WORKING PAPER AND PREPRINT **89/3**

SOTER

PROCEDURES MANUAL FOR SMALL-SCALE MAP AND DATABASE COMPILATION AND PROCEDURES FOR INTERPRETATION OF SOIL DEGRADATION STATUS AND RISK

(Revised Version of Working Paper and Preprint No. 88/2)

FOR DISCUSSION

Compiled by
J.A. Shields and D.R. Coote
Land Resources Research Centre
Under contract to the
Glasod Project, ISRIC, The Netherlands

January 1989

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

PREFACE:

In January 1986, a group of approximately thirty scientists (soil and related disciplines) from around the world assembled in Wageningen, the Netherlands, concerning the Structure of a Digital International Soil Resources Map and Database. The Workshop was sponsored by the ISSS with support from UNEP and others. From these Workshop recommendations, a proposal was written for the development of a World Soils and Terrain (SOTER) Digital Database at an average scale of 1:1 million. The list of possible interpretations tabled at this Workshop included:

Crop Suitability
Soil degradation
Irrigation Suitability
Forest productivity
Agroecological Zonation
Watershed management
Soil trafficability

A small international committee was appointed to develop a "Universal" map legend dataset suitable for compilation of small scale soil-terrain maps at 1:1 M scale and to include the attributes required for the interpretations noted above. An initial list of attributes and their class limits was compiled. This SOTER proposal was further endorsed at the ISSS Congress in Hamburg, West Germany, August 1986.

A second meeting sponsored by UNEP was held in Nairobi in May, 1987 to discuss application of the SOTER data base for preparing soil degradation assessment maps. Two working groups (legend development and soil degradation assessment) met concurrently during this meeting. The legend working group was charged with the task to develop guidelines for a World Soils and Terrain Digital Database at 1:1 million scale, to come forward with general legend concepts and definitions, to prepare an attribute file structure and to draft a tentative outline of a Procedures Manual. This task was completed and documented in the final report of the Ad Hoc Expert Group Meeting on Feasibility and Methodology of Global Soil Degradation Assessment, May, 1987, UNEP, Nairobi.

The Soil Degradation Assessment Working Group focussed on the definition of soil degradation, processes of soil degradation and global priorization of those processes: wind erosion, water erosion, salinization, alkalinization and chemical/nutrient decline. Data requirements of degradation assessment for both status and risk of these processes were listed and ranked for necessity (Mandatory, Desirable, Optional). For each of the processes it was recommended that the methodology developed should separate severity of degradation into four levels.

One of the major recommendations from this meeting was that status and risk assessment maps of soil degradation (wind erosion, water erosion, salinization) and essential attribute data be produced for five pilot areas in Third World countries; pilot areas in cooperating industrialized countries were also requested. Soils and terrain data for pilot areas will be entered into the SOTER database. It was also recommended that a detailed provisional Procedures Manual be prepared for development and use of the global soil and terrain digital database, including soil degradation assessment. As a follow-up of the Nairobi meeting, UNEP contracted ISRIC in Wageningen, The Netherlands, to compile a global map on the status of soil degradation at 1:10-15 Million, and to have it accompanied by a first pilot area at 1:1 Million scale in Latin America where both status and risk of soil degradation would be assessed on the basis of a digital soil and terrain data base at 1:1 Million scale under the terms of reference of this project code named GLOSOD. ISRIC subcontracted preparation of the Procedures Manual for the 1:1 M level pilot study area to the Land Resource Research Centre, Agriculture Canada.

The Procedures Manual documented following the Nairobi Meeting was presented at the First Regional Workshop on a Global Soils and Terrain Digital Database and Global Assessment of Soil Degradation held in Montevideo, Uruguay (March, 1988). Some revisions were made to the Manual at this Workshop. During the Montevideo Meeting, the terms of reference for the GLASOD-SOTER Pilot Area Project were finalized among the participating countries of Argentina, Brazil and Uruguay and the pilot area location established.

The methodology proposed in Soter Procedures Manual was then tested during a correlation meeting - field trip (June 5-19/88) which originated in Buenos Aires and traversed the above pilot area where the three national working groups applied the Manual and evaluated its workability. Based on this experience it was concluded that the SOTER Manual was both applicable and workable.

ACKNOWLEDGEMENT

Legend Working Group participants at the Wageningen and Nairobi meetings are acknowledged for their contributions toward development of guidelines for a world soil and terrain digital data base at 1:1 Million scale, general legend concepts and definitions, attribute file lists and classes, and procedures manual outline:

R. Arnold
A. Ayoub
P. Brabant
T. Cochrane
M. Ilaiwi
W. Peters
B. MacDonald
W. Reybold
J. Sehgal
J. Shields
W. Sombroek
R. Van de Weg

Participants of the Soil Degradation Assessment Working Group are also acknowledged for their contribution to sessions held at the Nairobi Meeting towards definition of the term "soil degradation", priorizing processes of soil degradation, their kind of assessment and their data requirements:

M. Baumgardner
R. Coote
I. Garbouchev
M. Purnell
R. Oldeman
A. Raziq
G. Varallyay

SOTER Procedures Manual For Small Scale Map and Data Base Compilation Including Proposed Procedures (For Discussion) For Interpretation Of Soil Degradation Status and Risk

Compiled by J.A. Shields and D.R. Coote
Land Resource Research Centre
Agriculture Canada, Ottawa
Under Contract to
The GLASOD Project, ISRIC, The Netherlands

January 1989 Version

SOTER PROCEDURES MANUAL FOR SMALL SCALE MAP AND DATABASE COMPILATION INCLUDING PROPOSED PROCEDURES (FOR DISCUSSION) FOR INTERPRETATION OF SOIL DEGRADATION STATUS AND RISK

TABLE OF CONTENTS

INTRODUCTION

Soils differ dramatically in suitability for specific crops, response to different systems of management, carrying capacity, water holding capacity, internal drainage properties, and liability to degradation processes such as erosion, salinization and fertility decline. Throughout the world, especially in developing countries, land resource managers are constrained in their planning and decision making because of a critical lack of information about their soil and terrain resources. In cases where scientific data do exist, its effective exchange and transfer is also constrained by lack of standardization in describing and recording important resource information.

Preparation of a manual documenting small scale mapping procedures or procedures for compilation of small scale maps and attributes from existing larger scaled maps will serve to overcome the above constraints. It will be further beneficial if the data are compiled in a computer compatible format facilitating timely electronic analysis and retrieval of information.

Increasing pressure on land use intensity coupled with indiscriminate destruction of forests results in a spectre of soil degradation causing decreased productivity and adverse social consequences. It has been recently concluded that both ISSS and UNEP can benefit by collaboration in an assessment of global soil degradation. It has been recommended that status and risk assessment maps of priority degradation processes (wind erosion, water erosion, salinization, alkalinization, and chemical/nutrient decline) be produced for five pilot areas in Third-World countries.

