, come mainly from areas which are both subjected to flooding and in close proximity to the Gernsheim-Biebesheim industrial estate (cf. profiles 102, 104 and 105). The analysis also showed that greater contents of heavy metals are predominantly found in A-horizons (Hagemeister and Meier, 1995). This would suggest that the heavy metal deposits were caused by human activity. There are two different sources for these deposits.

- Deposition of dissolved pollutants, which have been adsorbed onto suspended material, during flooding of the meadows. The distribution of pollutants on the flooded meadowland is determined by the rate of flow and the degree of aggregation of the suspended material. In addition, the level of deposition of pollutants depends on the mix of particle size and the organic content of the suspended matter.
- Deposition of polluted particles from the atmosphere (in both humid and dry conditions). The level of deposition is essentially dependent on the direction of...
the prevailing wind and the distance from the sources of the emissions.

Comparison of the readings with background and reference Values from LABO (1995)

The background and reference values from LABO (Joint Federal Study Group for Soil Protection) which were published in 1995 represent an advance on previously published values. They consist both of tables valid for the Federal Republic of Germany as a whole and others valid for individual federal states. The median (i.e. the 50th percentile) of the recorded values is defined as the background value, that is the natural content of a heavy metal in the soil. Values above the 90th percentile are taken to indicate profiles with heavy pollution of human origin. It is important when applying the LABO values that only measurements from samples from A-horizons should be considered in the analysis. In addition, the samples must be classified according to settlement pattern, type of substrate and land use. However, substrates are grouped differently for the different federal states. This means that an attempt at an interpretation involving more than one federal state raises serious problems. Since the chosen map, TK 25 sheet 6216 Gernsheim, covers areas of similar size in two federal states, the Soil Condition Register data for the whole area were compared twice with the LABO values, first according to the criteria for Hesse and then according to those for Rhineland-Palatinate. For this purpose the substrates in the study area were grouped in accordance with the following LABO categories (Table 2).

Table 2: Categories of substrate in two different federal states according to LABO

<table>
<thead>
<tr>
<th>Hesse</th>
<th>Rhineland-Palatinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>sands (drift sands, valley sands, etc.) and terrace sands</td>
<td>drift sand</td>
</tr>
<tr>
<td>loess, loess loam, colluvium</td>
<td>meadow / terrace sands</td>
</tr>
<tr>
<td>meadow loam</td>
<td>loess loam</td>
</tr>
<tr>
<td>high tide loam</td>
<td>meadow loam</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Given that only A-horizons are being considered, the amount that can be said about pollution from human sources is already strictly limited. Obviously, the grouping of these substrates in this manner results in a further considerable loss of information. Maps 6a and 6b (Appendix) make it recognizable that the Hessian classification scheme provides a better representation of the physical features of the study area. In particular, the Rhineland-Palatinate classification does not differentiate on the east of the map between the high tide loams of the Pleistocene terraces and the meadow loams.

Classification criteria from LABO (1995) correspond only to a limited extent to the pedological realities. Thus a comparison of data from more than one federal state produces an unsatisfactory result due to the use of categories with differing compositions.

Conclusions

The processing of pedological data to make interpretations of soil maps for the realization of concepts for sustainable land use, land management and soil protection and monitoring requires not only the availability of the necessary data within an efficient information system, but also well-defined and tested methods that must be applied from a digital base.

The main objectives of such investigations are:

- to quantify the validity of pedotransfer functions for estimating soil physical properties,
- to compare existing approaches on a common database
- to obtain a ranking according to the accuracy of the predicted values.

In addition to this, more methods, guidelines and instructions have to be standardized in the future, such as:

- for data collecting:
  - field sampling instructions
• generalization procedures for maps
• for analyses:
  • adjustment of classification diagrams
  • supplement for norms, standards and complete standardized research programs
• for input of external data:
  • adjustment of data on land use, climate and relief
  • instructions for data storage and visualisation.

These are themes that will have to be dealt with by a soil information system in the future.

Acknowledgements

The scientific activities concerning the Soil Condition Register Gernsheim (Hagemeister, A. and Meier, P., 1995) were financially supported by the Hessisches Ministerium des Inneren und für Landwirtschaft, Forsten und Naturschutz, Wiesbaden. The results and maps presented on the theme of ground water recharge originate from the diploma thesis of A. Hagemeister (1995): Ground Water Recharge as a Function of Soil Condition, Climate, Land Use and Relief, as applied to the test site of the TK 25 sheet 6216 Gernsheim; Geographical Institute of the Johannes Gutenberg University, Mainz. All fees and operating expenses were paid by the Geological Survey of Hesse, Wiesbaden.

References


Map 1: Soil map of the test site (TK25 sheet 6216 Gernsheim)
Map 2a: Land use classification from Landsat TM5 scene
Map 2b: Land use based on ATKIS data
Map 3: Zones with equal climatic water balances
Map 4a: Comparison of the groundwater recharge by two climatic scenarios
Map 4b: Comparison of the groundwater recharge by a simulated change of the land use pattern
Map 5a: Comparison of the readings with listed values from Eikmann and Kloke (1991)
Map 5b: Comparison of the readings with reference and intervention values from the Netherlands Lists (1994)
Map 6a: Comparison of the readings with background and Reference Values from LABO 81995b according to the criteria for Hessen
Map 6b: Comparison of the readings with background and Reference Values from LABO 81995b according to the criteria for Rhineland-Palatinate
Using soil data to predict potential native woodland distribution in Scotland

Introduction

Over the last four thousand years the natural woodland cover of Scotland has been reduced to less than 5% of its original distribution, through clearance for agriculture, timber harvesting, over-grazing, and climate change. In recent years, in contrast to the production-driven forestry policies of the past 50 years, there have been distinct changes in strategy towards multi-purpose forestry involving an increased use of native species. However, relatively little is known about the potential for native woodland types.

Based on our understanding of the relationship between native woodlands and site conditions, this paper describes how soils and land cover data have been integrated within a Geographic Information System, and subsequently used to predict the potential extent and distribution of native woodland types.

The study area

The study area is the core of the Cairngorms area of the Scottish Highlands, and extends to over 5000 km$^2$, with an altitude range from around 200 m to over 1200 m. Much of the the area is protected by national conservation designations and its international importance is evidenced by its candidature as a World Heritage site. Natural woodlands once covered 80% of the study area, but the percentage of semi-natural woodland cover is now less than 10% (Cairngorms Working Party, 1992).

The soils of the area are largely developed on acid parent materials, with leaching and podzolization being the principal soil forming factors (Walker et al., 1982). These podzolic soils show a strong altitudinal zonation, with humus-iron and cultivated podzols on the lowest ground, succeeded by peaty podzols, sub-alpine and alpine podzols with increasing altitude. Most of the soils show moderate to free drainage. Peat is extensive on upland plateaux and in some broad basins in the valley bottoms. The vegetation is dominated by semi-natural communities, largely heather moorland on the lower hills, with peatland and montane vegetation at higher altitudes. Coniferous forestry and improved agricultural land are locally important below about 500 m.

Data sources

The two data sources comprise the 1:250,000 scale national soils map (Walker et al., 1982) and the 1:25,000 scale Land Cover of Scotland 1988 (LCS88) data set (MLURI, 1993). These two data sources have been overlaid in a Geographic Information System (GIS) to produce a number of soil/land cover combinations.

The criteria used to separate the soil map units on the 1:250,000 scale soil map are: soil parent material (parent rock and mode of formation), component soils and topography (degree of rockiness and slope). Although the soil classification system adopted in Scotland (MISR, 1984) is typological rather than definitive in character (Butler, 1980), the soil properties important for the growth of trees, such as moisture status and nutrient regime, can be readily inferred.

The LCS88 data set (MLURI 1993) is the first-ever national census of land cover in Scotland.

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and was captured from the manual interpretation of aerial photographs. The hierarchical classification allows for 126 single land cover features, and well over 1000 mosaic categories were also identified.

**Methods**

Within the National Vegetation Classification (NVC) (Rodwell et al., 1991), there are nineteen major types of woodland, each with a distinctive mix of trees, shrubs, field and ground flora. Although the classification has been compiled for Britain, there are often strong affinities with woodlands in the rest of continental Europe (Aune, 1977). There are established relationships between these woodlands and existing site factors such as climatic zone, geology, soil type, topography and the existing vegetation.

Based on this knowledge and understanding, a series of decision rules were developed to predict which of the NVC woodland types would occur on the range of geology/soil/topography/land cover combinations generated from the integration of the two datasets. Some examples taken from this decision matrix are given in Table 1.

It must be stressed that although there is considerable knowledge about the relationships between NVC woodland types and site conditions, this knowledge requires careful “translation” when applied to the integrated data set derived from the soils and land cover data used in this study. By the very nature of what these data attempt to describe, they are imprecise and consequently, some expert judgement, interpretation and an underpinning understanding of the opportunities and constraints of the data are required.

**Table 1: Examples of decision rules for prediction of NVC Woodland Class**

<table>
<thead>
<tr>
<th>Geology</th>
<th>Soils1</th>
<th>Terrain1</th>
<th>Existing Vegetation2</th>
<th>Predicted NVC Woodland Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>granite</td>
<td>Podzols, peaty podzols</td>
<td>Non-rocky hill slopes</td>
<td>Calluna vulgaris</td>
<td>Scots pine woodland with heather</td>
</tr>
<tr>
<td>mica schist</td>
<td>Brown earths</td>
<td>Rugged terrain and steep valley sides</td>
<td>Acid grassland, bracken scrub</td>
<td>Upland oak-birch woodland</td>
</tr>
<tr>
<td>granite</td>
<td>Alpine podzols, lithosols, rankers</td>
<td>Bouldery or rocky mountain plateaux</td>
<td>Montane vegetation and bare ground</td>
<td>Unsuitable for woodland cover</td>
</tr>
</tbody>
</table>

1 From 1:250,000 soils map
2 From Land Cover of Scotland 1988 dataset

**Results and discussion**

Approximately 60% of the area has the potential to sustain a woodland cover, a further 20% has the potential to have scrub or scattered tree cover, and the remainder is predicted to be unsuited to any tree or scrub cover. This corresponds well to the estimate of former woodland cover for the Cairngorm Partnership Area (Cairngorms Working Party, 1992).

Scots pine woodland with heather has the greatest potential in the study area, reflecting the dominance of acid, freely-drained, podzolic soils under heather moorland. Upland oak-birch woodland types are predicted to have the potential to cover over 15% of the study area and are associated with the better soils, including land which is currently improved farmland. Although the soils have been mapped as podzols, they effectively behave as acid brown earths; the integration of the land cover data has added valuable extra information about these soils and allowed a more comprehensive and realistic assessment.

The scrub categories, largely juniper on the drier sites and scattered stunted trees on the exposed peatlands, are found at altitudes of 500-800 metres between the true woodland zone and the montane environment of the high tops. Land unsuited for woodland or scrub is the most extensive single category, which is understandable given the extreme climatic conditions of the mountain area and the low biological production potential of the acid soils.
Only limited validation was possible in this project due to the lack of existing climax vegetation. Even so, 65% and 75% of the present distribution of the two upland oak-birch categories have been correctly predicted in this work.

Conclusions

The data sources, the understanding and interpretation of them and the methodology applied provide a useful indication of the potential native woodland distribution in the Cairngorms area. The combined soil/land cover dataset has “added value” to each of the source datasets, for example by identifying cultivated land and through using vegetation to disaggregate some of the heterogeneity of the soil map units. Although the decision rules are explicit, some expert knowledge of the data was required to determine which is the most appropriate rule for particular circumstances. Possible future developments will test the assumption that soil is a useful surrogate for other environmental parameters such as temperature and rainfall. Some recognition of the potential errors in the primary data and hence the derived product also needs to be addressed in future work.

