A Geographical Information System for Soil Analysis and Mapping: HunSIS (Concepts and Functionality)

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Introduction, a brief review of soil information systems

The permanently increasing need for rational land use and management require adequate information on the soil. This leads to an enormous amount of soil data and maps. These data are being digitalized, edited and incorporated into digital databases. Systems providing input/output functions in both graphic and tabular form, database management and analysis tools for spatial data have been defined as geographical information systems since the late 1970's /TOMLINSON et al., 1976/.

The role of computers rapidly increased in handling large amounts of observations, however, in case of map makers there are additional constraints and requirements to traditional databases. Recognition of the need to introduce computer technology in mapping has led to digital cartography, specifically suitable for natural resource surveys. In general digital cartography means the formulation of the following basic features: /1/ the need for explicit coding of spatial relationships, i.e. for defining the topological structure, /2/ the need for numeric coding of attributes of map-elements, /3/ the need for transforming spatial data to bit-streams for computers /McEWEN et al., 1983/.

While in a number of fields /like geology, planning, etc./ there seemed to be a straightforward implementation of this new technology, soil science, being a relatively young branch itself, did not join this intensive research development and user community at an early phase. The dramatic boom of computers and information processing techniques reached pedologists with very different approaches to soil mapping. At that time the only common feature of soil scientists and computer cartography was that both required computers.

It was in Wageningen /Netherlands/ in 1975 that the Working Group on Soil Information Systems of the International Society of Soil Science held its first meeting. The major aim of this conference was to exchange experience and information on system developments and also to outline an international data transfer standard that could facilitate efficient exchange of information taking into consideration rather different mapping /e.g. classification, scale/ tradition /BIE and SCHELLING, 1975/. Due to the regular meetings of this working group research and development in the field of soil information systems at different places can communicate with each other and share the accumulated expertise.

The two major distinct approaches to soil information systems are rooted in /1/ operational advisory services and /2/ research. There are several dimensions of differences: in terms of soil parameters to be stored and access ways to individual data /BECKETT, 1983/. In terms of spatial addressing of objects that is based on the underlying map model of the system. In terms of interactivity in both input /e.g. digitization/ and output /e.g. graphics screens and hardcopy devices/; and, in general, the functional definitions of subsystems to serve as an information system /VAN-ORSHOVEN et al., 1988/.

Historically centralized, mainframe based systems came first with very limited interactive, especially graphic, capabilities. It was in the early 80's when minicomputers, professional micros, workstations and their networks provided the opportunity to develop distributed systems. Such systems can be characterized by much more flexible workload distribution, share of resources and information access. In addition to hardware upgrades the popularity of easy-to-use graphical program packages also increased, that lead to a wide variety of locally designed and implemented systems which seemed to be much less similar to each other from a soil scientific user point of view than in their use of computers.

Compatibility of soil information systems can also be judged in terms of data content. Traditional description of soils by horizons and assigning characteristic values of soil chemical /e.g. acidity, anion/cation conditions/ and physical /e.g. texture, stickiness/ parameters is typical of almost all of these systems. There are systems where overall descriptors are also stored /e.g. soil type, slope/. Advisory systems generally contain information on nutrient status as well, and in some cases the handling of dynamic variables had to be solved.