Documentation of procedures for risk assessment of priority soil degradation processes from information compiled for small scale map attribute files will contribute significantly to knowledge on location and extent of different types of soil degradation. These procedures further contribute toward implementation of a comprehensive information system capable of delivering accurate, useful and timely degradation information to decision-makers concerned with development, management and conservation of environmental resources.

SHORT-TERM OBJECTIVES:

1. To prepare a detailed Procedures Manual documenting standardized methods and descriptors to be used by all countries for compilation of a global soil and terrain (SOTER) digital database at an average scale of 1:1 M. A "Universal" legend describing soil and terrain attributes will be designed to accommodate all major soil mapping and classification systems for entry to a computerized database. It will also serve to minimize problems of correlation and quality controlled entry of information to the SOTER database thereby ensuring its consistent application and interpretation. The manual will be based on the outline prepared by the Legend Working Group during the Nairobi Meeting in May 1987.

2. To document selected polygon, terrain and soil attributes required for priority soil degradation interpretations, define their class limits and list them in a computer compatible format.

3. To document procedures for recording the present status of soil degradation in the SOTER EXTENDED LEGEND at the 1:1 M scale. The status of priority soil degradation problems of water erosion, wind erosion, salinization/alkalinization, chemical/nutrient decline and compaction are the first to be assessed.

4. To document procedures for water and wind erosion risk assessment under conditions of bare, unprotected soils, as well as under the present vegetative cover. Different procedural options will be provided so as to permit users to select the procedure that best uses the available climatic data for their region. The SOTER database will be the source of other relevant data.

5. To document procedures for assessment of the risk of salinization and/or alkalinization, and chemical/nutrient decline, using the SOTER database.

6. To test the methodology proposed in the Manual and evaluate its applicability and workability to at least one International Pilot area.

2 GENERAL LEGEND CONCEPTS AND DEFINITIONS

2.01 An enclosed map delineation or polygon is an area of terrain with a distinctive, often repetitive pattern of surface form, slope, parent material, soil and climate. (See Figure 2.1).

2.02 The minimum size of the terrain area (or polygon) should be about 1 cm. x 1 cm. at the 1:1 Million scale. However, smaller isolated areas which can be conveniently displayed and labelled on the map are permitted, when needed.

2.03 Each polygon is assigned a unique identifying number.

2.04 Each polygon is described in terms of a maximum of 3 terrain components. For the convenience of computerization, a terrain component is defined as a segment of the overall landscape of a polygon with comparable topographic (surface form and slope gradient) and soil patterns.

2.05 For each terrain component, at least one soil is characterized; a maximum of 3 soils may be characterized for each polygon. In cases where a polygon includes 2 terrain components, the map compiler may choose to describe 2 soils applying to the first component and 1 soil applying to the second component. Furthermore, the mapper must indicate which soil applies to what proportion of the polygon.

2.06 The polygon, terrain component and soil information (or "attributes") are recorded in 3 separate but interactive computer files, called:
a) The polygon file
b) The terrain component file
c) The soil layer file (see Figure 2.2)

2.07 The attributes which describe a polygon as a whole are recorded in the polygon file. These include descriptions of Regional Landform, Relief, Elevation, Surface Lithology, etc., which have been listed and described in Chapter 7 describing the SOTER Polygon File Attribute List and Structure.

2.08 The attributes that separate terrain components one from another within a polygon include a) Soil Parent Material/Parent Rock, b) Texture Class of Parent Material, c) Surface Form, d) Slope Gradient % Class and others. Attributes (a) to (d) are considered mandatory for differentiating terrain components and by inference, the delineation of mapped polygons. A general soil descriptive entry is optional (see Attribute No. 72 of the Soil Layer File).

Terrain components described within small scale map polygons at 1:1 Million scale include those parts of the polygon which normally would appear as separate polygons on larger scale maps of the same area. However, when the degree of terrain complexity is such that it prevents delineation of smaller polygons at larger scales (i.e.

1:100,000), the polygon is best considered to be comprised of only a single terrain component most representative of the area.

Note: A terrain component is not intended to describe different segments of a surface form with continuous unbroken slopes as on an undulating surface form. In contrast, if the slope is distinctly broken as in the case of a Tableland regional landform, then a terrain component can be assigned to each distinctly broken slope segment.

2.09 The attributes used to describe soils are listed and defined in Chapter 12 entitled Soter Soil Layer Attribute Classes, Codes and Descriptions.

2.10 For convenience of computerization, each soil may have a maximum of 4 "layers" in a continuum to a depth of 150 cm.

- 2 layers to about 50 cm.
- 2 layers from about 50 cm. to 150 cm.

2.11 Each layer attribute has a "necessity requirement" designated as "mandatory", "desirable" or "optional".

2.12 Soil classification system is not a required major legend entry.

2.13 Information required for interpretation such as climate, vegetation, etc. will be accessed from other disciplines with computerized databases.

2.14 In the absence of analytical data, an estimate by a qualified expert is acceptable and is referred to as an "Expert Estimate". Expert Estimates should be documented as such.