References


Section 7: Posters
Section 7: Posters

A systematic calibration and validation procedure for a soil-crop model
*S. Ducheyne, M. Vanclooster, J. Feyen*

A database of measured soil hydraulic properties for Europe (HYPRES)
*A. Lilly, J.H.M. Wösten*

Information on agricultural soils in Finland
*J. Sippola*

MMK characterisation and classification of site conditions in the new federal states of Germany
*D. Deumlich, J. Thiere, Monika Frielinghaus, L. Voelker*

Geoscientific maps of Baden-Württemberg developed by GIS applications
*Geoscientific, R. Schweizer, J. Schuff, G. Sokol*

A spatial information database for integrating soil, land use and relief
*E. D. Spies, S. Broschinski, K. Friedrich, Th. Vorderbrügge*

Pedotransfer functions for Portuguese soils
*M. da Conceição Gonçalves*

Characterizing vulnerability to acidification using the buffering capacity of soils
*I. Gavrila, Z. Borlan*
A systematic calibration and validation procedure for a soil-crop model

Introduction

The application of mechanistic simulation models for quantitative land evaluation purposes need to be preceded by a thorough evaluation of the model used. In this study, the numerical simulation model WAVE (Water and Agrochemicals in the Vadose Environment) has been evaluated by invoking a semi-automated procedure, which includes a sensitivity analysis, a calibration and a validation phase. An experimental data set collected in the loamy region of Belgium during a four year field study, was used for the evaluation.

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Materials and methods

A flowchart of activities within each evaluation step is given in Figure 1. In order to work in a systematic manner, the sensitivity analysis is performed first so as to reduce the number of sensitive model parameters to a reasonable number. The calibration is conducted in the following way:

(i) deriving first the optimal set of (relevant) model parameters for the water balance model;
(ii) using those optimised parameters for calibrating the remaining parameters of the crop growth model.

The calibration and validation procedure is illustrated using the WAVE model (Vanclooster et al., 1996) and data of a four-year sugar beet experiment with optimal nitrogen fertilisation (IWONL, 1989). The WAVE model is a one-dimensional, deterministic, physically-based soil-crop model, simulating the soil water and nitrogen balance, and the response of the crop to the availability of soil water and nitrogen. The system input and output variables of the WAVE model are shown in Figure 2.

Results and discussion

Water Balance

During the sensitivity analysis, the initial estimates of the parameters were taken as reference values, whereas the perturbations of the parameters were chosen as realistic ranges for the specific data set. The functional criterion for which the sensitivity of the parameters was assessed was the volumetric soil moisture content, measured at different depths. Table 1 ranks the tested model parameters according to their sensitivity.

The calibration for the soil water balance was conducted for the most sensitive model parameters $K_c$, $K_{sat}$ and $S_{max,z}$, making use of two years (1983, 1984) of the data set. The other parameters were set to their reference values.

Time series of simulated and measured soil moisture contents, before and after the calibration, are given in Figure 3. For the first 100 cm of the soil profile, the model predictions noticeably improved through calibration. Values of ME, RMSE, and EF were closer to their optimum after calibration. The value of the CRM factor is small, sometimes negative, sometimes positive, indicating that no systematic over- or underestimation exists.
Crop growth component

The calibration of the hydraulic component of the model was followed by the calibration of the crop growth component. As functional criteria for crop growth the total dry matter weight ($W_{tot}$, kg ha$^{-1}$), being the sum of the weight of the leaves, stems, crowns and beets, and on the leaf area index (LAI, m$^2$ m$^{-2}$) were taken. Table 2 lists the sensitivity coefficients of the crop parameters with LAI and $W_{tot}$ as functional criteria.

The calibration was done using the data of 1985, tuning the most sensitive parameters SLA and $k_L$, while the other parameters were kept at their reference (initial) value.

In Figure 4, the effect of the calibration is shown with respect to the dry matter for the total crop, leaves and stems, beets and crowns. Figure 5 shows the effect of the calibration on the simulated LAI. Systematic under- and overestimation can easily be observed from the scatter plots in Figure 6. The calibration considerably improved the prediction capacity of the model for the total crop, the beets, the leaves and stems and the LAI, whereas improving the simulation of the crown dry matter was not feasible.

Conclusions

The use of a systematic calibration and validation procedure, consisting of a screening sensitivity analysis, a calibration of the most sensitive parameters, and a validation phase, enables to evaluate in an objective way the prediction capacity of an integrated soil-crop model. Improved predictions were obtained for the water balance, LAI and crop growth. The modular structure of the WAVE model allowed the application of a systematic, stepwise procedure, starting with the water balance, followed by the crop growth module.

Acknowledgement

This research is financially supported by a PhD research grant of the Flemish Institute for the Encouragement of Scientific and Technological Research in the Industry (IWT).

References


Table 1: Sensitivity coefficient of the crop and soil parameters used in the sensitivity analysis of the WAVE model

<table>
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<tr>
<th>PARAMETER</th>
<th>SENSITIVITY COEFFICIENT</th>
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<tr>
<td>$K_c$</td>
<td>1.08</td>
</tr>
<tr>
<td>$ET_0$</td>
<td>0.83</td>
</tr>
<tr>
<td>$K_{sat}$</td>
<td>0.71</td>
</tr>
<tr>
<td>$S_{max,z}$</td>
<td>0.60</td>
</tr>
<tr>
<td>$b$</td>
<td>0.56</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.32</td>
</tr>
<tr>
<td>$\theta_s$</td>
<td>0.26</td>
</tr>
<tr>
<td>$m$</td>
<td>0.24</td>
</tr>
<tr>
<td>$n$</td>
<td>0.23</td>
</tr>
<tr>
<td>$\theta_r$</td>
<td>0.22</td>
</tr>
</tbody>
</table>

crop parameters $K_c$ (crop coefficient), $ET_0$ (reference evapotranspiration), $S_{max,z}$ (maximum water uptake function by the roots), and soil parameters $K_{sat}$ (saturated hydraulic conductivity), $b$ (slope of the Gardner’s hydraulic conductivity curve; Gardner, 1958), $\theta_s$ and $\theta_r$ (saturated and residual moisture content of the soil), $\alpha$, $n$ and $m$ (parameters of the van Genuchten moisture retention curve; van Genuchten, 1980)

Table 2: Sensitivity coefficients for the crop parameters with leaf area index (SC(LAI)) and total dry weight (SC(Wtot)) as functional criteria

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SC (Wtot)</th>
<th>PARAMETER</th>
<th>SC (LAI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_L$</td>
<td>1.433</td>
<td>$k_L$</td>
<td>1.643</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.690</td>
<td>SLA</td>
<td>0.613</td>
</tr>
<tr>
<td>SLA</td>
<td>0.582</td>
<td>LAI$_{cr}$</td>
<td>0.448</td>
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<td>$A_{max}$</td>
<td>0.564</td>
<td>$T_b$</td>
<td>0.335</td>
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<tr>
<td>$N_r$</td>
<td>0.424</td>
<td>$N_r$</td>
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<td>$T_b$</td>
<td>0.301</td>
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<td>0.300</td>
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<tr>
<td>LAI$_{seedling}$</td>
<td>0.293</td>
<td>$A_{max}$</td>
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<td>0.288</td>
<td>LAI$_{seedling}$</td>
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<td>kdf</td>
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<td>ASR$_{so}$</td>
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<td>$\sigma$</td>
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<td>kdf</td>
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<tr>
<td>LAI$_{cr}$</td>
<td>0.008</td>
<td>$\sigma$</td>
<td>0.008</td>
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<tr>
<td>$M_{so}$</td>
<td>0.006</td>
<td>$M_{so}$</td>
<td>0.002</td>
</tr>
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</table>

$k_L$ (crop specific LAI development coefficient), SLA (specific leaf area), LAI$_{cr}$ (critical leaf area), $T_b$ (base temperature), $N_r$ (number of seedlings), $\varepsilon$ (initial light use efficiency), $A_{max}$ (potential CO2-assimilation rate of a unit leaf area for light saturation), LAI$_{seedling}$ (green leaf area index of seedlings), ASR$_{so}$ (conversion efficiency for the storage organs), kdf (extinction coefficient for diffuse light within the canopy), $\sigma$ (scattering coefficient) and $M_{so}$ (maintenance energy of the storage organs)
SENSITIVITY ANALYSIS

one-dimensional differential sensitivity coefficient

\[ S(i) = \frac{|Y(x+dx)-Y(x-dx)|}{Y(x)} \]

- \( Y(x) \) = functional criteria calculated with initial parameter \( x \)
- \( x + dx; x - dx \) = perturbations of parameter \( x \)

CALIBRATION

- iterative way
- ‘split sample’

VALIDATION

- ‘split sample’
- ‘goodness of fit’

graphical methods

statistical methods (Loague et al., 1988):

<table>
<thead>
<tr>
<th>Statistical criteria</th>
<th>( P_i ) = prediction at time ( i )</th>
<th>( O_i ) = observation at time ( i )</th>
<th>( O ) = observed mean over time period</th>
<th>optimum</th>
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<td>Maximum error</td>
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<td>( ME = 0 )</td>
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<td>Root mean square error</td>
<td>( )</td>
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<tr>
<td>Model efficiency</td>
<td>( )</td>
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Figure 1: Flowchart of activities within each evaluation step
Figure 2: The system input variables for the WAVE model and the calculated output variables.
Figure 3: Comparison between the mean observed (+/- two standard deviations) and the simulated soil water content under sugar beet (Jan. 1982 - Sep. 1985) for the soil layers 0-20, 20-40, 40-60 cm
Sugar Beet

DASHED LINE = BEFORE CALIBRATION
FULL LINE = AFTER CALIBRATION

Figure 4: Comparison between mean observed (+/- one standard deviation) and simulated dry matter weight of sugar beet (total dry weight, dry weight of leaves and stems, dry weight of beet and dry weight of crowns) for the growing season 1985
BEFORE CALIBRATION = DASHED LINE
AFTER CALIBRATION = FULL LINE

Sugar Beet

Figure 5: Comparison between mean observed (+/- one standard deviation) and simulated leaf area index of sugar beet for the growing season 1983 and 1985

sugar beet

Figure 6.: Scatter plots (with 1:1 bisectrice, slope of linear regression and $R^2$) of the measured and predicted dry weights of the beets, leaves and stems, crowns, and the total dry weight for the four growing seasons (1982-1985)
A database of measured soil hydraulic properties for Europe (HYPRES)

Simulation models are increasingly being used to investigate and predict a wide range of complex environmental processes. Many of these models are concerned with water and solute movement in the vadose zone and require water retention and unsaturated hydraulic conductivity data. However, these properties are difficult and time-consuming to measure and there is renewed interest in the establishment of pedotransfer functions in order to estimate them from more easily measured soil properties.

In order to facilitate the development of these pedotransfer functions, the EU funded a project (Using existing soil data to derive hydraulic parameters for simulation modelling in environmental studies and in land use planning – CHRX-CT94-0639) in which a number of European Institutions are collaborating to develop the HYPRES database (HYdraulic Properties of European Soils).

This database will comprise measured soil hydraulic properties as well as data and information on soil texture, organic matter contents and pedology from which a range of pedotransfer functions can be derived. In the first instance, class pedotransfer functions will be developed for topsoils and subsoils based on the five soil texture classes (plus organic soils) currently used to describe the soil units depicted on the 1:1,000,000 Soil Map of Europe.

Later, and after parameterization of the measured data with empirically and/or theoretically based models, multiple regression of the soil hydraulic properties against individual particle size classes will be used to derive continuous pedotransfer functions. Novel techniques such as Neural Networks may also be employed. The overall result will be a map showing the soil physical composition of Europe and a set of non-scale-specific pedotransfer functions.

In order to achieve the high level of flexibility needed in both the storage and retrieval of data, the database has been designed (and tested) within an Oracle Relational Database Management System and care has been taken to ensure that the database remains compatible with existing EU-wide soils databases. The database is divided into seven separate tables (Figure 1) linked by a geo-reference and, where appropriate, soil horizon notation, thus allowing links to be made with GIS and with the 1:1,000,000 Soil Map of Europe.