While in case of data content differences are mainly caused by different terminology or measurement standards, spatial object referencing is a crucial point in evaluating compatibility and/or functionality of a system. Let us exclude from further discussion all those systems which apply a certain code /sometimes called "geocode"/ to identify objects whose exact location in space cannot be found out from the database. One basic spatial identifier for a soil scientist must be the /point-like/ location of a soil profile. Areal identifiers can have the form of a grid-cell, polygons /patches or agricultural fields, where in the latter case often only the boundary arcs are stored/. Since the relationships of different spatial objects is rather complicated, hierarchical and statistical at the same time /for better understanding of the soil landscape and thus enhancing our power of predicting soil conditions/ /BIE and SCHELLING, 1975/, a great number of systems handles only one of them: For instance, soil modelling systems use only profile data without providing information on spatial distribution, advisory and/or gridoriented systems store only one "characteristic" value per field without reflecting the natural phenomena, and CAD-oriented /vector-graphics/ systems treat the soil surface as a continuum of step functions. There is no direct relationship between the applied map-database model and the spatial extent of the coverage of the information systems /e.g. local-farm, regional, national, global/, there are examples of various implementations at various scales. The last aspect of soil information systems to be shortly discussed here is their functionality as adjusted to their purpose of application. Operational systems assisting advisory services most frequently examine and evaluate the suitability of the land to the cultivation of a certan kind of crop and the comparison of optimum and actual values of predetermined critical parameters is in the focus of their interest. Research supporting systems, however, have a general goal of collecting and processing information with more flexibility to enable the efficient incorporation of expertise. These systems aim to overcome the limitations of present operational systems even if their strategy may not be widely feasible today. The rapid increase in the application of sophisticated mathematical-statistical tools in soil information systems is due to two key problems: /1/ the quantitative interpretation and modelling of genetic soil processes in space and time, and /2/ the accurate handling of errors, their sources and propagation in terms of geometry and attributes of maps being processed /CSILLAG and KUMMERT, 1989a; WEBSTER, 1975/.

HunSIS - concepts and data sources

HunSIS is the acronym for Hungarian Soil Information System. In Hungarian it is abbreviated as "TIR", while its software is called SzATIR standing for computerized soil information system.

Concepts

Scientifically based planning and implementation of rational land use and management /amelioration, irrigation, drainage, agrotechnics, etc./, ensuring the maintenance or increase of soil fertility require adequate /i.e. well-defined, quantitative, territorial/ information on the soil /VÁRALLYAY, 1989; VÁRALLYAY et al., 1982; 1988/. A large amount of such information is available in Hungary as a result of numerous soil surveys, analysis, and mapping projects accomplished in the last 50 years /VÁRALLYAY, 1989/. The comprehensive and up-to-date synthesis, and the systematically controlled processing of this amount of soil profile data and maps require a computerized cartographic soil information system. This would enable soil scientists to establish and verify relationships concerning soil properties, soil characteristics and environmental factors or crop yields, as well as to survey soil types and monitor soil processes, such as erosion, water- and plant-nutrients dynamism, acidification, salinization, alkalization, structure destruction, compaction, etc. /CSILLAG, 1986/.

Based on these foundations the HunSIS project team has been working on new terminology, data standards, data formats, data quality requirements. This also proved to be a major step toward communication /networking and data transfer formats/ standards for geographical information systems in Hungary. The fast and widespread use of geographic information systems necessitate an entirely different understanding of basic cartographic terms. /like accuracy, resolution/ and data handling technology. Such systems generally consist of several /input, storage, retrieval and analysis, and output/ subsystems, and are capable of cartographic information processing by computer /MARBLE, 1984/.

Data sources

Geometric/geodetic base - A number of thematic information systems have been designed in Hungary without a common reference system /CSILLAG, 1985/. The initiative for a Unified National Map System /UNMS/ was introduced and approved for all computerized cartographic applications in 1981 /JOÓ, 1985/. The UNMS involves the regulations for projection, scale, topographic data content and quality, and it consequently opened the possibility for establishing the geodetic data standards and geographic reference system of the HunSIS /HEGEDŰSNÉ, 1984/. This also proved to be a major step toward communication /networking and data transfer formats/ standards for geographical information systems in Hungary.

Soil data - The main sources of soil information /data/ are as follows: /VÁRALLYAY, 1989; VÁRALLYAY et al., 1982/:

- 1:25 000 KREYBIG soil maps /prepared for the whole country between 1935 and 1955/, supplemented by an explanatory booklet, including the morphological description of soil profiles, data of field observation and laboratory analyses;
- 1:10 000 genetic soil maps /prepared for 60% of Hungary between 1960 and 1970/; consists of a genetic soil map; thematic maps on the most important soil properties and recommendations for rational land use and agrotechnics; and an explanatory booklet, including the morphological description of soil profiles, data of field observations and laboratory analyses;
- data of soil profiles described and analysed within the framework of the Hungarian soil evaluation programme /1980-/;
- 1:100 000 maps of soil factors determining the agro-ecological potential of Hungary /1975-1980/. This is a complete data set in standardized map and tabular form /VÁRALLYAY et al., 1978, 1982, 1985/.
- 1:100 000 agro-topographical maps /with the contribution of L. SZŰCS, in: VÁRALLYAY, 1989/.