2.15 The class data which have been documented for all attributes will be used in this draft of the Procedures Manual.

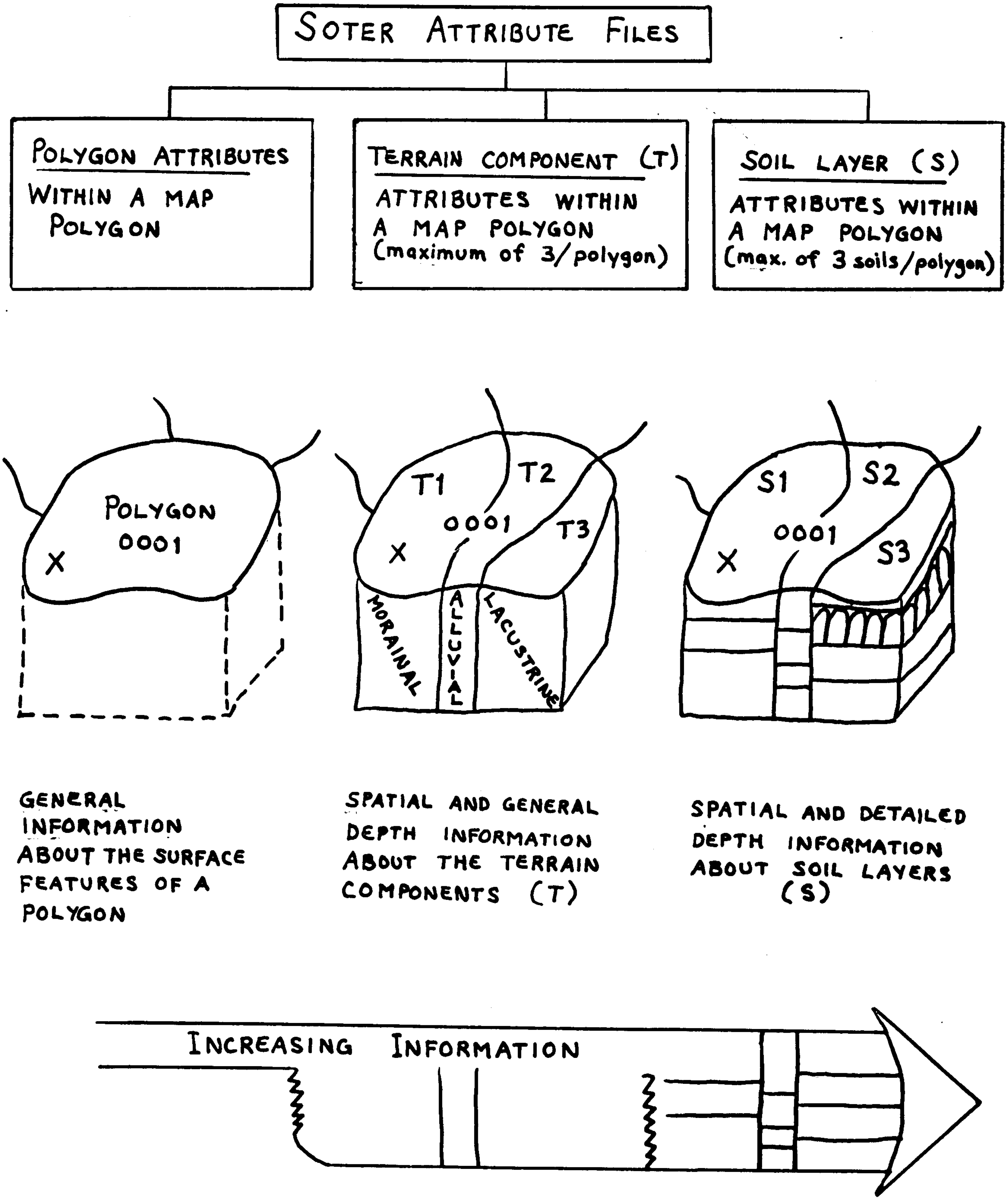

SOTER ATTRIBUTE FILES
POLYGON ATTRIBUTES
WITHIN A MAP POLYGON
TERRAIN COMPONENT (T)
ATTRIBUTES WITHIN A MAP POLYGON (maximum of 3/polygon)
SOIL LAYER (S)
ATTRIBUTES WITHIN A MAP POLYGON (max. of 3 soils/polygon)
POLYGON 0001
X
T1
T2
T3
0001
X
MORAINAL
ALLUVIAL
LACUSTRINE
S1
S2
S3
0001
X
GENERAL INFORMATION ABOUT THE SURFACE FEATURES OF A POLYGON
SPATIAL AND GENERAL DEPTH INFORMATION ABOUT THE TERRAIN COMPONENTS (T)
SPATIAL AND DETAILED DEPTH INFORMATION ABOUT SOIL LAYERS (S)
INCREASING INFORMATION

Figure 2.1

RELATION BETWEEN SOTER ATTRIBUTE FILES

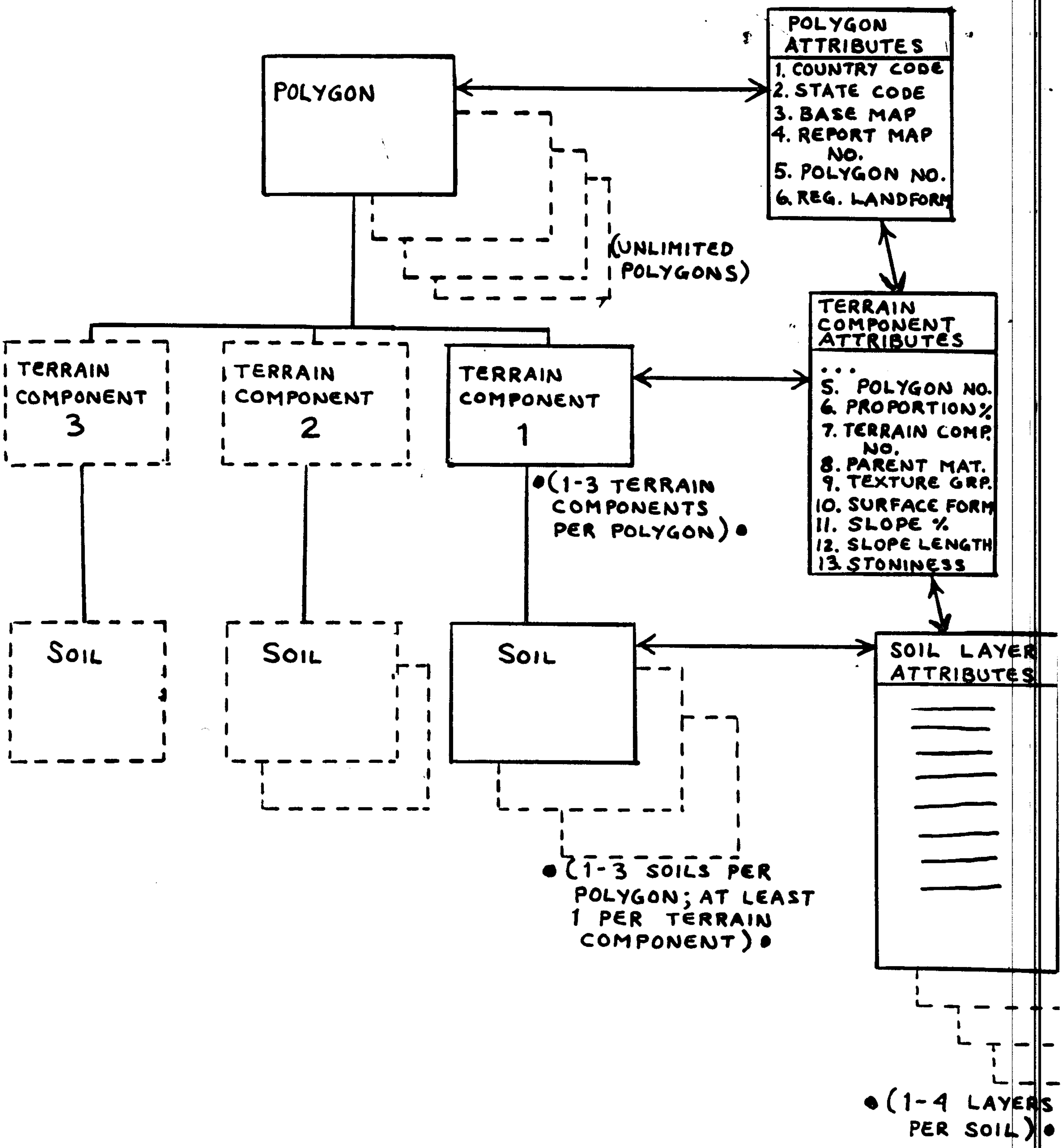


Figure 2.2

3 GUIDELINES FOR MAP COMPILATION PROCEDURES USED WHERE MAPS EXIST

3.01 Maps are generalized (or compiled) from the most recently available published soil survey and other source maps.

3.02 Establish the size of area at the source map scale that reduces to 1 cm x 1 cm at a scale of 1:1 million (large enough area to insert a map symbol). This is the smallest area you should map. Most areas will, of course, be larger. There are a few exceptions where a compiled map polygon at 1:1 million may be smaller than 1 cm x 1 cm, such as:

- narrow elongated features and drainage patterns
- strongly contrasting soil or terrain areas

Map symbols can be attached to these polygons by use of a leader, assuming the polygon density adjacent to these areas has room for the extra symbol and leader.

3.03 Overlay and register transuluscent material with a matte surface to the source soil survey map.

3.04 Delineate the major drainage pattern, regional landforms (see Polygon File) and other major physiographic features on the source map. Care must be taken not to exaggerate the width of narrow elongated features to justify their inclusion on the map. These features often bisect larger areas with similar soil and terrain attributes which thereby greatly increases the number of polygons required.

3.05 Delineate large, uniform areas with similar differentiating terrain and soil attributes on the source map. Translate the source map symbol and legend information to the compiled map symbol format and assign a unique polygon number. A change in at least one differentiating attribute class limit on the source map results in a separate compiled polygon.

3.06 Where necessary, group smaller source map polygons which are most similar while keeping in mind which attributes apply to the dominant (or most extensive) portion of the compiled polygon; translate its map symbol and assign a unique polygon number.

3.07 If necessary, group source map polygons which are dissimilar and proceed as indicated in item 3.05.

3.08 Continue the above procedure until most of the source map area is compiled. Review any remaining small areas and decide to which compiled polygons they should be most sensibly added.

3.09 Review the compiled polygons, their map symbols and source information (map legend and report) required for recording the attribute classes on the appropriate extended legend attribute file coding form; code attributes applying to the polygon, terrain component and soil layer attribute files.

3.10 Consideration should be given to adding any important agro-climatic or agroecological boundaries that are not yet coincident with map polygons delineated to this point. This will ensure continuity with future characterization of Agroecological Resource Areas.

3.11 Correlate polygon boundaries along adjacent source maps and also along International boundaries.

3.12 Reduce the compiled maps on the matte surface mylar overlays photomechanically to 1:1 million scale, process onto clear material, then register and mozaic to an appropriate base map. This mozaic is then recompiled for a pilot study area and edited.
During recompilation, it is recommended that Landsat imagery be used to help maintain overall project consistency and standardization of major physiographic and drainage features. Color composite 9 X 9 transparencies work well when used with a light table and their placement registered to the base map.

3.13 An island with a minimum size of 0.25 cm x 0.25 cm should be recognized and coded as a polygon.

3.14 If small islands are situated close together in a group, a line should be drawn around them to form a polygon. The portion of such a polygon which is water should be estimated and indicated as a percentage on the appropriate coding form.

3.15 Map Symbol Proposal - During previous working group meetings, there was no discussion on map symbols suitable for use on compiled maps. However, experience has shown during map compilation, it is convenient to record some of the most important differentiating polygon attributes on the map overlay in a concise symbol. The following symbol provides a quick, readily available reference to selected attributes in addition to a unique polygon number. The following format is proposed:

TOP LINE	Regional Landform, Number of Terrain Components, Soil Development
SECOND LINE	Parent Rock or Soil Parent Material and its soil texture group (general grouping of USDA soil texture classes into sand, loam, clay)
THIRD LINE	Surface Form, Slope
FOURTH LINE	Unique polygon number
EXAMPLE 1:	U 2 C MO L R 16 0001

EXPLANATION: The above symbol describes a polygon within an Upland(U) regional landform comprised of 2 terrain components dominated by Chernic(C) soils developed on morainal material(MO) of the loam texture group(L) with a rolling surface form(R) and slopes of 16-29%, and a unique polygon number 0001.

EXAMPLE 2:

H 2 P
I A
H 30
0002

EXPLANATION: The second example describes a polygon within a Hilland (H) regional landform comprised of 2 terrain components dominated by Podzic(P) soils developed on igneous acid rock material (IA) with a hummocky (H) surface form and slopes of 30-59%, and a unique polygon number 0002.

The codes for the above attribute classes are restricted to one or two characters to facilitate their use in the map symbol. Additional data are then coded on the map legend and in the computerized extended legend to complete the respective polygon, terrain component and soil attribute files.

3.16 Legend Concepts Reviewed.

During the above map compilation procedure, it is necessary to group source map polygons into larger polygons which have similar differentiating attributes thereby comprising a sensible consolidation of areas based on permanent natural occurring soil and terrain features. The guidelines in Section 2 on General Legend Concept indicate that each compiled polygon may have a maximum of 3 terrain components and that at least one soil is characterized for each component. A maximum of 3 soils may be characterized by layer (maximum of 4 layers) for each compiled polygon.

A maximum of 3 terrain components and a maximum of 3 soils characterized (or described) within a polygon encourages the compiler to be very selective in choosing those soils which are most important to the subsequent interpretations. To complete this selective process, it is important that the concept of a terrain component as defined earlier (Section 2.04) is clearly understood. That definition described a terrain component as a segment of the overall regional landform of a polygon with comparable topographic (surface form and slope gradient) and soil patterns. Accordingly, it is implicit that the differentiating attributes of a terrain component include parent rock, soil parent material, its soil texture, surface form and slope gradient. A significant change in any one of these attributes thereby results in a different terrain component as is indicated in the following examples.

Consider the case of a terrain component comprised of morainal material (MO) with loam texture(L), hummocky surface form (H) and slopes of 10%. The map compiler would like to describe 3 different soils occurring on quite different slope positions (i.e. summit, midslope, depression). It is permitted to describe up to 3 soils for one terrain component provided there is only one component within the polygon (see Case 1 below). However, if two terrain components occur within a polygon, as in Case 2 (morainal material with loam texture on hummocky 10% slopes and alluvial material with sand texture on undulating 4% slopes), one must choose carefully which soils from terrain component 1 are described along with the major soil from terrain component 2. The choice becomes even more critical in Case 3 where the polygon consists of 3 terrain components including morainal loam, alluvial sand and lacustrine clay materials. In this latter case only the major soil occurring on each of the 3 different materials can be described.