Data on individual soil profiles and soil horizons are donated by the Network Partners in a standardised (but non-restrictive) format to aid data entry and manipulation and include data on the soil hydraulic properties, soil textures as well as information on the land use and site characteristics. It was anticipated that there would be data for more than 3000 soil horizons by the end of 1996.

A fuller description of the database structure and the types of data stored are available from the authors.
Figure 1: Structure of the HYPRES database. Each column represents a separate table linked by georeference and horizon.

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Information on agricultural soils in Finland

Summary

Agrogeological mapping in Finland has been carried out by the Agricultural Research Centre since the 1920s using a national soil classification based on texture and organic matter content. In the beginning, results were published at the scale of 1:50,000 or 1:100,000. Later the mapping was carried out at scale 1:20,000 and the same scale was used when work continued in cooperation with the National Survey Board and the Geological Survey. About one-third of the whole country has now been surveyed. The maps prepared during the last few years are available only in numeric form.

This makes possible the production of maps not only at different scales, but also maps containing different information according to specific needs. A substantial number of samples have been collected during the surveys. Some of the samples have been analysed for texture and organic matter for bases of soil classification. Nutrient elements and pH have been determined on all samples with a method which is used also for commercial soil testing in Finland (Vuorinen and Mäkitie, 1955).

Because of the young age of Finnish soils, the genetic classification has little practical use. However, the Finnish contribution for the soil map of the world using FAO soil classification system has been prepared in the 1970s. Based on this material, together with that of other Scandinavian countries, the soil map has been published (Rasmussen et al. 1989). The same material has been forwarded to the European Geographical Soils Database project. For the European Analytical Profiles Database analytical results of typical soils have been provided.

The Agricultural Research Centre holds a lot of soil information data collected during soil surveys and other investigations. This data mostly exists as individual computer databases and contains no geographic co-ordinates. However, the most recently collected data does have co-ordinates to make localization possible. At the moment we are organizing this data to form an "Environmental information register". It is planned to store soil data from other important investigations in this register, too.

The soil testing method used in Finland is the acid-ammonium-acetate extraction method at pH 4.65 (Vuorinen and Mäkitie, 1955). Macronutrients P, K, Ca and Mg in addition to pH are normally determined. The Commercial Soil Testing Service handles about one hundred thousand samples yearly. Quite a number of results have been collected over the years and reports are written periodically. According to the results soil pH has increased because of liming and at present averages 5.9. The phosphorus concentration is 12 mg/l soil, potassium 146 mg/l, calcium 1517 mg/l and magnesium 237 mg/l on average in the year 1988.

The acid-ammonium-acetate EDTA method is used to extract micronutrients and heavy metals (Lakanen and Erviö, 1971). Surveys of nutrients and heavy metals in cultivated soils and in the indicator crop timothy grass have been carried out in years 1974 and 1987 to check their status and development. According to the results of these surveys, relatively large increases were observed in concentrations of soil P, B, Co Cr, Cu and Mo. Zn was the only nutrient which decreased in concentration during the measured period.

Of the harmful heavy metals, the concentration of Cd increased and that of Pb decreased. The same method has been used also in...
global studies in co-operation with FAO (Sillanpää, 1982). The data exist as a computer database, and GIS methods are under development to improve the possibilities for further interpretation and presentation of results obtained in different investigations.

References


RASMUSSEN, K. et al. (1989). Soil map of Denmark, Finland, Norway and Sweden. Scale 1:2,000,000. Landbruksforlaget, Oslo.


MMK characterisation and classification of site conditions in the new federal states of Germany

Summary

Good basic information is necessary as a decision support tool for classifying high-risk areas and for categorising the protection necessary for them.

Land classifications for agricultural production and land management methods, and classes for erosion risks can be calculated on the basis of digitized data from municipalities with the results of the Mesoscale Agricultural Mapping program (MMK) and the state soils evaluation (Reichsbodenschätzung), using the VERMOST comparison location method program.

The calculated comparison data (groups, indices, index classes, groups of contrasts, association groups) make possible an area-orientated grouping based on natural or administrative units according to site conditions and/or contamination and risk potentials.

The calculations refer to individual features such as quality of arable land (Ackerzahl), substratum, slope steepness, stoniness, hydromorphy or complex parameters derived from it such as the estimation of the potential water erosion risks. Statements of the different predominant use (forest, water, grassland, farmland, settlement) can also be included in the area units. The results are documented in tables and general maps. With the comparison method, a site-specific estimate is given for different environmentally-oriented themes. Input data for mesoscale models can be deduced by transfer functions. The continuous control of the site-oriented information through updating field measurements, remote sensing and GIS is imperative.

Water erosion Database

The database contains the following:
- aggregated data of the MMK
  - soil association groups
  - relief association groups
- soil erodibility
  - slope steepness
- land use
- soil types (Reichsbodenschätzung)
- profile data
- point data and spatially integrated data
  - meteorology (precipitation, intensity, duration)
  - maps in different scales for different topics
- rainfall energy
  - slope length

Methodology

- Soil loss estimation using the Universal Soil Loss Equation (USLE) of Wischmeier and Smith (1978) by using regionalized data
- Calculation of nutrient input in the rivers
- Comparison method (Thiere et al., 1991)
Regionalization of factors of USLE

For municipalities, calculations were made according to the Universal Soil Loss Equation (Wischmeier and Smith, 1978, adapted by Schwertmann et al., 1987).

\[ A = R \times K \times LS \times C \times P \]

with \( A \) = average long-term soil loss (t/ha.y);

factors:
- \( R \) - rainfall and runoff;
- \( K \) - soil erodibility;
- \( L \) - slope length;
- \( S \) - slope steepness;
- \( C \) - cover and management;
- \( P \) - support practice

\[ R[N/\text{h.a}] = -6.88 + 0.152 P_S \]

\( P_S \) - Precipitation during summer period [mm]

Soil erodibility (\( K \))

This was regionally weighted for municipalities on the basis of site units.

### Table 1: K-factors for site types in the unconsolidated rock region

<table>
<thead>
<tr>
<th>natural site units</th>
<th>dominating soil texture in the top layer</th>
<th>Thiere et al., 1983</th>
<th>K-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>S</td>
<td>&gt; 80 % sand</td>
<td>0.1</td>
</tr>
<tr>
<td>D2</td>
<td>l’s, S</td>
<td>&gt; 60 % loamy sand or sand, &lt; 40 % covered(^1) loam</td>
<td>0.2</td>
</tr>
<tr>
<td>D3</td>
<td>l’s...lS</td>
<td>40 - 60 % covered loam, loam-sand or cover-loam or cover-loam-sand, 40 - 60 % sand or loamy sand</td>
<td>0.3</td>
</tr>
<tr>
<td>D4</td>
<td>lS, lL</td>
<td>&gt; 60 % covered loam or covered clay (partially cover loam), cover-sand-loess or cover-sand-loam</td>
<td>0.35</td>
</tr>
<tr>
<td>D5</td>
<td>lS...L</td>
<td>40 - 60 % loam, 40-60 % covered loam; &gt; 60 % loam and covered loam; &gt; 60% sand loess</td>
<td>0.25</td>
</tr>
<tr>
<td>D6</td>
<td>sL...T</td>
<td>&gt; 60% loam or heavy loam, partially loam or clay</td>
<td>0.2</td>
</tr>
</tbody>
</table>

\(^1\) covered = substrate below 60 cm soil depth

### Table 2: Examples of regional LS-factors

<table>
<thead>
<tr>
<th>region</th>
<th>slope class</th>
<th>slope area class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>04(^1)</td>
<td>49</td>
</tr>
<tr>
<td>loamy hill region in Uckermark</td>
<td>0.44</td>
<td>1.51</td>
</tr>
<tr>
<td>Lower Lausitz</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) slope steepness from 0 - 4 % ... > 23 %; \(^2\) weighted LS-factors for slope area classes
**Topography (LS)**

Topography was calculated regionally for slope classes of the medium-scale agricultural site maps.

**Cover and management (C)**

This was estimated from regional combined weather (rain erosivity) and cropping data (Table 3).

**Table 3: C-factors of crops in north-east Germany (in relation [%] to continuous fallow)**

<table>
<thead>
<tr>
<th>crop</th>
<th>C-factor Brandenburg, Mecklenburg-Vorpommern and Saxonia</th>
<th>average of BBG, MVP and Saxonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>winter wheat</td>
<td>7.7...14.4</td>
<td>9.2</td>
</tr>
<tr>
<td>winter barley</td>
<td>5.7...10.4</td>
<td>8.0</td>
</tr>
<tr>
<td>winter rye</td>
<td>3.2...5.9</td>
<td>4.2</td>
</tr>
<tr>
<td>summer barley</td>
<td>2.9...6.6</td>
<td>4.7</td>
</tr>
<tr>
<td>oats</td>
<td>2.9...6.6</td>
<td>4.7</td>
</tr>
<tr>
<td>winter rape</td>
<td>8.9...12.7</td>
<td>11.4</td>
</tr>
<tr>
<td>potatoes</td>
<td>15.0...24.2</td>
<td>20.5</td>
</tr>
<tr>
<td>sugarbeet</td>
<td>17.7...28.5</td>
<td>21.8</td>
</tr>
<tr>
<td>corn (silage)</td>
<td>25.6...37.8</td>
<td>33.8</td>
</tr>
</tbody>
</table>

**Estimation of enrichment ratio (ER) for nutrients (N and P) in sediments according to Auerswald (1989)**

\[
ER = 2.53 \times A^{-0.21}
\]

A - average soil loss on arable land [t/ha]

Calculation of sediment yield from the catchment (soil loss - deposit)

\[
SED = 700 + 8.5 \times CA \times A_{c}^{0.5}
\]

SED - sediment transport by rivers (t/y)
CA - catchment area (km²)
Ac - mean soil loss of the whole catchment area.

Nutrient input = SED of 1000 km² * catchment area * ER * N/P-concentration of arable lands for N- and P-concentration cf. Table 4

**Table 4: Example of calculation for nitrogen content in soils**

<table>
<thead>
<tr>
<th>soil group</th>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>natural site units</td>
<td></td>
<td>poor sandy soils</td>
<td>sandy soils</td>
<td>sandy and loamy soils</td>
<td>mountaineous soils</td>
</tr>
<tr>
<td>D1, D2</td>
<td></td>
<td>&lt; 7</td>
<td>8 - 15</td>
<td>16 - 25</td>
<td>26 - 38</td>
</tr>
<tr>
<td>D3, D4</td>
<td></td>
<td>580</td>
<td>760</td>
<td>1120</td>
<td>1770</td>
</tr>
<tr>
<td>D5, D6, V4-9</td>
<td></td>
<td>58</td>
<td>76</td>
<td>112</td>
<td>177</td>
</tr>
<tr>
<td>V1-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For phosphorus a concentration of 60 mg/100 g soil was assumed.