All sorts of input data are collected by MTA TAKI and rigorous coding rules have been developed for profile data, and experienced soil surveyors and cartographers compile the input maps from existing data /for detailed data content refer to Appendix I and CSILLAG, 1986/.

System description - The data stored and processed in HunSIS is available in both graphic and digital form to assist large scale mapping of soils and monitoring of soil processes. To accomplish these tasks the software known as SzATIR has been designed and is being developed. SzATIR is designed to accept digitizer input, to provide comprehensive information system facilities and to produce cartographic and statistical output. The distributed system is operational for an approximately 10,000 km^2 area /Pest County/ to search for either location or attributes and display results in a graphic and/or tabular form. Current system development is focused upon the enhancement of local /i.e. workstation/ modelling and editing functions, as well as to make this quadtree based thematic GIS compatible with other data sources /Fig. 1/.

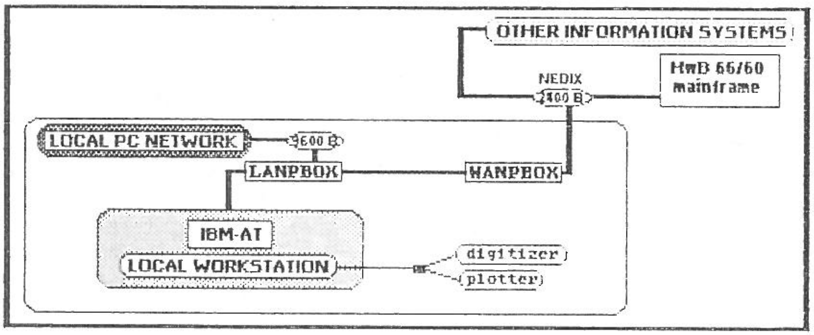

Fig. 1

HunSIS - system scheme

In system design several aspects were taken into consideration from both soil and computer scientific point of view. One of the basic aims for pedologists has been the creation of a system that can iterate to a stage, where experienced soil surveyors can be modelled in constructing soil maps from borings. Another approach emphasized the non-production oriented use of the system resulting in a mixture of low speed/high quality software and hardware. The system is well connected to the Hungarian scientific /X.25 based/ computer network /called IIF/.

Data capture - There are two main data types entered into HunSIS as described above: soil profile data and 1:25 000 scale soil maps /Fig.2/.

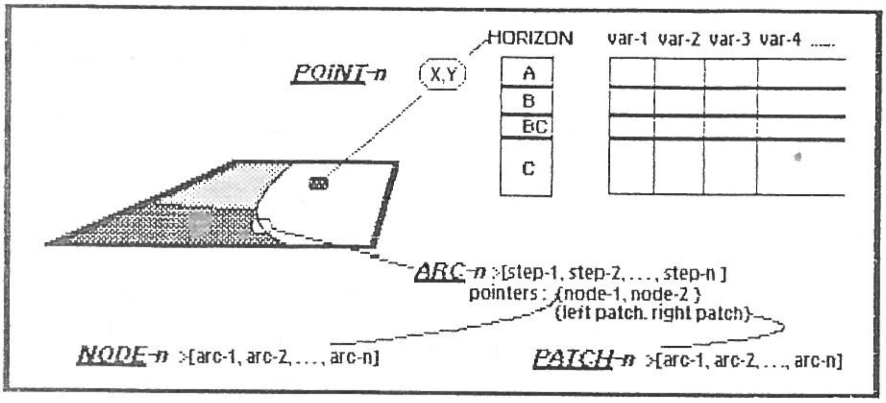

Fig. 2
HunSIS input data encoding

The input subsystem handles these data in a unified manner, providing more enhanced attribute handling for profile data, while more sophisticated geometric/topologic control for maps. Both data types can be entered from any projection with ground control points registered to UNMS.