Case	Terrain Component Number	P.M. Origin	Texture	Surface Form	Slope	Soil Description 1	2 (Slope Position)	3
1	1	Morainal	Loam	Hummocky	10%	SUM	MID	DEP
2	1	Morainal	L	Hummocky	10%		MID	DEP
	2	Alluvial	Sand	Undulating	4%		MID	
3	1	Morainal	L	Hummocky	10%		MID	
	2	Alluvial	S	Undulating	4%		MID	
	3	Lacust	Clay	Undulating	1%		MID	

The above legend concepts although somewhat restrictive, do however provide sufficient flexibility to describe terrain components representative of permanent, naturally occurring soil and terrain attributes essential to satisfy the interpretive requirements.

Finally, it is also important to remember that it is not advisable to describe any more terrain components or soils than is necessary. Discretion at this point will save much time required for the coding and computer processing of extra data.

4. METHODOLOGY USED WHERE SOURCE MAPS AND DATA DO NOT EXIST

Little or no soil information is available for some areas where soil surveys are to be carried out in the future. Examples of these areas include northern Canada, parts of Africa, and parts of south America. In many cases, there is also a lack of geomorphological data concerning such features as regional landforms, surficial lithology and local surface forms. This lack of information which is sometimes coupled with inaccessiblity of terrain, requires development of a mapping methodology providing both detailed information on specific sites and general information in the form of small scale soil terrain maps based on LANDSAT imagery. Thus, the survey methodology used is different from that used in areas with existing source maps where small scale maps represent scaled down (or generalized) versions of the earlier source maps.

The field mapping procedures described below are taken from the experience described for exploratory mapping in Canada (Tarnocai, 1977) and from that documented in the Field Manual for Soil Mapping of India (Sehgal et al., 1987, of the National Bureau of Soil Survey and Land Use Planning, Nagpur). Both of the above utilized LANDSAT imagery coupled with traverses. In cases where cloud free satellite imagery is not available, it is necessary to use side looking radar imagery as reported by Cochrane et al. (1985) while mapping land in tropical America. The traverses may be by ground vehicle or by air where areas are inaccessible.

4.1 Mapping is carried out using 1:1M scale cloud-free, Landsat imagery of high quality which is interpreted manually. Multidate imagery is used if obtainable. If cloud free landsat imagery is not available, it is necessary to use side looking radar imagery.

4.2 Panchromatic photographs of the Landsat imagery may be used to aid manual interpretations.

4.3 Prefield activities include assembly of maps with accompanying reports dealing with topography, geomorphology, geology, climate, forestry (vegetation), soils and landuse of the area or part of it for study and use as aid to satellite image interpretation.

4.4 Prefield activities also include interpretation of satellite imagery employing a regional landform (or physiographic) approach including resource material listed in 4.3. Generally, bands 2 and 4 Landsat imagery are used for soil mapping. The bands used will depend on the imagery available.

4.5 Further interpretations are made on the basis of observable surface forms such as gullied, ridged, undulating or level.

4.6 Where areas are largely inaccessible by vehicle, systematic traverses are made by properly equipped fixed wing aircraft or by helicopter; periodic planned stops are made where possible. During these traverses, it is important to collect the maximum amount of information while in the air and during short ground traverses adjacent to the waterbody stops.

4.6.1 Information collected aerially (between stops) is mainly of use for interpreting satellite imagery. The most important features to observe include regional landforms, lithological materials, local surface forms, size and type of water bodies, vegetation patterns, land use patterns and patterned ground features.

4.6.2 During stops, detailed information is collected relating to terrain, vegetation and landuse.

4.6.3 Soils are described and sampled on representative sites at these stops. This detailed soil and site information provides the basis for characterizing the association between soil and vegetation.

4.6.4 It is noteworthy that this is often the only data available for the soils, terrain and vegetation of the area. Therefore, the information must be collected quickly, efficiently and cost effectively by a soil surveyor experienced in the local environment.

4.7 Where areas are accessible by vehicle, a series of systematic ground traverses to complement interpretation of satellite images are made. Bands 2 and 4 are used in combination with false color composites produced by a combination of bands 1, 2 and 4 with primary color filters of blue, green and red, respectively. The false color composite offers the interpreter an advantageous blend of contrasts that are easily identifiable even by a person not familiar with image interpretation.

4.8 Regional landforms are delineated on the satellite imagery based on interpretation of geomorphology, drainage pattern, vegetative cover and landuse. These polygons are further subdivided according to patterns indicative of specific surface forms and unique image characteristics of tone, texture, color, etc., occurring simply or in combination. A unique polygon number is then assigned to each compiled polygon.

4.9 Three kinds of field transect activities are conducted to characterize the map polygons:

4.9.1 At grid point sites of 10 km intervals to provide general information on the soil population.

4.9.2 At sites within selected sample strips on an intensive scale. These strips are sampled to ensure the correct soil distribution composition within a map polygon. A minimum of about 20 observations is prescribed for a sample strip of 50 sq. km spread. The strips are selected on the basis of regional landform and local surface form delineations shown on the interpreted image. Strips are selected so all important and extensive polygons are covered.

4.9.3 Random observations.

4.10 Soil profiles are identified, described and sampled at all transect or random observation sites. Both site and soil morphological attributes are recorded according to national standards.

4.11 Soil samples are dried and passed through a 2 mm sieve until only coarse fragments remain. Both portions of a sample are weighed to determine percentage of coarse fragments by weight.

4.12 Samples are submitted to the laboratory for analysis; national referencing standards are also analysed along with these samples.

4.13 Observations and information collected during transecting are used to assign a map symbol to each polygon.

4.14 Polygon boundaries and numbers are transferred from the satellite images to a topographic base at 1:1M scale which has planimetric accuracy.

4.15 SOTER Soil Layers Attribute file (see Section 12) is compiled pending receipt of the laboratory analysis data.

5. CORRELATION PROCEDURES FOR QUALITY CONTROL OF SOTER PROJECT AREAS

Soil correlation is the process of maintaining consistency of terminology and conventions during compilation of map and attribute data. It also includes assessment of the attribute classes and the compiled map polygons for interpretations.

In the correlation process, source map symbols and legends are examined for similarities and differences between differentiating attribute classes. The source map symbols and legend data must be interpreted consistently prior to their compilation (or grouping) into larger map polygons with common soil and terrain attributes which apply to most of the area enclosed.

Correlation begins with the planning phase of each pilot study area and continues through to the final report. It includes informal map compilation decisions and quality control carried out by the project leader and other participants during map and attribute compilation (adapted from Expert Committee on Soil Survey Handbook, Vol. 2. 1985). It also includes the formal procedures called for in Correlog. Correlog as described herein is a log of correlation activities pertaining to these pilot study mapping requirements.