**VERMOST (method for site comparison)**

The potential water erosion risk of larger units or plains under agricultural use can be derived from the SFT and NFT of the MMK, whereby their concrete within MMK contours given percentage is procured connection for the classification (Tables 5 and 6).
Table 5: Algorithm to calculate the relief association groups (MMK)

<table>
<thead>
<tr>
<th>Relief association groups</th>
<th>Combined slope steepness groups(^1) (slope steepness groups I...V and 1...8)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>&lt; 4%</td>
</tr>
<tr>
<td>01 plane</td>
<td>&lt; 4%</td>
</tr>
<tr>
<td>03 flat</td>
<td>60 - 80</td>
</tr>
<tr>
<td>05 flat with moderately inclined portions</td>
<td>&gt;80</td>
</tr>
<tr>
<td>07 flat with stronger inclined portions</td>
<td>&gt;80</td>
</tr>
<tr>
<td>09 moderate with strongly inclined portions</td>
<td>40 - 60</td>
</tr>
<tr>
<td>11 strongly inclined</td>
<td>&gt;40</td>
</tr>
</tbody>
</table>

\(^1\) maximum area portion on slope steepness groups

Table 6: Estimation of potential water erosion risk on younger moraine sites on the basis of the Medium Scale Agricultural Mapping

<table>
<thead>
<tr>
<th>Soil association group</th>
<th>Relief association group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>01</td>
</tr>
<tr>
<td>Substratum texture</td>
<td>key number</td>
</tr>
<tr>
<td>&lt; 0.0063 mm clay; &gt;38%</td>
<td>18, 19 very small</td>
</tr>
<tr>
<td>≤ 7% sand;</td>
<td>1,2,28,33,36,39,42,43,92, 94 very small</td>
</tr>
<tr>
<td>&gt;25... ≤ 38% loam and silty loam;</td>
<td>11,14...17,20 very small</td>
</tr>
<tr>
<td>&gt;7... ≤ 25% loamy sand, sandy loam;</td>
<td>3..10,12,13,2 1..27,44 very small</td>
</tr>
</tbody>
</table>

Through the application of VERMOST, not only the dominant but also the sub-dominant and accompanying characteristics of the areas are considered in the classification. The algorithm was modified in parts for younger moraine sites. The agrarian use has not yet been considered.

Calculation of comparison data:
This combination algorithm was used to appraise the potential water erosion risk of the contours of the STR. For a more precise comparison of units, in which several map units occur (municipalities, districts, natural space units or arbitrary parts of landscapes), comparison data are calculated according to the “method of comparison of sites” (VERMOST). Comparison data are soil characteristics and classification units documented in comparison steps (0-5 or 0-9) and values such as comparison index, index classes, dominance-triple and groups of contrasts derived from them. The comparison index was chosen.
for the comparison of municipalities as an administrative unit or natural space units. It is calculated by equation (1)

\[
\text{comparison index number} = \frac{\sum_{i=1}^{5} \text{comparison step}_i \times \text{percentage of area}_i}{5}
\]

Comparison step (see Table 6)
- 0 - very small erosion risk
- 2 - small erosion risk
- 3 - moderate erosion risk
- 4 - strong erosion risk
- 5 - very strong erosion risk

<table>
<thead>
<tr>
<th>index classes</th>
<th>range of index number</th>
<th>potential erosion risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>≤ 22</td>
<td>none</td>
</tr>
<tr>
<td>1</td>
<td>23-31</td>
<td>very small</td>
</tr>
<tr>
<td>2</td>
<td>32-44</td>
<td>small</td>
</tr>
<tr>
<td>3</td>
<td>45-63</td>
<td>moderate</td>
</tr>
<tr>
<td>4</td>
<td>64-80</td>
<td>heavy</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 80</td>
<td>very heavy</td>
</tr>
</tbody>
</table>

dominance-triple and level of dominance
- 1. number - the dominating step of danger
- 2. number - the subdominant step
- 3. number - third portion of area

level of dominance of one comparison step:
- 1 – slight \( \geq 40 \% \)
- 2 – moderate \( > 40 \ldots \geq 60 \% \)
- 3 – high \( > 60 \ldots \geq 80 \% \)
- 4 – very high \( > 80 \% \).

Results

The VERMOST method of site comparison allows the evaluation of potential water erosion risks on agricultural areas for different spatial units (catchments, geographical areas or administrative units). It can display similar rows and groups to compare spatial units. Data for actual land use, rainstorm properties, slope length and slope shape are not integrated

For the Oder catchment, the sequence of relative shares of the different erosion risk emerges at the LN with 48 % at the level of no disposition = VST 0 \( \langle 1. \text{number} \rangle \),

Table 7: Porportion of areas with erosion risks and data to compare catchments

<table>
<thead>
<tr>
<th>catchment</th>
<th>up to very small</th>
<th>small</th>
<th>moderate</th>
<th>strong</th>
<th>very strong</th>
<th>dominance TRIPLE</th>
<th>level of dominance</th>
<th>index number</th>
<th>index-class</th>
</tr>
</thead>
<tbody>
<tr>
<td>comparison steps</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oder</td>
<td>48</td>
<td>25</td>
<td>13</td>
<td>14</td>
<td>0</td>
<td>024</td>
<td>2</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>Neisse</td>
<td>42</td>
<td>23</td>
<td>15</td>
<td>20</td>
<td>0</td>
<td>024</td>
<td>2</td>
<td>34</td>
<td>2</td>
</tr>
<tr>
<td>Coast (Polish border to Peene)</td>
<td>36</td>
<td>26</td>
<td>19</td>
<td>18</td>
<td>1</td>
<td>023</td>
<td>1</td>
<td>37</td>
<td>2</td>
</tr>
<tr>
<td>Peene</td>
<td>46</td>
<td>24</td>
<td>18</td>
<td>11</td>
<td>1</td>
<td>023</td>
<td>2</td>
<td>30</td>
<td>1</td>
</tr>
</tbody>
</table>

Map of the potential water erosion risk
The index classes are the basis for identifying the erosion risks with the aim of the comparability of large areas aggregated on municipalities, natural units or basins. By means of these classes an overview is given of the erosion risk prevailing on the agricultural area (LN) of the municipalities or catchments.

The map (available from the author D. Deumlich), with the underlying uniform methodology, gives an overview of the potential erosion risk in the regions of the Oder catchment. The high-risk sites are found primarily in the areas with high relief energy (>NFT 05). But on plains where a relatively weak indication (NFT03) is given, important soil losses, which are not calculated by this method, can also occur at high rain intensity and where soil cover is missing.

**USLE**

The Universal Soil Loss Equation allows the quantification of soil loss and the comparison of potential water erosion risks on arable lands, agricultural areas and other spatial units on the basis of lumped data integrating rainstorm and management properties.

**Calculation of sediment and nutrient losses caused by water erosion**

Table 8 shows the result of first calculations for sediment and nutrient losses caused by water erosion.

A further step is necessary to harmonize the data sets of catchment areas with the Institute for Hydrology. At present a difference of around 1000 km² exists in the data set covering the area.

**Table 8: Sediment and nutrient losses caused by water erosion from the German part of the Oder catchment**

<table>
<thead>
<tr>
<th>catchment</th>
<th>land area (WF) in ha</th>
<th>arable land (AF) in ha</th>
<th>potential soil loss</th>
<th>sediment input</th>
<th>N-content in average</th>
<th>input by nutrients</th>
<th>input by nutrients in kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>t/ha AF</td>
<td>ER</td>
<td>t</td>
<td>t/ha WF</td>
<td>mg/100g soil</td>
<td>N-input</td>
</tr>
<tr>
<td>Oder</td>
<td>411999</td>
<td>225339</td>
<td>267953</td>
<td>1.19</td>
<td>2.44</td>
<td>28942</td>
<td>0.070</td>
</tr>
<tr>
<td>Neiße</td>
<td>125686</td>
<td>51344</td>
<td>212274</td>
<td>4.13</td>
<td>1.88</td>
<td>14584</td>
<td>0.116</td>
</tr>
<tr>
<td>Coast (Peene up to Warnow)</td>
<td>247178</td>
<td>110008</td>
<td>112988</td>
<td>1.03</td>
<td>2.52</td>
<td>14905</td>
<td>0.060</td>
</tr>
<tr>
<td>Peene</td>
<td>519782</td>
<td>318390</td>
<td>252347</td>
<td>0.79</td>
<td>2.66</td>
<td>31484</td>
<td>0.061</td>
</tr>
</tbody>
</table>

**Literature: contact the author, D Deumlich**
Geoscientific maps of Baden-Württemberg developed by GIS applications

Introduction

The project “Small-scale Geoscientific Maps for State-wide Land Management” was funded by the German State Department of Agriculture and the State Department of Economy. User-orientated geoscientific maps on a scale of 1:200,000 were derived from geoscientific base maps by using GIS-applications. Data sources are soil maps on a scale of 1:200,000 and geological maps on a scale of 1:500,000. These were used to generate thematic maps by different evaluation methods. The geometries of the base maps were digitized and processed with ARC/INFO, and attributes were stored in the ORACLE relational database management system (RDBMS).

For visualization purposes, raster data of topographical maps on a scale of 1:200,000 from the Institute of Applied Geodesy (Institut für angewandte Geodäsie, Frankfurt) and the Digital Elevation Model at 50 m spacing of the Baden-Württemberg State Survey (Landesvermessungsamt Baden-Württemberg, Stuttgart) were used. The developed maps are an important database for applications in the field of land management, agricultural production and environmental protection. It is planned to set up an information system within a client-server architecture using ARC/INFO, ArcView and ORACLE on SGI workstations. It will provide the user with an efficient access to all project results. At the moment project results are primarily used for in-house applications, but in future they should be available for external use as well.

Comments

The following maps resulted from the project.

Map 1: Soil Map of Baden-Württemberg at 1:200,000 scale

Principal soil units of the Soil Map of Baden-Württemberg at a scale of 1:200,000 as classified by the German Soil Mapping Guide (Bodenkundliche Kartieranleitung, 1982). Using the catena concept, a map unit is composed of several genetically-related soil groups, a soil group is aggregated by similar soil units.

Map 2: Available Water Capacity

Classified average values of the map unit related available water capacity as derived from the database of the Soil Map Baden-Württemberg at a scale of 1:200,000, considering the estimated surface area in % of map unit related soil groups and the corresponding soil unit values.

Map 3: Water Storage Capacity

Evaluation of the water storage capacity as derived from the soil parameters of available water and air capacity, as well as saturated hydraulic conductivity by applying a method proposed by the Environmental Department of Baden-Württemberg (Umweltministerium Baden-Württemberg, 1995).

Map 4: Geological Map of Baden-Württemberg at 1:200,000 scale

The geological map is generated by digitizing the existing geological map of 1:500,000 which has been partly revised to fit the scale of 1:200,000. Mapping is based on a stratigraphic classification which
leads to 130 different geological units. The geological map is the base map for hydrogeological evaluations.

**Map 5: Map of Hydrogeological Units of Baden-Württemberg at 1:200,000 scale**

Hydrogeological units are created by interpretation of geological units. 54 hydrogeological units out of 130 geological units are built. The resulting map shows the hydrogeological situation on the surface. Data processing is undertaken by database tables that contain geological units and their corresponding hydrogeological units and GIS reclassification techniques.

**Map 6: Permeability of the Upper Groundwater Bearing Hydrogeological Layers**

Permeability for each hydrogeological unit of Map 5 is determined by evaluating literature and archive data of the State Geological Survey. These permeabilities are assigned to permeability classes using a classification scheme of the State Geological Survey of Nordrhein-Westfalen (Schlimm, 1996). Within this scheme eight permeability classes for porous and fractured aquifers are distinguished (see table at the lower right-hand corner of the map). Impermeable layers that cover the upper aquifer are determined and eliminated before classification.

**Map 7: Groundwater Vulnerability Map**

Vulnerability mapping is applied by assessing the protection potential of the groundwater covering layers. A rating system that was developed by a working group consisting of members of the State Geological Surveys of Germany (Hölting et al., 1995) is used. It is based on assessing the residence time of an ideal tracer in the unsaturated zone using a separate rating for soil (< 1m) and geological layers in the unsaturated zone. Parameters used are groundwater recharge rate, field capacity, thickness and petrographic structure of the groundwater covering layers below soil.

**Map 8: Prognostic Map of Raw Materials Near Surface**

The Prognostic Map of Raw Materials Near Surface is derived from the Prognostic Map of Mineral Resources at the scale of 1:50,000 and a map showing the distribution of mineral occurrences and an estimation of their economical potentials. The map units show the classified groups of raw materials with their useable thickness.

**References**


A spatial information database for integrating soil, land use and relief

Summary

A spatial database for administration and research which attempts to meet the growing demands on basic soil data has been developed using the surface area data catalogue of the “UAG FIS Soil Science”.

Today, planning and other applied problems do not require soil maps of the traditional type, they generally require specific problem-oriented soil information.