For point data the coding scheme defines all accessible fields /64 altogether including depth limits of horizons/. Data sources are also entered in addition.

Map data are digitized in an easy-to-use AutoCAD-like environment with maximized auto-check and auxilliary functions. Arcs are digitized with higher geometrical accuracy than the required nominal resolution of the database, because they are filtered later on. As seen in Fig. 2., patches are built up automatically from digitized arcs, who have pointers to their nodes. New entry to an existing map is immediately checked against previous nodes, arcs and polygons taking some time for preprocessing, but minimizing operator error. The input subsystem can store input data at any stage and can export it for further local processing or completely checked /topological/ data can be sent to the host of the database via network.

Data base management system - There are two controversial requirements concerning data base management: /1/ to minimize storage space for the compensation of the slow modem /cf. interactivity/ and /2/ to optimize map/ data processing capabilities.

These requirements lead up to a combination of indices by area and by attribute, where geometry is stored in very space-efficient increment mode, while users' queries access data in region quadtree representation /see Fig. 3/.

Quadtrees of regions are constructed by pages /256x256 pixels, 6400 m x6400 m/: first boundaries are encoded and their regions are converted

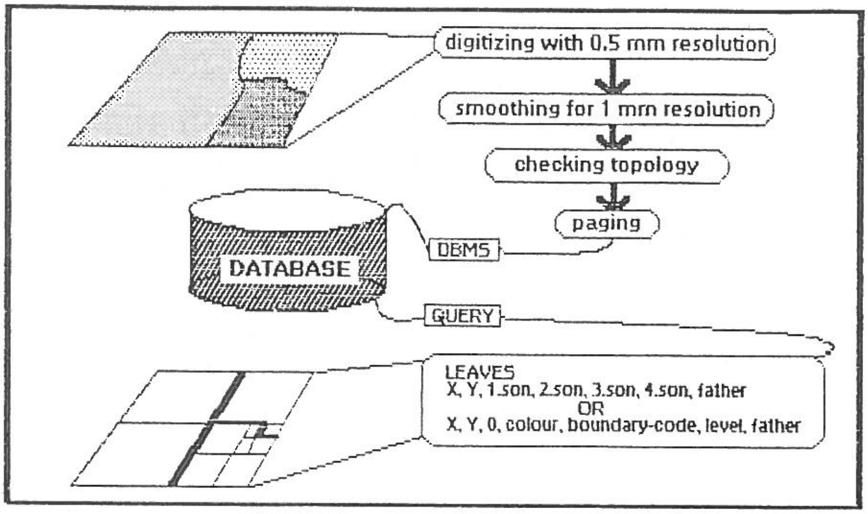

Fig. 3
Map data flow of HunSIS: from input via database to output

similarly as described by H. SAMET /1980/. Levels of the quadtree are coded in the page-relative coordinates of the centre point of the nodes. The efficiency of this type of storage and the union-intersection operations on it for binary images were pointed out by DYER /1980/. This experimental system provides efficient manipulation of spatially large, homogenous patches, making use of fast tree-traversal and boundary codes. The latter pointers allow us to introduce cartographic constraints in a query and in making "traditional" maps, including hardcopies as well. Handling point- and patch-like spatial objects in a similar spatial addressing manner is a tool to derive inferences on heterogeneity, complexity and/or reliability of the database from specific viewpoints /CSILLAG and KUMMERT, 1989a,1989b/.

The output subsystem: Data retrieval and query - Data can be retrieved from the data base using its query language. The initialization of the query can be started with area selection: the highest acceptable level is a region /96 km x 64 km/: additionally a county, a set of pages or a polygon can be defined for restricting unnecessary data, as well as depth intervals /for point data only/. Readout is executed when data or map types (connected with any of the following logical operators: &, +,) and specific conditions /data type → R → number: where R can be any of the following relations: =, ≠, >, <, >=, <=/ are listed. Additionally SzATIR accepts data from archive files or tapes of previous runs. Map manipulation is allowed for previously defined maps /and their combinations with logical operators/, and there is a sequence of commands for recording a map. An arbitrary set of points can be defined by conditions on data-types, value-intervals, previously defined sets and maps, as well as by locational /e.g. nearest n/ functions /see Fig. 4/.