A detailed draft of the SOTER Legend is documented later in this Procedures Manual. As polygons, map symbols and legend attributes are reviewed during preliminary studies of an area, the information is assembled and used in correlation. Source Soil Map Legend descriptions and associated information in the report are used to group polygons with similar differentiating mapping attributes. As part of the continuing correlation process, periodic formal reviews are also conducted as described below.

To ensure that the correlation process functions quickly and efficiently, it is necessary that roles be clearly defined and responsibilities assigned. In addition to continuing correlation roles of compilers and the Project Leader, it is also required to designate a National Correlator and SOTER Correlators. The National Correlator is responsible for correlation among the map areas of a participating Country. The SOTER correlator is responsible for correlation of polygons and attributes along International Boundaries; a small correlation group with International experience should be established for this purpose.

Formal Reviews

As stated earlier, correlation activities of an informal nature continue from commencement to completion of a pilot study project. To complement these activities, two distinct levels of progressive correlation activities are conducted more formally. The critical times chosen for these formal reviews are when 10% and 75% of the project map area and attribute compilation is completed. These are referred to as Correlation

Levels 1 and 2. During these reviews, the Correlog Form (See following page) is filled out by the project leader in the presence of the SOTER (or International) correlator(s). This form is retained as a record of progress toward objectives documented in the Project Plan. It also provides an opportunity to document problems encountered with the SOTER Legend and the actions required.

Level 1 review is conducted during the first or second months of active map and attribute compilation. It should occur as soon as is practical after the project leader has reviewed both SOTER and Source Map Legends. Level 1 is the most important review. It must be conducted on the perimeters of all adjacent maps (i.e. 1/10 width of map) from within a Country and between Countries. This is to ensure that all compilation participants are familiar with the SOTER legend files and the map compilation procedures documented in the SOTER Procedures Manual.

All queries and concerns must be addressed and resolved during this review so compilation can proceed quickly and efficiently. All polygon location and map symbol differences on adjacent maps must be resolved during this review. If inappropriate procedures or inadmissable attributes or symbols are not identified early in the project program, they tend to become entrenched thereby making adjustment to the errors more difficult. These discrepancies arise due to differences in source map scale, intensity of inspections and soil classification systems used. Reconciliation of these differences is achieved by carefully reviewing the source map legend and report information in the presence of compilers (map and attribute), National Correlators and SOTER Correlators. This review will take at least one-two weeks per project area.

Level 2 review is conducted after 75% of the project area including parts of all regional landforms in the pilot area have been completed. Its function is to ensure that compilation (map and attribute) has been done consistently and that all polygon map symbols and attribute files have been compiled according to SOTER standards. It requires the presence of the project leader, participating National correlators and at least one SOTER correlator. Deficiencies in the SOTER legend files should be documented and justifiable changes documented on a "correlation change sheet".

It is assumed that compilation for the remaining 25% of the project area can proceed with the required consistency and quality control of data. Any remaining correlation requirements will be considered as being essential to completion of the project.

CORRELOG FORM PROPOSED FOR SOTER PROJECT AREAS

Project Number:
Project Title:
Project Leader:

Participating National Correlator:

SOTER Correlator:

Date Correlog Conducted:

Correlation Level;.....

SOTER Procedures Manual Review Completed:

- Map Compilation Procedures;____Y, ____N
- Legend Attribute Files; ____Y, ____N

Plan is to compile map from source map;____Y, ____N

Source Maps and Reports Gathered;____Y, ____N

Source Maps and Reports Review Completed;____Y, ____N

Minimum size Map Delineation on Source Map when adjusted to 1:1M scale, cm x cm;.....

Training session by SOTER Correlator(s) Conducted; ____Y, ____N

Transparent overlay material accurately registered in place;_____Y, _____N

Perimeters (i.e. 1/10 of map width) of adjacent maps compiled, %;.....

Parts of each Regional Landform Compiled;____Y, ____N

Compiled Polygon Map Symbols in place; %;....

Compiled Polygon attribute files completed, %;....

Hard copy coding forms are available;____Y, ____N

Computer Hardware and Required Software is Functional;____Y, ____N

Computer Data File Compiled; ____Y, ____N

Differentiating Attributes of Compiled Map Polygons include:

- Regional Landform

- Parent Material/Rock
- Soil Texture
- Local Surface Form
- Slope Gradient

  Other, ______________

Differentiating Attributes of Terrain Component include:

- Parent Material/Rock
- Soil Texture
- Local Surface Form
- Slope Gradient

  Other, ______________

Differences in Compiled boundaries on adjacent source maps are resolved;____Y, ____N

Differences in attributes records for compiled polygon are resolved;____Y,____N

Compiled polygon boundaries are coincident with important Agroclimatic or Agroecological resource area boundaries; ____Y, ____N

Additional boundaries indicative of Agroclimate are required; ____Y, ____N

Review of Attribute files for coding errors completed;____Y, ____N

Attribute files input to computer completed; ____Y, ____N

Source map overlays photoreduced to final scale;____Y, ____N

Reduced maps recompiled on final base;____Y, ____N

Air Photos being Utilized ____Y, ____N Scale (K);.....

Landsat(L) or Radar(R) imagery being utilized ____Y, ____N Scale (K);.....

Radar imagery being utilized; ______Y, ______N

Polygons covered by Air Traverse, % of area;.....

Polygons covered by Vehicle Traverse, % of area;.....

Planned transects complete, %.....

Planned Soil Sampling Complete, %;.....

Number of Soils Described;.....

Soil Analysis Complete, %;.....

Soil Description Entered to State/Prov Data File, %;.....

CORRELOG COMMENT SHEET TO BE COMPLETED BY PROJECT LEADER AND SOTER CORRELATOR:

1. Map polygons accord with current SOTER Map compilation procedures;____Y, ____N

2. Compiled map polygons are appropriate for planned interpretations;____Y, ____N

3. Small source map polygons of limited occurrence have been amalgamated with appropriate compiled polygons;____Y, ____N

4. Interpretation accuracy of source map symbols was observed to be acceptable;____Y, ____N

5. Interpretation accuracy of source map information to SOTER attribute files was observed to be acceptable; ____Y, ____N

6. Map Symbols are legible; ____Y, ____N

7. Resource material check list suggested to be available for Correlation Reviews:

    - Climate Data
    - Surficial Geology
    - Bedrock Geology
    - Bedrock Topography
    - Vegetation Cover
    - Topographic Maps

CORRELATION CHANGE SHEET FOR SOTER PROJECTS See Level 2 Review

6. SOTER ATTRIBUTE FILES AND CODING CONVENTIONS

Development of a world soil and terrain digital database applicable to 1:1 M map scale requires organization of data into a series of computer compatable files. The first and shortest file includes only general attributes pertinent to the entire polygon, hence the term Polygon file. Attributes in the second file describe the geomorphology, hydrology and the general soil conditions of each terrain component. The third and most comprehensive file provides detailed information on the soil, not only on its planar dimensions but also on its third dimension, depth; this file is referred to as the Soil Layer file. Each soil layer attribute is assigned a necessity requirement designation (mandatory, desirable or optional). When complete, these three attribute files provide information required for many interpretations.