These demands must be reflected in mapping and data administration with regard to the scientific soil data fundamentals. Above and beyond this, land use and relief play a decisive role in many applied problems. Information of this sort should thus be integrated into the geometrical and attribute data. This new flexibility is achieved by detachment of the physical and chemical characteristics of the soil from its spatial (topographical, geographical and geometrical) characteristics.

Introduction

Project

The spatial database for soil knowledge is a joint project of the Geological Surveys of Rhineland-Palatinate and Hesse.

The use of geo-science maps

Classical geo-science maps depict highly complex contents which offer important basis material (data) to answer to questions concerning land management such as soil conservation, preservation of resources, preservation of biotopes, ecological compatibility, landscape planning, location of waste deposits, large construction projects and much more.

Only specialized personnel can deliver a useful evaluation and/or interpretation for many applications of these maps.

The continually growing and ever-changing demands on geo-science base data require new concepts for maintenance of such data, especially for questions of application.

Regional geo-science data have to be prepared and presented in a manner which permits direct use by a non-specialist for the solution of the problem at hand.

The information technologies available today allow creative freedom in administration, research and visualization of specific geo-science data. New data structures must be developed in accordance with the new opportunities, and these necessarily have great influence on the survey methodology, data administration and data presentation.

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Soil data from the perspective of soil protection

Traditional concept for soil maps

- The soil map represents the most distinct basic unit of spatial soil information (including explanation).
- The mapping units (pedological legend units) are described on the basis of a “Bodenform” independent of utilisation.
- Evaluation maps are derived on the basis of mapping units.

New concept for area soil data

- Mapping units are described according to the spatial variation of the soil associations. These can be hierarchical aggregates.
- The smallest unit of soil association is the “Bodenform” (detailed description of the sequence of the horizons of a soil)
- Some important characteristics of soils are determined by the utilization of the soil. Thus soil data are stored in relation to utilization.
- The soil units are not formed exclusively on the basis of soil classification, but also with regard to soil characteristics (physical, chemical, etc.). They represent the general, area-oriented soil science basic data. These are processed thematically by means of algorithms and documented as evaluation maps. The preparation of a classic soil map represents one of several specific evaluation methods of the basic data.
- Complex models such as soil water balance and soil erosion models which require additional non-soil information (climatic and relief data) can be used.

Demands on a surface area data catalogue for soil science

Soil maps

Digital soil science basic map contents

The digital soil map serves as a basis for information stored in the database. Data can be derived from the following origins:

a) New mapping in the field
   - mapping (area, mapper, date, project)
   - processing the maps (area, compiler, date, project)
   - input into the Geographic Information System (compiler, date, etc.)
   - status

b) Input of existing analog maps and their revision
   - datafields as in a)

c) Input of existing digital maps and their revision

Digital soil scientific basic maps – output possibilities

Aside from the classical possibilities of output with the familiar established layout, data processing offers the possibility of producing thematic maps on a point and/or surface area basis. The data derived from algorithms and models can be incorporated in the output.

a) Basic soil map/traditional soil map with the familiar established layout
   - contents (soil(overview))
   - cut-out
   - map border legend
   - topographical background
   - status information
b) Thematic evaluation maps
   - contents (theme; e.g.: risk of soil erosion by water)
   - other data fields as in a)

c) Evaluation of specific map sections
   - data fields as in b)

d) Point-related evaluation maps
   for example the representation of the points of the investigation of map
   - data fields as in b)

Data

The data to be addressed are stored in different parts (tables) of the database according to the “themes” to which they belong. These are:

a) soil archive
   - data in relation to horizons of any soil
   - profile related data (basis data for soil)

b) soil association
   - special areas
   - complete soil units

c) hierarchical structure of the legend
   - organisation of soil units with descriptive characteristics

Application of methods in the soil information system

a) Determination of characteristic data:
   - characteristic data related to horizons
   - characteristic data related to soils (profiles)
   - characteristic data related to soil associations

b) Preparation of maps

c) Representation of areas

d) Evaluation
   - statistics
   - evaluation related to surface area

General structure

The soil data are stored in three partitions of the data bank.

a) Soil archive: The soil archive is a successive list of all soils which will be needed for the description of surface area data in a mapping project. It consists of the profile related data and the horizon related data which are linked with the profile related data 1:n. Both partitions contain basic soil data (not derived data!). Both are linked with a specific module, which generates the evaluations and administers the methods.

b) Catalogue of mapping units: The catalogue of mapping units is a hierarchical structured list of all mapping units, which are needed in a mapping project to describe the soil scientific area data. The specific mapping unit is linked with a specific list of soils through which it is described. These are linked to mapping specific data concerning surface area, relief, use and distribution pattern of the individual soils, which are only valid within the mapping unit. Each mapping unit can be linked with several soils and each soil can be linked with several mapping units.

c) Catalogue of legend structures: The catalogue of legend structures is a hierarchical structured list of all legend units of a mapping project. Legend units are groups of mapping units, which are included in regional units.

Regional data are administered as a fourth partition. The surface area data are connected with the module with the regional data over an interface. This is the partition of the database in which the geometrical data are administered and in which the soil data are connected to the geometrical data.

Geometrical data are managed by ARC/INFO.

Methods are organized with a thematic structure:

a) Methods related to horizons

b) Methods related to profiles

c) Methods related to mapping and legend units

d) Methods related to regional units

The methods are managed within their own “substructure” and are stored hierarchically in groups. Data can be input automatically by mask, but manual input of available data is also possible.
Major components of the surface area database

Figure 1:
Figure 2:
Figure 3:
Figure 4:
Pedotransfer functions for Portuguese soils

Introduction

Modelling the water flow and solute transport in the vadose zone requires knowledge of the unsaturated soil hydraulic properties (soil water retention curve and hydraulic conductivity curve). Actual physical measuring of these properties is relatively expensive and time-consuming, and they are hence frequently predicted with so-called pedotransfer functions (PTFs), using basic soil properties (e.g., particle-size distribution, organic matter content, bulk density).

In this study PTFs are developed between hydraulic data and basic soil properties. Parameters are quantified for:
(i) the retention model of van Genuchten (1980) using 80 soil profiles with a total of 230 retention curves,
(ii) the conductivity model of Gardner (1958) using 20 soil profiles and 129 hydraulic conductivity curves.

The studied profiles represent the main soil families in Portugal, ranging from coarse sands to heavy clays.

Objectives

Methodology

Water Retention Curve

The water retention curve was measured on undisturbed 100 cm³ samples using a suction table with sand or kaolin (log h ≤ 2.7), while a pressure membrane apparatus was used to determine retention data on 25 cm³ undisturbed or disturbed samples at higher suctions (log h > 3).

The retention data were described by the equation of van Genuchten (1980), condition m=1 (Vereecken, 1988).

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

where \(\theta\) is the observed volumetric water content (cm³/cm³), \(h\) is the imposed soil water pressure head (cm water), \(\theta_r\) and \(\theta_s\) are the residual and saturated water contents while \(\alpha\), \(n\) and \(m\) are empirical shape factors.

Hydraulic Conductivity

The hydraulic conductivity was measured on 4700 cm³ samples using the crust method (Bouma et al., 1971) and on 200 cm³ samples with the hot-air method (Arya et al., 1975).

The hydraulic conductivity data were described by the equation of Gardner (1958)

\[
K(h) = \frac{K_s}{1 + (bh)^p}
\]

where \(K_s\) is the saturated hydraulic conductivity and \(b\) and \(p\) are empirical parameters.

M. da Conceição Gonçalves

Departamento de Pedologia,
Estação Agronómica Nacional,
Quinta Do Marques
P-2780 Oeiras, PORTUGAL
**Pedotransfer functions (PTFs)**

PTFs were obtained by stepwise regression analysis allowing the prediction of individual hydraulic parameters based on the basic soil properties, for different combinations of data sets:

(i) a pool of all soils,
(ii) three FAO textural groups,
(iii) soil textural classes.

The following soil properties were investigated as arguments of the PTFs:

1. soil texture (CS, FS, S, C),
2. mean particle diameter (GPD) and geometrical standard deviation (GSD),
3. bulk density ($\rho_b$),
4. organic matter content (OM),
5. pH,
6. mean soil depth (Z)
7. clay type - swelling or not (CT) (only for the PTFs concerning the hydraulic conductivity curve).

Selected hydraulic data were sometimes used as argument as well. The water content at h=2.5, 100 and 15000 cm water may be included in the PTFs for retention parameters whereas the PTFs for the conductivity could contain the measured saturated hydraulic conductivity.

**Results**

**PTFs for the parameters of the van Genuchten model (All Soils, N=230 samples, considering the basic soil properties):**

\[
\theta_r = 0.53 - 0.0048 \text{CS} + 0.0129 \log(\text{CS}) - 0.0013 \text{FS} - 0.047 \log(\text{FS}) - 0.0097 \text{S} + 0.0001 \text{S}^2 - 0.0258 \text{OM} - 0.0002 Z \quad \left( R^2_{adj} = 0.548 \right)
\]

\[
\theta_s = 0.68 + 0.0028 \text{CS} + 0.00003 \text{FS}^2 + 0.0063 \text{S} + 0.0005 \text{OM} - 0.0004 \text{Z} - 0.014 \text{pH} \quad \left( R^2_{adj} = 0.747 \right)
\]

\[
\log(\alpha) = -2.16 + 0.00016 \text{FS}^2 - 0.0184 \text{S} + 1.959 \text{GPD} - 0.584 \text{OM} - 0.005 \text{Z} + 0.0725 \text{pH} \quad \left( R^2_{adj} = 0.333 \right)
\]

\[
n = 3.57 - 0.015 \text{CS} - 0.078 \log(\text{FS}) - 0.00005 \text{FS}^2 - 508 \log(\text{S}) + 0.009 \text{S} - 0.396 \text{C} + 0.001 \text{Z} \quad \left( R^2_{adj} = 0.659 \right)
\]

**PTFs for the parameters of the Gardner model (All Soils, N=129 samples, considering the basic soil properties):**

\[
\log(\text{Ks}) = 3.4 + 2.17 \text{GPD} + 0.0023 \text{GSD} + 0.156 \text{pH} - 1.043 \text{OM} - 0.993 \text{CT} \quad \left( R^2_{adj} = 0.490 \right)
\]

\[
\log(\text{b}) = -88 + 0.89 \text{AG} + 0.125 \text{A} - 0.0005 \text{AG}^2 + 0.0004 \text{A} + 0.125 \text{MO} + 0.227 \text{pH} - 1.41 \text{OM} + 0.0044 \text{Z} - 0.445 \text{CT} \quad \left( R^2_{adj} = 0.504 \right)
\]

\[
\log(\text{p}) = 5.5 - 0.048 \text{AG} - 0.00024 \text{AG}^2 - 0.064 \text{AF} + 0.00012 \text{AF}^2 - 0.058 \text{L} + 0.00005 \text{L}^2 - 0.048 \text{A} + 2.21 \text{GPD} - 0.0008 \text{GSD} + 0.123 \text{OM} - 0.0005 \text{Z} - 0.0105 \text{pH} \quad \left( R^2_{adj} = 0.679 \right)
\]

**Conclusions**

Relatively poor predictions of the hydraulic parameters were obtained when the PTF was derived from basic soil properties of the entire data set. The prediction of log(\(\alpha\)) and log(b) especially was improved by using PTFs from data sets with a more uniform texture such as the textural groups and textural classes.

Basing the PTFs solely upon basic soil properties was the most successful method for predicting retention parameters for coarse soils, sands, loamy sands and clays and conductivity parameters for coarse and heavy soils and sands clay loams and clays.
As was supposed, improvements were obtained in the prediction of all parameters when the selected hydraulic data were included.

References


Section 8: Appendices
Section 8: Appendices

Attribute coding: Database Dictionary of the Soils geographical Database of Europe at scale 1:1,000,000
(Version: 3.21, 30/10/1996)

List of participants
ATTRIBUTE_CODING:
DATABASE DICTIONARY OF THE SOILS GEOGRAPHICAL DATABASE
OF EUROPE AT SCALE 1:1,000,000
VERSION 3.21, 30/10/1996

See also: metadata.txt, dictionary.txt.