It is a unique feature of the query language that it handles point and polygon data in a similar way, so the user can have access to both data types orienting his or her attention to soils and not to cartographic

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---------------------------------------------------------------------

 ****   ******    **    *****  *  *****     1988.02.13. 14:35:11
*    *       *   *  *     *    *  *    *
 **         *   *    *    *    *  *****     AZ ADATBAZIS
   **      *    ******    *    *  *   *     ON-LINE ELERHETO
*    *   *      *    *    *    *  *    *
 ****   ******  *    *    *    *  *     *

---------------------------------------------------------------------

TARTOMANY= 55;                              < region definition
SOKSZOG= 6440,7858,                         < polygon definition
         6954,7856,
         6952,8420,
         6400,8428;
ADATOK= PHH2O,                              < data type selection
        CACO3,
        HUMUSZ,
        HUMUSZVAST2
        FIZIKFELESEG;
PONT= K1+K2;                                < data source selection
GOODSET= CACO3>5&                           < definition of a
         PHH2O<7&PHH2O>5&                     point-set according
         HUMUSZ>1.5&                          to given conditions
         HUMUSZVAST2>30&                      on properties and
         \EROZIOS&\DEGRADALT;               < maps (e.g. non-eroded)
SZAMOSSAG GOODSET;                          < number of points in set