The above files can be defined into file structures compatible with dBASE, INFO, or other commercial software database files. Thereby, the information when coded can be input to the selected database management system for analysis, processing and retrieval in reports.

Each file consists of a number of attributes. The range of numeric values reported for each quantitative attribute has been subdivided into classes with defined limits. If the attribute is qualitative, descriptive classes are documented. This class data must be captured (or recorded) on coding forms. The format used for selecting attribute class codes essential to concise connotative data capture is as follows:

1. NUMERIC CLASSES are designed to be connotative by recording the lowest value of the class (or range) except when the class commences with zero. In this case, record the number 1, or 0.1 or 0.01 as is appropriate to indicate that it is the lowest class.

2. DESCRIPTIVE CLASSES are designed to be connotative by using the first 4 characters of the class name except in the case of attributes shown in the map symbol (Regional Landform, Parent Material/Rock, Local Surface Form, Texture Group, Soil Development) where only 1 or 2 characters are permitted to facilitate a concise map symbol.

3. NOT APPLICABLE (#) is used when it is not relevant to record the attribute, i.e. it is not necessary to record soil drainage for hard rock material.

4. If the attribute is mandatory, the values estimated by an expert must be coded.

5. The above conventions ensure that information must be completed for every mandatory attribute record thereby facilitating easy editing for missing data. i.e. When editing, each blank field must be carefully reviewed.

SOTER CODING FORM 1 POLYGON FILE ATTRIBUTES | TERRAIN COMPONENT ATTRIBUTES SHEET 1

	C				S		B				R				P				R	R
	O				T		A				E				O				E	E
	U				A		S				P				L				G	L
	N				T		E	.			O				Y	·			I	I
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	1			0	2	0	3			0	4			0	5			6	0
2																				
3																				
4																				

				E				L				L		I		D			D	L
				L				I				A		N		I			E	A
				E				T				K		U		S			N	N
				V				H				E		N		T			S	D
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	7			0	8			0	9			1	0	1	1	1	2		13	1
2																				
3																				
4																				

				P		T	P		G	F	S		L			S				R
				R		E	A		R	O	L		E			T				O
				O		R	R		O	R	O		N			O				C
				P		R	E		U	M	P		G			N				K
	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	4			0	6	7	0	8	9	10	1	1	1	2		1	3			1
2																				
3																				
4																				

			D					Q				R			L		F			
			E					U				O			U		L			
			P					A				O			S		O			
			T					L				T			E		O			
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	4		1	5				1	6			1	7		1	8	1	9		
2																				
3																				
4																				

SOTER CODING FORM 1 (CONTINUED) TERRAIN COMPONENT ATTRIBUTES SHEET 2

S				W		B	
D				A		L	
R				S		O	
A				H		W	
5	6	7	8	9	10	11	12
2	1			2	2	2	3

C	P	I	P				T	D															
O	E	C	P				N	E															
M	R	E	O				U	P															
P	M		L				M	R															
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
24	27	28	29				30	31															

39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59

60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

SHEET 1

COUN	01
STAT	02
BASE	03
REPO	04
POLY	05
TERR	6
POSI	07
DRAI	08
PROP	09
PPOL	10
SNUM	11
SOIL	12
LAYE	13
LOWE	14
ABRU	15
DIST	16
MHUE	17
MVAL	18
MCHR	19
DHUE	20
DVAL	21
DCHR	22
CARB	23
NITR	24
CECT	25
CECC	26 .
CECE	27 .
ANIO	28

SOTER CODING FORM 2 SOIL LAYER ATTRIBUTES

SHEET 2

CA	29 .
MG	30
NA	31
K	32
MN	33
AL	34
CAMG	35
CAK	36
MGK	37
ALSA	38
AVAP	39
PFIX	40
AVAS	41
TRAC	42
TOXI	43
BSAT	44
PHW	45
PHC	46
ELEC	47
ESP	48
CACO	49
GYPS	50
MINE	51
COAR	52
TEXT	53
SAND	54

SOTER CODING FORM 2 SOIL LAYER ATTRIBUTES

SHEET 3

VFS	55
SILT	56
CLAY	57
AVUP	58
AVLO	59
AWCU	60
AWCL	61
BULK	62
INFI	63
SATU	64
STRU	65
AGGR	66
DECO	67
BIOL	68
CONT	69
DIAG	70
DEFI	71
DEVE	72
PEDO	73

7. SOTER POLYGON FILE ATTRIBUTE LIST AND STRUCTURE

No.	Attribute Name	Type	Width
01	Country Code	CHAR	4
02	State/Province Code	CHAR	2
03	Base Map Code (ONC Number)	CHAR	4
04	Report/Map Number Ref Code	CHAR	4
05	Polygon Number (unique)	CHAR	4
06	Regional Landform	CHAR	1
07	General Relief (median difference between highest/lowest), m	CHAR	4
08	Elevation, Median, m	CHAR	4
09	General Surface Lithology	CHAR	4
10	Permanent Lake Surface Occupance, %	CHAR	2
11	Seasonally Inundated Lands, %	CHAR	2
12	Median Distance Between Rivers and Streams,km	CHAR	3
13	River and Stream Drainage Density	CHAR	1
14	Predominant General Land Use and Vegetation	CHAR	4
15	Climate (refer to "separate file").		
16	Annex documenting aerial photograph, satellite and radar information (numbers, flights, date)		

NOTE: Underlined four characters of attribute name key words are used to label attributes (or fields of information) on the coding forms.

8. SOTER POLYGON FILE ATTRIBUTE CLASSES, CODES AND DESCRIPTIONS

01	Country Code	- 4 Number International Code
02	State or Province Code	- 2 Number National Code
03	BASE Map Code	- 4 Character National Code
04	Report/Map Number Code	- 4 Number State or Province Code
	# Not Applicable	
05	Polygon Number	- Number Code, Unique for each Map Poly
06	Regional Landform	- The general physical description (or shape) of the regional landform in contrast to its genetic origin or processes causing its shape.