How to read this file: each attribute is described by:

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Attribute names are sorted alphabetically.

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0 m2 when polygons, km2 when SMUs or STUs
... 100.003 ...

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S Sea

CFL (STU)
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H High confidence in the STU description
M Medium confidence in the STU description
L Low confidence in the STU description
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MAT1 (STU) NB: if parent material is drift or residuum from various rocks, then last number (unit) is coded "9".

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| 2 | Calcareous rocks |
| 3 | Clayey materials |
| 4 | Sandy materials |
| 5 | Loamy materials |
| 6 | Detrital formations |
| 7 | Crystalline rocks and migmatites |
| 8 | Volcanic rocks |
| 9 | Other rocks |
| No information |
| 10 | Undifferentiated alluvial deposits (or glacial deposits) |
| 11 | River alluvium |
| 12 | Estuarine/Marine alluvium |
| 13 | Glaciofluvial deposits |
| 14 | Glaciofluvial drift |
| 15 | Colluvium |
| 20 | Calcareous rocks |
| 21 | Limestone |
| 22 | Secondary chalk |
| 23 | Marl |
| 24 | Gypsum |
| 25 | Dolomite |
| 30 | Clayey materials |
| 31 | Old clayey sedimentary deposits |
| 32 | Alluvial or glaciofluvial clay |
| 33 | Residual clay from calcareous rocks |
| 34 | Claystone, mudstone |
| 35 | Calcareous clay |
| 40 | Sandy materials |
| 41 | Old sandy sedimentary deposits |
| 42 | Alluvial or glaciofluvial sands |
| 43 | Eolian sands |
| 44 | Coastal sands (Dune sands) |
| 45 | Sandstone |
| 50 | Loamy materials |
| 51 | Residual loam |
| 52 | Eolian loam |
| 53 | Siltstone |
| 60 | Detrital formations |
| 61 | Arkose |
| 62 | Breccia and Puddingstone |
| 63 | Flysch and Molasse |
| 64 | Ranas |
| 70 | Crystalline rocks and migmatites |
| 71 | Acid crystalline rocks (and migmatites) |
| 72 | Non acid crystalline rocks (and migmatites) |
| 73 | Crystalline metamorphic rocks |
| 74 | Schists |
| 75 | Other metamorphic rocks |
| 80 | Volcanic rocks |</p>
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EUROPEAN SOIL BUREAU — RESEARCH REPORT NO. 4

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Ul Luvic Ranker
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H Phaeozem
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>TD2</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No information</td>
</tr>
</tbody>
</table>
| 9       | No texture (histosols, ...)
| 1       | Coarse (clay < 18 % and sand > 65 %)
| 2       | Medium (18% < clay < 35% and sand > 15%, or clay < 18% and 15% < sand < 65%)
| 3       | Medium fine (clay < 35 % and sand < 15 %)
| 4       | Fine (35 % < clay < 60 %)
| 5       | Very fine (clay > 60 %)

515
<table>
<thead>
<tr>
<th>USE1</th>
<th>(STU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No information</td>
</tr>
<tr>
<td>1</td>
<td>Pasture, grassland, grazingland</td>
</tr>
<tr>
<td>2</td>
<td>Poplars</td>
</tr>
<tr>
<td>3</td>
<td>Arable land, cereals</td>
</tr>
<tr>
<td>4</td>
<td>Wasteland, shrub</td>
</tr>
<tr>
<td>5</td>
<td>Forest, coppice</td>
</tr>
<tr>
<td>6</td>
<td>Horticulture</td>
</tr>
<tr>
<td>7</td>
<td>Vineyards</td>
</tr>
<tr>
<td>8</td>
<td>Garrigue</td>
</tr>
<tr>
<td>9</td>
<td>Bush, macchia</td>
</tr>
<tr>
<td>10</td>
<td>Moor</td>
</tr>
<tr>
<td>11</td>
<td>Halophile grassland</td>
</tr>
<tr>
<td>12</td>
<td>Arboriculture, orchard</td>
</tr>
<tr>
<td>13</td>
<td>Industrial crops</td>
</tr>
<tr>
<td>14</td>
<td>Rice</td>
</tr>
<tr>
<td>15</td>
<td>Cotton</td>
</tr>
<tr>
<td>16</td>
<td>Vegetables</td>
</tr>
<tr>
<td>17</td>
<td>Olive-trees</td>
</tr>
<tr>
<td>18</td>
<td>Recreation</td>
</tr>
<tr>
<td>19</td>
<td>Extensive pasture, grazing, rough pasture</td>
</tr>
<tr>
<td>20</td>
<td>Dehesa (extensive agricultural-pasture system in forest parks in Spain)</td>
</tr>
<tr>
<td>21</td>
<td>Cultivos enarenados (artificial soils for orchards in SE Spain)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>(STU)</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>1</td>
<td>Yes, agricultural land normally has a water management system</td>
</tr>
<tr>
<td>2</td>
<td>No, agricultural land normally has no water management system</td>
</tr>
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<th>(STU)</th>
</tr>
</thead>
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</tr>
<tr>
<td>1</td>
<td>To alleviate waterlogging (drainage)</td>
</tr>
<tr>
<td>2</td>
<td>To alleviate drought stress (irrigation)</td>
</tr>
<tr>
<td>3</td>
<td>To alleviate salinity (drainage)</td>
</tr>
<tr>
<td>4</td>
<td>To alleviate both waterlogging and drought stress</td>
</tr>
<tr>
<td>5</td>
<td>To alleviate both waterlogging and salinity</td>
</tr>
</tbody>
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### WM3 *(STU)*

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</thead>
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<td>No information</td>
</tr>
<tr>
<td>1</td>
<td>Pumping</td>
</tr>
<tr>
<td>2</td>
<td>Ditches</td>
</tr>
<tr>
<td>3</td>
<td>Pipe underdrainage (network of drain pipes)</td>
</tr>
<tr>
<td>4</td>
<td>Mole drainage</td>
</tr>
<tr>
<td>5</td>
<td>Deep loosening (subsoiling)</td>
</tr>
<tr>
<td>6</td>
<td>'Bed' system (ridge-funow or steching)</td>
</tr>
<tr>
<td>7</td>
<td>Flood irrigation (system of irrigation by controlled flooding as for rice)</td>
</tr>
<tr>
<td>8</td>
<td>Overhead sprinkler (system of irrigation by sprinkling)</td>
</tr>
<tr>
<td>9</td>
<td>Trickle irrigation</td>
</tr>
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### WR *(STU)*

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</tr>
</thead>
<tbody>
<tr>
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<td>No information</td>
</tr>
<tr>
<td>1</td>
<td>Not wet within 80 cm for over 3 months, nor wet within 40 cm for over 1 month</td>
</tr>
<tr>
<td>2</td>
<td>Wet within 80 cm for 3 to 6 months, but not wet within 40 cm for over 1 month</td>
</tr>
<tr>
<td>3</td>
<td>Wet within 80 cm for over 6 months, but not wet within 40 cm for over 11 months</td>
</tr>
<tr>
<td>4</td>
<td>Wet within 40 cm depth for over 11 months</td>
</tr>
</tbody>
</table>

### ZMIN *(STU)*

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<th>Value</th>
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</tr>
</thead>
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<td>No information</td>
</tr>
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<tr>
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<tr>
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</tr>
<tr>
<td>1</td>
<td>m</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>1000</td>
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</tr>
<tr>
<td>1500</td>
<td>m</td>
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### ZMAX *(STU)*

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<tr>
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<td>m</td>
</tr>
<tr>
<td>2</td>
<td>m</td>
</tr>
<tr>
<td>3</td>
<td>m</td>
</tr>
<tr>
<td>5</td>
<td>m</td>
</tr>
<tr>
<td>3500</td>
<td>m</td>
</tr>
<tr>
<td>4000</td>
<td>m</td>
</tr>
</tbody>
</table>
DICTIONARY:
DATABASE DICTIONARY OF THE SOILS GEOGRAPHICAL DATABASE
OF EUROPE AT SCALE 1:1,000,000
VERSION 3.21, 30/10/1996

Last date modified: 10/12/1996 by Joël Daroussin.
See also: metadata.txt, attribute_coding.txt.

How to read this file: each object is described by:

<Object type> <OBJECT_NAME>
{More about object type}.
<Description of object>.
{Sources of data}.
{Contents, including description of attributes for Info files}.

CONTENTS:

$EURHOME

README    METADATA    DIAGRAM    DICTIONARY    ATTRIBUTE_CODING    DATABASE
-FIRST    .TXT    .EPS    .TXT

SOIL    COUNTRY

1 - Directory $EURHOME
1.1 - File README
1.2 - File METADATA.TXT
1.3 - File DIAGRAM.EPS
1.4 - File DICTIONARY.TXT
1.5 - File ATTRIBUTE_CODING.TXT
2 - Workspace DATABASE
2.1 - Coverage SOIL
2.1.1 - Info file SOIL.PAT
2.1.2 - Info file SMU
2.1.3 - Info file STU.ORG
2.1.4 - Info file STU
2.2 - Coverage COUNTRY
2.2.1 - Info file COUNTRY.AAT
2.2.2 - Info file COUNTRY.PAT
2.3 - Postscript file SOIL_DB_EUR.EPS
2.4 - Postscript file BD_SOLS_EUR.EPS
1 - Directory $EURHOME
System directory.
Project root directory.

1.1 - File README
Flat Ascii system file.
Delivery of the Soils Geographical Database of Europe at Scale 1:1,000,000.
First things first read-me file for installing the database.

1.2 - File METADATA.TXT
Flat Ascii system file.
Data about the Soils Geographical Database of Europe (identification, overview, quality, administrative...).
This file complies to the CEN (European Committee for Standardization) project for a standard metadata description for geographic information, prEN 287009, April 1996.
This file is also delivered as a Word 6 for Windows file named METADATA.DOC.

1.3 - File DIAGRAM.EPS
Postscript file providing a schematic diagram of the organization of the database.
To view the diagram with Aladin Ghostscript software, type the following command:
   gs -r70 -g580x810 diagram.eps

1.4 - File DICTIONARY.TXT
Flat Ascii system file.
Database dictionary of the Soils Geographical Database of Europe.
This file.
This file is also delivered as a Word 6 for Windows file named DICTIONA.DOC.

1.5 - File ATTRIBUTE_CODING.TXT
Flat Ascii system file.
Attribute coding description for Info file attributes of the Soils Geographical Database of Europe.
This file is also delivered as a Word 6 for Windows file named ATTRICOD.DOC.

2 - Workspace DATABASE
Arc/Info workspace.
Database of basic data.
The data stored here are considered being:
- self sufficient: all the data necessary to the project are stored here;
- stable: the data must not be modified by others than the database administrator for updating purposes. An update increments the database's version number. An update implies that any previous analyses be re-run;
- reliable: the data are considered as of the best possible quality.
For analysis purposes, copy the necessary basic data to another appropriate workspace.
2.1 - Coverage SOIL
Polygon topology.
Soil types in Europe.

Sources:
- CORINE program (CEC-DG XI);
- archives held in Gent University (B) of the attempt to publish the FAO Soil Map of Europe at scale 1:1,000,000 (1973-1974) for Eastern European countries;
- archives held in Gent University (B) of the published EC Soil Map at scale 1:1,000,000 (CEC, 1985) for European Union 12 countries.

Revisions:
- support: MARS project (JRC Ispra);
- general coordination: INRA (Institut National de la Recherche Agronomique), SESCPF (Service d'Etude des Sols et de la Carte Pedologique de France);
- national coordination: representatives of each country.

Projection: standard CORINE.