> A GOODSET     HALMAZ PONTJAINAK SZAMA: 955

STATISZTIKA PHH2O GOODSET                   < statistics of a parameter
                                              on the defined set
> GYAKORISAG.................  878            frequency
> ATLAG......................    7.22         mean
> SZORAS.....................    4.58         standard deviation
> SZORASNEGYZET..............   28.98         variance
> RELATIV SZORAS.............    0.63         coefficient of variation
> MINIMUM....................    6.51         minimum
> MAXIMUM....................    7.68         maximum
> TERJEDELEM.................    1.19         range
```

Fig. 4
Sample query output of HunSIS

motivations. At the same time, however, the query language limits, for instance, intervariable operations to avoid meaningless profile evaluations and point in polygon operations. The functionality of the system had gained importance since HunSIS is connected to the X.25-based Hungarian scientific computer network.

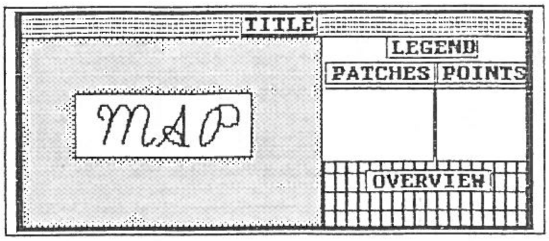
A wide set of help and technical control functions /reset, list valid commands, list valid syntax, etc./ assists in performing interactive functions in a more user-friendly environment. Data retrieval can be represented with a set of commands concerning the total number of points, area of a map, statistics for data types and/or maps /categories/.

Although the query language does not provide extensive support for graphic devices there is an option to perform map compilation on a local workstation. Files generated during a query can be exported in "raw" ASCII format to the local workstation, where can be further processed /see Fig.5/. All retrieved points, their sets, polygons /individually or by categories/ can be accessed and graphical output can be generated in a CGI-compatible environment.

Current status and development, practical application

The design and development of the HunSIS can be considered as a significant contribution to the solution of several soil mapping problems. The system itself not only provides and opportunity for data retrieval and analysis, but during its use, methodological benefits can be achieved either in soil science or in computer cartography.