Units: meters
Nominal scale: 1:1,000,000
Precision: single

Dataset internal tolerances:
- fuzzy set to 100 m (0.1 mm accuracy at scale 1:1,000,000)
- minimum polygon area set to 9 ha (0.3 x 0.3 mm at scale 1:1,000,000)

Spatial index(es): on arcs and polygons.
See also figure in Postscript file diagram.eps.

2.1.1 - Info file SOIL.PAT
Polygon attribute table for coverage SOIL.

Key attribute: SOIL#.
Sorted on: SOIL# (ascending order).

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>ITEM NAME</th>
<th>WIDTH</th>
<th>OUTPUT</th>
<th>TYPE</th>
<th>N.DEC</th>
<th>INDEXED?</th>
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</thead>
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<td>12</td>
<td>F</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>PERIMETER</td>
<td>4</td>
<td>12</td>
<td>F</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>SOIL#</td>
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<td>5</td>
<td>B</td>
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<td>-</td>
</tr>
<tr>
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<td>SOIL-ID</td>
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<td>5</td>
<td>B</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>SMU</td>
<td>7</td>
<td>7</td>
<td>I</td>
<td>-</td>
<td>Indexed</td>
</tr>
</tbody>
</table>

AREA
Area of polygon (in square metres).

PERIMETER
Perimeter of polygon (in metres).

SOIL#
Arc/Info internal identifier for polygon.

SOIL-ID
User's identifier for polygon.

SMU
Soil Mapping Unit number: identifier of Soil Mapping Unit to which the polygon belongs.
2.1.2 - Info file SMU
Table describing the Soil Mapping Units.
Key attribute: SMU.
Sorted on: SMU (ascending order).

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>ITEM NAME</th>
<th>WIDTH</th>
<th>OUTPUT</th>
<th>TYPE</th>
<th>N.DEC</th>
<th>INDEXED?</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
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<td>7</td>
<td>I</td>
<td>-</td>
<td>Indexed</td>
</tr>
<tr>
<td>8</td>
<td>NB-POLYS</td>
<td>4</td>
<td>5</td>
<td>B</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>AREA</td>
<td>8</td>
<td>8</td>
<td>F</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>NB-STU</td>
<td>4</td>
<td>2</td>
<td>B</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

SMU: Soil Mapping Unit number: identifier of Soil Mapping Unit. NB: an SMU can belong to more than one country.

NB-POLYS: Number of polygons making SMU as computed by CHECK_AND_BUILD_SOILDB.AML.

AREA: Area of SMU (in square kilometers) as computed by CHECK_AND_BUILD_SOILDB.AML.

NB-STU: Number of STUs composing SMU as computed by CHECK_AND_BUILD_SOILDB.AML.
2.1.3 - Info file STU.ORG
Table describing the organization (arrangement) of Soil Typological Units within each Soil Mapping Unit.
Key attributes: SMU and STU.
Sorted on: SMU (ascending order), PCAREA (descending), and STU (ascending).

<table>
<thead>
<tr>
<th>COLUM</th>
<th>ITEM NAME</th>
<th>WIDTH</th>
<th>OUTPUT</th>
<th>TYPE</th>
<th>N.DEC</th>
<th>INDEXED?</th>
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<td>3</td>
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</tr>
</tbody>
</table>

SMU      Soil Mapping Unit number: identifier of Soil Mapping Unit.
STU      Soil Typological Unit number: identifier of Soil Typological Unit.
PCAREA   Proportion (percent) of the area of the Soil Mapping Unit covered by the Soil Typological Unit (for each SMU, sum of PCAREA is 100%).

2.1.4 - Info file STU
Table describing the Soil Typological Units.
Key attributes: STU.
Sorted on: STU (ascending order).

<table>
<thead>
<tr>
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<th>ITEM NAME</th>
<th>WIDTH</th>
<th>OUTPUT</th>
<th>TYPE</th>
<th>N.DEC</th>
<th>INDEXED?</th>
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</table>

**REDEFINED ITEMS**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
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</tr>
<tr>
<td>24</td>
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<td>40</td>
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<tr>
<td>40</td>
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<td>C</td>
</tr>
<tr>
<td>43</td>
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<td>1</td>
<td>1</td>
<td>C</td>
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<tr>
<td>43</td>
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<td>1</td>
<td>C</td>
</tr>
<tr>
<td>26</td>
<td>SN3</td>
<td>1</td>
<td>1</td>
<td>C</td>
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<tr>
<td>40</td>
<td>PM11</td>
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<td>1</td>
<td>C</td>
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<td>PM21</td>
<td>1</td>
<td>1</td>
<td>C</td>
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<tr>
<td>44</td>
<td>PM22</td>
<td>1</td>
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<td>C</td>
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<tr>
<td>45</td>
<td>PM23</td>
<td>1</td>
<td>1</td>
<td>C</td>
</tr>
<tr>
<td><strong>STU</strong></td>
<td>Soil Typological Unit number: identifier of Soil Typological Unit. NB: at this time, an STU can only belong to not more than one country.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NB-POLYS</strong></td>
<td>Number of polygons containing STU as computed by CHECK_AND_BUILD_SOILDB.AML.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NB-SMU</strong></td>
<td>Number of SMUs containing STU as computed by CHECK_AND_BUILD_SOILDB.AML.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AREA</strong></td>
<td>Area of STU (in square kilometers) as computed by CHECK_AND_BUILD_SOILDB.AML.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SOIL</strong></td>
<td>Full 1974 (modified CEC 1985) FAO legend soil name.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SOIL90</strong></td>
<td>Full 1990 FAO legend soil name.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TEXT1</strong></td>
<td>Dominant surface textural class.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TEXT2</strong></td>
<td>Secondary surface textural class.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SLOPE1</strong></td>
<td>Dominant slope class.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SLOPE2</strong></td>
<td>Secondary slope class.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE1</strong></td>
<td>Dominant phase.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PHASE2</strong></td>
<td>Secondary phase.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MAT1</strong></td>
<td>Dominant parent material code.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MAT2</strong></td>
<td>Secondary parent material code.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ZMIN</strong></td>
<td>Minimum above sea level altitude (in metres).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ZMAX</strong></td>
<td>Maximum above sea level altitude (in metres).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>USE1</strong></td>
<td>Dominant land use.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>USE2</strong></td>
<td>Secondary land use.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DT</strong></td>
<td>Depth class to textural change.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD1</strong></td>
<td>Dominant sub-surface textural class.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD2</strong></td>
<td>Secondary sub-surface textural class.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ROO</strong></td>
<td>Depth class of an obstacle to roots.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IL</strong></td>
<td>Presence of an impermeable layer within the soil profile.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WR</strong></td>
<td>Dominant annual average soil water regime class of the soil profile.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WM1</strong></td>
<td>Normal presence of a water management system in agricultural land.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WM2</strong></td>
<td>Purpose of the water management system.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WM3</strong></td>
<td>Evident type of water management system.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CFL</strong></td>
<td>Global confidence level of the Soil Typologic Unit attributes description.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**REDEFINED ITEMS**

| **SOIL1** | First level 1974 (modified CEC 1985) FAO legend soil name. |
| **SOIL2** | Second level 1974 (modified CEC 1985) FAO legend soil name. |
| **SOIL3** | Third level 1974 (modified CEC 1985) FAO legend soil name. |
| **SOIL901** | First level 1990 FAO legend soil name. |
| **SOIL902** | Second level 1990 FAO legend soil name. |
| **MAT11** | First level dominant parent material code. |
| **MAT12** | Second level dominant parent material code. |
| **MAT21** | First level secondary parent material code. |
| **MAT22** | Second level secondary parent material code. |
| **SN1** | First character in item SOIL (meant for pedotransfer rules) |
| **SN2** | Second character in item SOIL (meant for pedotransfer rules) |
| **SN3** | Third character in item SOIL (meant for pedotransfer rules) |

524
<table>
<thead>
<tr>
<th>PM11</th>
<th>First character in item MAT1 (meant for pedotransfer rules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM12</td>
<td>Second character in item MAT1 (meant for pedotransfer rules)</td>
</tr>
<tr>
<td>PM13</td>
<td>Third character in item MAT1 (meant for pedotransfer rules)</td>
</tr>
<tr>
<td>PM21</td>
<td>First character in item MAT2 (meant for pedotransfer rules)</td>
</tr>
<tr>
<td>PM22</td>
<td>Second character in item MAT2 (meant for pedotransfer rules)</td>
</tr>
<tr>
<td>PM23</td>
<td>Third character in item MAT2 (meant for pedotransfer rules)</td>
</tr>
</tbody>
</table>
2.2 - Coverage COUNTRY
Network topology (polygon + arc).
Boundaries of EC countries.

Sources: this coverage was built from several coverages:
1. coastlines were extracted from the SOIL coverage;
2. terrestrial boundaries were extracted from the OUTLINE coverage provided by CORINE, and then snapped to 1, except:
3. terrestrial boundary between England and Scotland which was extracted from the NUEC (NUTS regions) coverage, and then snapped to 1;
4. coastlines for Yugoslavia and Albania were extracted from Digital Chart of the World (DCW).

Spatial index(es): on arcs.

2.2.1 - Info file COUNTRY.AAT
Arc attribute table for coverage COUNTRY.

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>ITEM NAME</th>
<th>WIDTH</th>
<th>OUTPUT</th>
<th>TYPE</th>
<th>N.DEC</th>
<th>INDEXED?</th>
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<td>-</td>
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<tr>
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<td>-</td>
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<tr>
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<td>LPOLY#</td>
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<td>5</td>
<td>B</td>
<td>-</td>
<td>-</td>
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<td>RPOLY#</td>
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<td>12</td>
<td>F</td>
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<td>-</td>
</tr>
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<td>-</td>
</tr>
<tr>
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<td>B</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>29</td>
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<td>1</td>
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<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>PE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**BORDER_TYPE**  
Type of border line.
2.2.2 - Info file COUNTRY.PAT
Polygon attribute table for coverage COUNTRY.

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>ITEM NAME</th>
<th>WIDTH</th>
<th>OUTPUT</th>
<th>TYPE</th>
<th>N.DEC</th>
<th>INDEXED?</th>
</tr>
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<tbody>
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<td>12</td>
<td>F</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>PERIMETER</td>
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<td>12</td>
<td>F</td>
<td>3</td>
<td>-</td>
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<td>4</td>
<td>5</td>
<td>B</td>
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<td>-</td>
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<tr>
<td>13</td>
<td>COUNTRY-</td>
<td>5</td>
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<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>ID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>COUNTRY</td>
<td>3</td>
<td>3</td>
<td>I</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

AREA Area of polygon (in square meters).
PERIMETER Perimeter of polygon (in meters).
COUNTRY# Arc/Info internal identifier for polygon.
COUNTRY- User's identifier for polygon.
ID
COUNTRY Country code: identifier of country.

2.3 - Postscript file SOIL_DB_EUR.EPS
Postscript language file.
English logo of the Soils Geographical Database of Europe at Scale 1:1,000,000.
Includes database name, copyright and logo of the European Soil Bureau.
Should be displayed on any published document (in English) representing extractions from the database.

2.4 - Postscript file BD_SOLS_EUR.EPS
Postscript language file.
French logo of the Soils Geographical Database of Europe at Scale 1:1,000,000.
Includes database name, copyright and logo of the European Soil Bureau.
Should be displayed on any published document (in French) representing extractions from the database.
METADATA:
DATA ABOUT THE SOIL GEOGRAPHICAL DATABASE OF EUROPE

This file complies with the CEN (European Committee for Standardization) project for a standard metadata description for geographic information, prEN 287009, April 1996.

DATASET IDENTIFICATION

Dataset title:
Soil Geographical Database of Europe at Scale 1:1,000,000 version 3.21, 30/10/1996.

Alternative title:
Soil Geographical Database of Europe.

Alternative title:
Base de Données Géographique des Sols d'Europe au 1/1 000 000 version 3.21, 30/10/1996.

Alternative title:
Base de Données Géographique des Sols d'Europe.

Abbreviated title:
SGDE.