There are two major projects to develop HunSIS: /1/ To increase the data content of the database in terms of area /other counties/ and derived maps /presently only genetic soil maps are available for Pest County - See Fig. 6, Appendix II and Appendix III/, and /2/ to develop a cartographic data exchange standard for natural resource mapping in Hungary based on HunSIS experience.



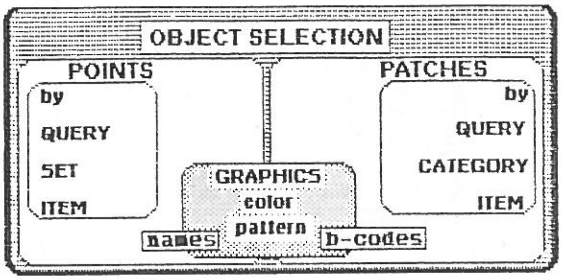


Fig. 5
Functions and output design of the local graphic HunSIS workstation

One of the most attractive features of HunSIS is the opportunity to introduce, test and verify various scientific models that concern its data-base. The enhancement of the local expert system functions of the GIS is a field of intensive research and development. Another area of interest is the multidisciplinary use of the information system, that requires compatibility and interactive communication with other /e.g. agrochemical, hydrological, meteorological, etc./ data-bases, information systems. These connections are planned to be established either through the host mainframe or through the national computer network of information systems.

Thematic soil maps and the synthesis of their information by the HunSIS in its present phase can be properly used /VÁRALLYAY et al., 1985, 1988/:

- in the planning and implementation of rational land use and cropping pattern, according to ecological conditions /delineation of ecologically favourable regions for certain crops/;

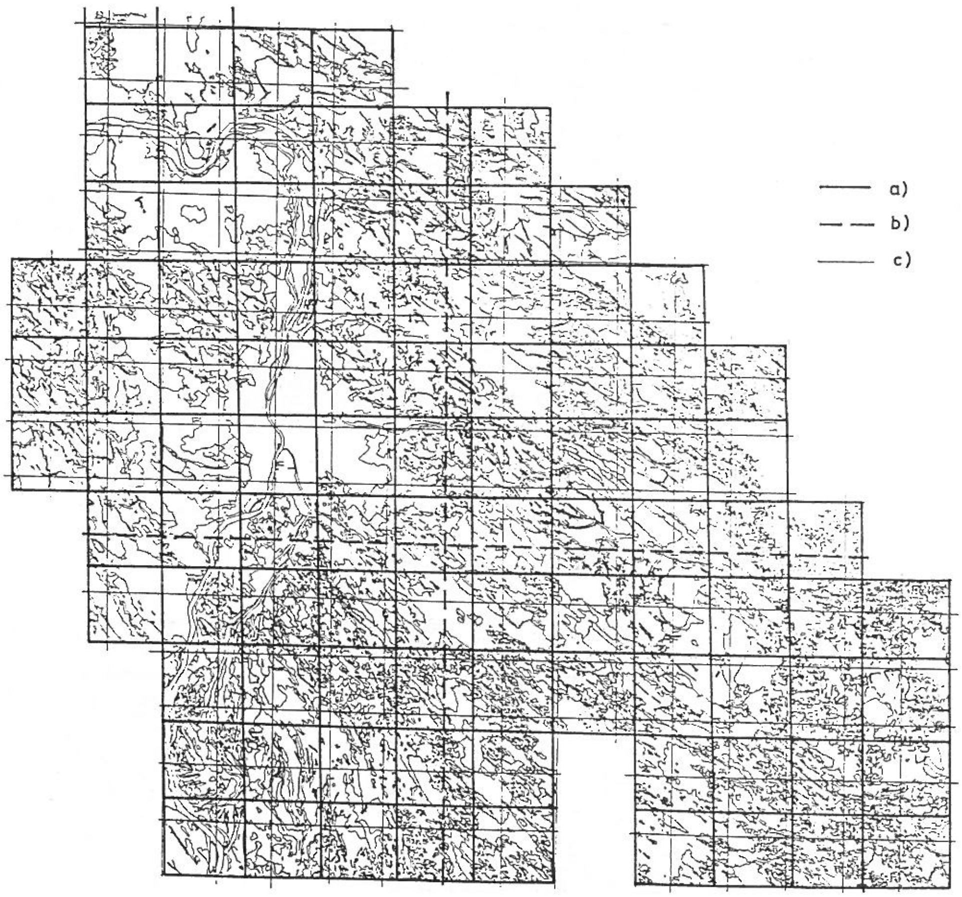


Fig. 6

Soil type contours digitized at 1:25 000 scale for Pest County with input maps sheets and HunSIS standard reference pages. a/ Border of sheets 1:25 000 scale; b/ Border of regions; c/ Border of pages

- in the determination of the preconditions and possibilities of adaptive agriculture that can promptly and flexibly respond to natural and economical "stress-situations" /frost, drought, excess moisture; import-export relations, market and price situations, etc./;
- in estimating the necessity, the predictable impact and efficiency of various measures required to ensure good crop yields and the maintenance or increase of soil fertility /amelioration: erosion control, soil reclamation, increase of water-use efficiency; agrotechnics: tillage, nutrient control, etc./;
- in the implementation and control of the above measures on national, regional, farm and field levels;
- in the prediction and prevention of unfavourable soil degradation processes due to natural factors or anthropogenic activities /soil erosion by water or wind; acidification, salinization-alkalization, structure destruction, compaction, waterlogging, etc./;
- in land and soil evaluation /for the determination of real "fertility values" and indices expressing the sensitivity and responses of soils to different treatments/;
- in the elaboration and selection of rational territorial variants of non-agricultural land use /industrial, urban and rural development; landscape planning, etc./;
- in the protection of the environment and nature conservation;
- in soil science - agrochemistry - soil biology researches;
- in education on various levels.

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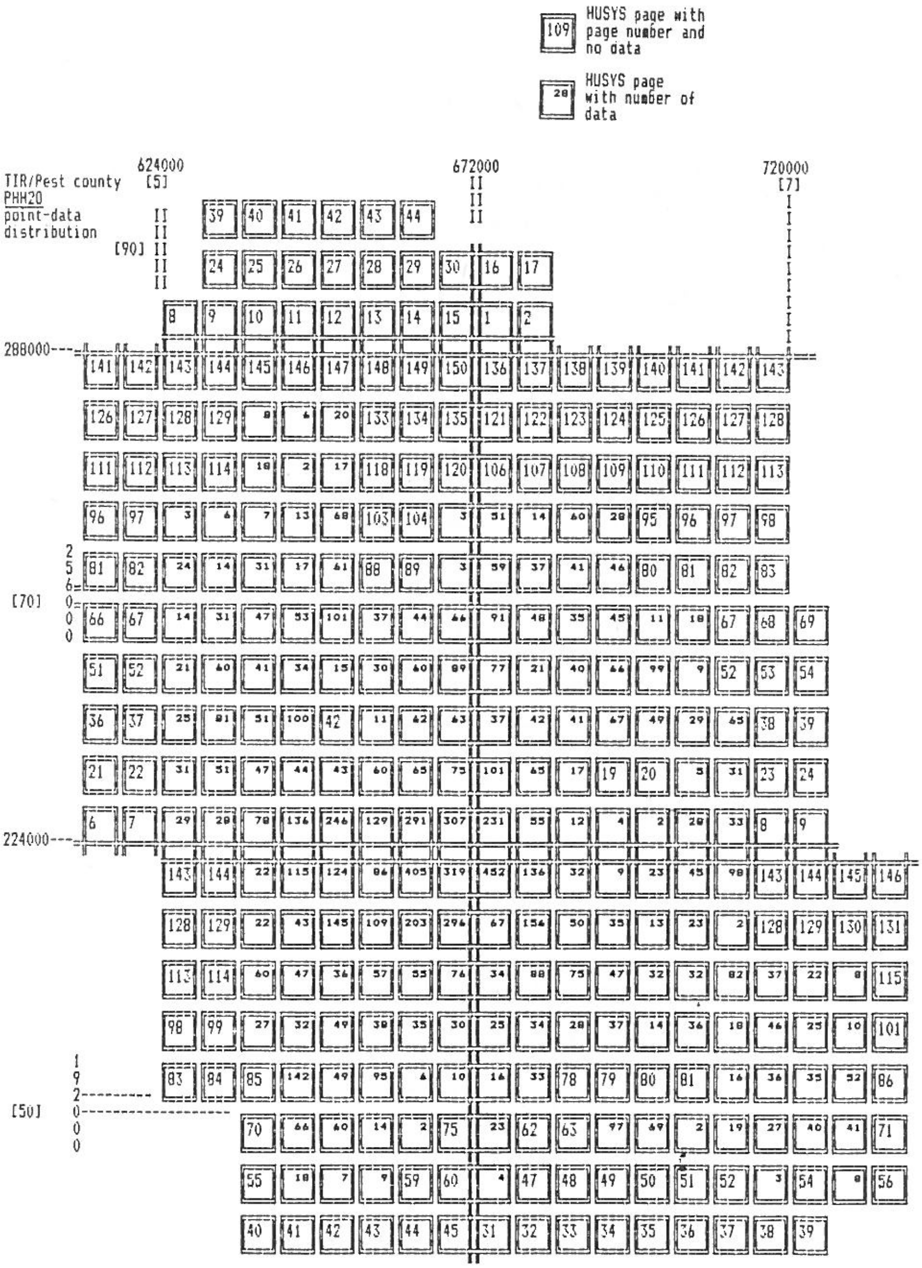
Appendix I

Point Data Base of HunSIS



Appendix II

Sample Aerial Distribution by Pages /6400 m x 6400 m/ PHH2O

RELIEF
TEXTURE
CONCRETIONS
DEPTH OF THE HUMUS HORIZON
PHH_2O
DEPTH OF THE GROUNDWATER TABLE
PHKCL
HYDROLYTIC ACIDITY
EXCHANGEABLE ACIDITY
CARBONATE-CONTENT
2 HOURS CAPILLARY RISE
5 HOURS CAPILLARY RISE
20 HOURS CAPILLARY RISE
100 HOURS CAPILLARY RISE
INFINITE TIME CAPILLARY RISE
ORGANIC MATTER CONTENT
WATER-SOLUBLE SALT CONTENT
EXCHANGEABLE CA COMPOSITION
EXCHANGEABLE MG COMPOSITION
EXCHANGEABLE NA COMPOSITION
EXCHANGEABLE K COMPOSITION
BASE SATURATION
MECHANICAL FRACTION 1
MECHANICAL FRACTION 2
MECHANICAL FRACTION 3
MECHANICAL FRACTION 4
MECHANICAL FRACTION 5
MECHANICAL FRACTION 6
MECHANICAL FRACTION 7
MECHANICAL FRACTION 23
MECHANICAL FRACTION 456
STICKY-POINT ACCORDING TO ARANY
ALKALINITY AGAINST PHENOLPHTALEIN
SOLUBLE CA
SOLUBLE MG
SOLUBLE NA
SOLUBLE K
SOLUBLE CO_3
SOLUBLE HCO_3
SOLUBLE CL
SOLUBLE SO_4
CHARACTERISTIC POINTS OF THE
WATER RETENTION CURVE
BULK DENSITY
SATURATED HYDRAULIC CONDUCTIVITY
SOIL TYPE
PARENT MATERIAL
ELECTROLIC CONDUCTIVITY
CATION EXCHANGEABLE CAPACITY
SPECIFIC SURFACE
A CONSTANT OF K-PSZI CURVE
B CONSTANT OF K-PSZI CURVE
N CONSTANT OF K-PSZI CURVE
FINE FRACTION
WATER PERMEABILITY
SODA ALKALINITY

Appendix III
Map Inputs of HunSIS

Map input - TIR

GENETIC SOIL TYPES	1:25,000	Pest county	100 %
THICKNESS OF THE HUMUS LAYER AND HUMUS CONTENT	1:25,000	Pest county	10 %
TEXTURAL TYPES	1:25,000	Pest county	5 %
PARENT MATERIAL	1:25,000	Pest county	1 %

CHEMICAL COMPOSITION
SOLUBLE SALTS
AVERAGE DEPTH OF GROUND WATER TABLE
MAXIMUM DEPTH OF GROUND WATER TABLE
MINIMUM DEPTH OF GROUND WATER TABLE
SALT CONTENT OF GROUND WATER
HYDRAULIC CONDUCTIVITY
CAPILLARY CONDUCTIVITY
FIELD CAPACITY
MOISTURE POTENTIAL
EROSION