DATASET OVERVIEW

Abstract:
The Soil Geographical Database of Europe at Scale 1:1,000,000 is part of the European Soil Database. It is the resulting product of a collaborative project involving all the European Union and neighbouring countries. It is a simplified representation of the diversity and spatial variability of the soil coverage. The methodology used to differentiate and name the main soil types is based on the terminology of the F.A.O. legend for the Soil Map of the World at Scale 1:5,000,000. This terminology has been refined and adapted to take account of the specificities of the landscapes in Europe. It is itself founded on the distinction of the main pedogenetic processes leading to soil differentiation: brunification, lessivage, podzolisation, hydromorphie, etc.

The database contains a list of Soil Typological Units (STU). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example the texture, the water regime, the stoniness, etc. The geographical representation was chosen at a scale corresponding to the 1:1,000,000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMU) to form soil associations and to illustrate the functioning of pedological systems within the landscapes (see figure below or in Postscript file diagram.eps).

Harmonisation of the soil data from the member countries is based on a dictionary giving the definition for each occurrence of the variables. Considering the scale, the precision of the variables is weak. Furthermore these variables were estimated over large areas by expert judgement rather than measured on local soil samples. This expertise results from synthesis and generalisation tasks of national or regional maps published at more detailed scales, for example 1:50,000 or 1:25,000 scales. Delineation of the Soil Mapping Units is also the result of expertise and experience. Heterogeneity can be considerable in European regions. The spatial variability of soils is very important and is difficult to express at global levels of precision. Quality indices of the information (purity and confidence level) are included with the data in order to guide usage.

Purpose of production:
To provide a harmonised and spatially exhaustive coverage of soil types and descriptions in European participating countries at a resolution compatible with a 1:1,000,000-scale map.
Usage:
Soil spatial data query, extraction and thematic mapping, soil spatial data layer input to agro-environmental models (e.g. soil erosion risk, yield forecasting).

INFORMATION ORGANIZATION
IN THE SOIL GEOGRAPHICAL DATABASE OF EUROPE

SMU 1
- geometrically defined by 2 polygons
- composed of STU 10 and 11

SMU 2
- geometrically defined by 1 polygon
- composed of STU 12

SMU 3
- geometrically defined by 3 polygons
- composed of STU 13 and 14

SMU 4
- geometrically defined by 1 polygon
- composed of STU 10
(which also is part of SMU 1)

PEDOLOGICAL LANDSCAPE

Polygon Attribute Table

<table>
<thead>
<tr>
<th>AREA</th>
<th>SMU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

SPATIALIZED DATABASE

Semantic dataset

Geometric dataset

STU Attribute Table

<table>
<thead>
<tr>
<th>SMU</th>
<th>STU</th>
<th>% AREA</th>
</tr>
</thead>
<tbody>
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<td>3</td>
<td>13</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

STU.ORG

1, 0

1, n

n, n

n, 1

1, 1

529
Spatial sub-schema type:
Topological planar graph.

Spatial reference system type:
Positioning by Lambert Azimuthal coordinates.

Language:
English.

Document reference:
CEC, 1985 - Soil map of the European Communities at 1:1,000,000. CEC-DGVI. Brussels, Belgium. 124 pp.

Sample:
No sample dataset provided, but a Postscript file (diagram.eps) provides a schematic diagram of the organization of the database.

Related datasets:
Soil Profiles Database of Europe for Scale 1:1,000,000.

DATASET QUALITY INDICATORS

Process history:
1974: soil information was compiled and harmonised over Europe at 1:1,000,000 scale by Prof. R. Tavernier (B) (coordinator) and national representatives under FAO funding. Project was abandoned before map publication due to lack of funding.
1985: a map limited to the 12 EC member countries is published by Prof. R. Tavernier (B) (coordinator) and national representatives under CEC-DG VI for Agriculture funding:
→ Soil Map of the European Communities at scale 1:1,000,000 (CEC, 1985).
1986: the EC Soil Map and legend are computerized at ADK (Danish Bureau of Land Data, DK) under CORINE program (CEC-DG XI for Environment) funding:
→ EC Soil Database (Platou et al., 1986).
1988: the database is geo-registered to ONC (Operational Navigation Charts) map sheets at Birbeck College (GB) under CORINE program (CEC-DG XI) funding:
→ EC Soil Database version 1.
1991: 1) soil database attributes are added using the original FAO project archives (i.e. before across-country harmonisation) by D. King (MARS project, CEC-DG VI);
2) errors checked against original map and corrected in database by INRA (National Agronomic Research Institute, F) under MARS project funding:
→ EC Soil Database version 2 (King et al., 1994).
1992: start computerization of Eastern countries from FAO project archives under MARS project funding:
→ Eastern countries Soil Databases at level of EC Soil Database version 2.
1995: 1) database is further geo-registered through “rubber-sheeting” adjustment to drainage, political, ocean and populated places layers in DCW (Digital Chart of the World database) by INRA (F) under MARS project funding:
2) database is checked for errors and new attributes are added by Contributing Organisations within database member countries, coordination and data management by INRA (F), funding from MARS project:
→ EC Soil Database version 3 (King et al., 1995).
1996: database is extended to several non EU countries by Contributing Organisations within new database member countries, coordination and data management by INRA (F), funding from MARS project:
→ EC Soil Database version 3.1.
1996: minor corrections, minor database structure modifications by INRA (F), border harmonisation for some countries by Contributing Organisations, coordination and data management by INRA (F), funding from MARS project:

→ EC Soil Database version 3.21.

**Overall positional accuracy:**
Estimated: 500 - 5000 m (0.5 - 5 mm at scale 1:1,000,000). Dataset internal tolerance set to 100 m (0.1 mm at scale 1:1,000,000). Minimum polygon area set to 9 ha (0.3 x 0.3 mm at scale 1:1,000,000).

**Overall thematic accuracy:**
1. Each Soil Typological Unit in the database is characterised by a overall confidence level (high, medium, low; see further "data definition and classification").
2. All polygons representing areas above 25 km2 have been checked/corrected against original soil map.
3. There is a remaining heterogeneity among database member countries in the mapping methodology (e.g. discrepancies in the amount of detail given to object geometry and/or description).
4. This version of the database lacks border harmonisation for some countries.

**Overall temporal accuracy:**
No temporal values within the dataset. The earliest data are from 1980, the latest from 1996. Year of reference of each object is not indicated.

**Overall logical accuracy:**
100% structural integrity according to tests carried out by coordinator (INRA, F).

**Overall completeness:**
Estimated 90% (there is still some missing information for some attributes).

**SPATIAL REFERENCE SYSTEM**

**INDIRECT SPATIAL REFERENCE SYSTEM:**

*Type of indirect spatial reference system:*
By country.

*Reference date:*
1996.

**DIRECT SPATIAL REFERENCE SYSTEM:**

*Datum:*
Lambert azimuthal.

*Ellipsoid:*
International 1909.
Map projection:
Projection: LAMBERT_AZIMUTHAL
Units: METERS
Spheroid: DEFINED
  Major Axis: 6370997.00000
  Minor Axis: 0.00000
Parameters:
  radius of the sphere of reference: 6370997.00000
  longitude of center of projection: 9° 0’ 0.000
  latitude of center of projection: 48° 0’ 0.000
  false easting (meters): 0.00000
  false northing (meters): 0.00000

Height reference system:
Mean sea level.

EXTENT

CURRENCY OF EXTENT DATA AND COMPLETENESS OF DATASET:

Extent date:
30/10/1996

Extent status:
100% of the extent covered.

PLANAR EXTENT:

Bounding XY:
  Min XY: -1594087.250 -1335931.250
  Max XY:  1714229.625  1463266.625

Bounding Area:
Definition: -

Geographic area:
Type of indirect spatial reference system:
  by country.
Name of areal unit:
  GREECE, NETHERLANDS, BELGIUM, FRANCE, SPAIN, HUNGARY, ITALY, ROMANIA,
  DENMARK, POLAND, GERMANY, PORTUGAL, LUXEMBOURG, IRISH REPUBLIC,
  BULGARIA, CZECH REPUBLIC, SLOVAKIA, ENGLAND AND WALES, SCOTLAND,
  NORTHERN IRELAND.
Id code of areal unit:
  30, 31, 32, 33, 34, 36, 39, 40, 45, 48, 49, 351, 352, 353, 359, 421, 422, 440, 441, 442.
Coverage:
  all countries 100%.
VERTICAL EXTENT:

Min elevation value:
-6 m

Max elevation value:
4000 m

TEMPORAL EXTENT:

From date:
Not applicable.

To date:
Not applicable.
DATA DEFINITION

APPLICATION SCHEMA DESCRIPTION:
Application schema id: SOIL.
Application schema text: Soil types in Europe.

OBJECT TYPE:
Object type name:
Object type definition:
Geometric primitive type:
Structure primitive type:
Object type code:
Occurrences:
Positional accuracy:
Thematic accuracy:
Completeness:

ATTRIBUTE TYPE:
Attribute type name: See file dictionary.txt, paragraph 2.1.
Attribute type definition:
Attribute type code:
Attribute type domain:
Thematic accuracy:
Temporal accuracy:

ASSOCIATION TYPE:
Association type name:
Association type definition:
From object type:
To object type:
Cardinality:
Constraints:
Thematic accuracy:
Logical consistency:
CLASSIFICATION

THESAURUS:
Name of thesaurus:
Thesaurus administrator:

THESAURUS ELEMENT:
Term:
Definition:
Synonyms: See file
Related term: attribute_coding.txt.
Broader term:
Narrower term:
Picture:

ADMINISTRATIVE METADATA

ORGANISATION AND ORGANISATION ROLE:
Organisation name:
European Soil Bureau.
Abbreviated organisation name:
ESB.
Organisation address:
European Soil Bureau, Space Applications Institute, Joint Research Centre, TP 440, Ispra Establishment 21020 Ispra (Va), ITALY.
Organisation role:
Distributor.
Alternative organisation name:
Bureau Européen des Sols.
Function of organisation:
Scientific committee for coordination on soil information in Europe.

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DISTRIBUTION:

Restrictions on use:
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536
Pricing policy:
Yearly leasing, by project leasing, reduced pricing at second project, for details see Point of contact.

Unit of distribution:
First project: whole dataset.

Media:
CD-ROM

Formats:
All files are flat Ascii text with no compression, delivered with metadata information and a README_FIRST explanatory text for use of distribution formats:
1) Arc/Info EXPORT (usable by Arc/Info sites);
2) Arc/Info UNGENERATE for polygon geometry and flat Ascii files for attribute tables (usable by other mapping or GIS systems).

On-line access:
No on-line dataset delivery.
There will be WWW product brochure at http://aisws6.jrc.it:2001/ais.html

Order:
See Point of contact.

Support services:
See Point of contact.
METADATA REFERENCE

Entry date:  
18/06/1996

Last check date:  
02/12/1996

Last update date:  
02/12/1996

Future review date:

Spatial reference system of metadata:
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European Soil Bureau Research Reports:


This volume contains a large number (45) papers on the subject of soil and land information systems and their application for planning the sustainable use of the land resources of Europe. The Proceedings are divided into 8 sections. Section 1 gives The European Perspective on the compilation, management, distribution and application of soil and land related databases. The background to the establishment of the European Soil Bureau is described. A framework for a European Soil Information System is put forward. The concept of data ownership is introduced and data distribution procedures are proposed. There is also a report on a forest soils database for monitoring atmospheric pollution at EU level.

The National Perspective in Europe is presented in Section 3 – 17 papers from all over the continent – and some trends are emerging. Section 4 contains 11 papers on Techniques and Technologies. The application of Fuzzy Logic and the integration of GIS and RDBMS will undoubtedly play a significant part in future developments. The use of information systems for solving practical problems is a major goal and Section 5 comprises 8 papers describing Environmental Applications. Soil and land information has always been used for Land Evaluation and this is the subject of Section 6. Section 7 comprises Poster presentations and Section 8 lists the Database Dictionary for the Soil Geographical Database of Europe and the list of Participants.