(SEE DIAGRAMS AT THE END OF SECTION 8)

Code	Class	Descriptions
M	Mountain Dominated	- Erosion and volcanic landscapes with relief (vertical distance between higher and lower parts) of at least 300 m with most of the area comprising valley to summit; slopes generally over 30%; in general with a restricted summit area and steep sides, irregular shape and considerable bare rock surface, or very thin soil cover. - Occur as a single, isolated feature or in a group forming a long chain or range. - Major scarps are the relatively steep and straight cliff-like slopes of considerable linear extent separating surfaces such as plateaus lying at different levels.
H	Hilland Dominated	- Natural elevations rising prominently above the surrounding plain and having a recognizably denser pattern of generally higher knolls or crest lines with an irregular or chaotic surface form composed of upper surface convexity and lower concavity

		- Includes hummocky morainal material, volcanic cones, conical hills of lava - Slope generally 10-30% - Relief generally less than 100 m
T	Tableland (or Plateau) Dominated	- Comparatively flat areas of great extent commonly bounded on at least one side by an abrupt escarpment, or may be terminated by mountains. - May be dissected by deep valleys and deeply incised rivers - May be tectonic, erosional or volcanic in origin - May be step-faulted - Slopes generally less than 10%, occasionally 10-15% - Relief generally less than 50 m.
P	Plain Dominated	- Flat to very gently undulating areas which have few or no prominent irregularities. They may be formed by erosion or by deposition (or constructional) processes - Include broad continuous, gently sloping piedmont plains extending along and from the base of a mountain, formed by the lateral coalescence of a series of separate but confluent alluvial fans; alluvial processes are mainly responsible for the sedimentation. Coarse fragments are rounded by transport over relatively long distances. - Slopes generally <6% - Relief generally less than 10 m - Extent generally more than 5 km in one direction
V	Valley Dominated	- Comprise major spillways, drainageways or mountain trenches which are separated from surrounding landforms by a significant and abrupt break in slope. The valley profile may be V-shaped or U-shaped with an extensive valley floor and flood plain up to about 5 km wide. - The valley profile may also include eroded terraces and their irregular slope segments.

NOTE: May have to expand concept of valley to include very large valleys with walls and flood plains that are mappable.

U Upland Dominated - Surfaces of erosion and former accumulation which have undergone erosional degradation processes of moderate to slight intensity. The dissections are mainly due to past erosion and only to a lesser extent to present erosion. The present surface is controlled to varying degrees by the underlying bedrock surface. Many flat to gently sloping remnants of the former original surface are still found. Major rivers are deeply incised.
- Includes dissected peneplains
- Slope generally <16%
- Relief generally <50 m

F Footslope Dominated - Include sloping area where debris carried mainly by slope wash have accumulating or have accumulated from adjacent mountains. Downward movement is mainly by colluvial processes. Gravelly colluvial fans are included and also gravel covered
- pediments.
- Slopes variable
- Relief up to 100 m

Not Applicable

<u>References</u> for Regional Landforms include:
Kenya Soil Survey, 1978, 2nd ed 1987
Geoanalyses Limited, 1981
National Soils Handbook (USDA)

07 General Relief (median difference between highest/lowest), Nearest 50 m
Not Applicable

08 Elevation, Median, Nearest 100 m
Not Applicable

09 General Surface Lithology - Generalized description of the consolidated or unconsolidated surficial materials which occupy most of the polygon. These materials include the kinds of rockmass from which parent material is derived and other unconsolidated mineral or organic deposits.

Code	Class		Description
IGNE	Igneous Rock	-	Formed by solidification from a molten or partially molten state; major varieties include plutonic (or intrusive) and volcanic (or extrusive) rocks. Examples: andesite, basalt, granite.
META	Metamorphic Rock	-	Rock of any origin altered in mineralogical composition, chemical composition, or structure by heat, pressure, and movement at depth in the earth's crust. Nearly all such rocks are crystalline. Examples: schist, gneiss, quartzite.
SEDI	Sedimentary Rock	-	A consolidated deposit of clastic particles, chemical precipitates and organic remains accumulated at or near the surface of the earth under "normal" low temperature and pressure conditions.
SAND	Sandstone Rock	-	Sedimentary rock consisting of consolidated sands, grits, graywackes, and conglomerite.
SHAL	Shale Rock	-	Sedimentary rock consisting of shales (clays/silts with fine stratification), marls (calcareous mudstones), siltstones, mudstones (clays).
PYRO	Pyroclastic rock	-	Fragmental particles produced by usually explosive, aerial ejection of clastic particles from a volcanic vent either on land or under water.
MIXE	Mixed Rock	-	Mixture of any two or more of the above rock types.
UNSP	Unspecified rock	-	Unspecified rock
MARI	Marine	-	unconsolidated deposits of clay, silt, sand, or gravel that are well to moderately well sorted and well stratified to moderately stratified

		(in some places containing shells). They have settled from suspension in salt or brackish water bodies or have accumulated at their margins through shoreline processes such as wave action and longshore drift.
ALLU	Alluvial	- Pertaining to sediment or processes associated with transportation and disposition by running water. - Sediment generally consisting of gravel and sand with a minor fraction of silt and clay. The gravels are typically rounded and contain interstitial sand. Alluvial sediments are commonly moderately to well sorted and display stratification.
EOLI	Eolian	- Sediment, generally consisting of medium to fine sand and coarse silt particle sizes, that is well sorted, poorly compacted, and may show internal structures such as cross bedding or ripple laminae, or may be massive. These materials have been transported and deposited by wind action.
GLAC	Glacial Drift	- All rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice or by running water emanating from a glacier. Drift includes unstratified material (till) that form moraines, and stratified glaciofluvial deposits that form outwash plains, eskers, kames and glaciolacustrine deposits.
COLL	Colluvial	- Massive to moderately well stratified, nonsorted to poorly sorted sediments with any range of particle sizes from clay to boulders and blocks that have reached their present position by direct, gravity-induced movement - They are restricted to products of mass-wasting whereby the debris is not carried by wind, water, or ice (excepting snow avalanches).

RESI	Residuum	- Unconsolidated, weathered, or partly weathered mineral material that accumulates by disintegration of bedrock in place.
UNDI	Undifferentiated	- A layered sequence of more than three types of unconsolidated genetic material outcropping on a steep erosional escarpment. This complex class is to be used where units relating to individual genetic materials cannot be delimited separately at the scale of mapping.
ORGA	Organic	- Organic materials known as peat, muck, bog or swamp that are commonly saturated with water for prolonged periods. They contain 17% or more organic C by weight.
ICE	ICE	- The ice component includes areas of snow and ice where evidence of active glacier movement is present within the boundary of the defined unit area. This movement will be indicated by features such as crevasses, superglacial moraines, icefalls, and ogives. The assumed process status is active.

10. Permanent Lake Surface Occupance, whole unit of %

11. Seasonally Inundated Lands, whole unit of %

12. Median Distance Between Rivers, Streams and Lakes for Livestock Watering Source, km

13. River and Stream Drainage Pattern Density, estimated by comparison to standard reference areas/showing low, medium or high density (See diagrams at end of Section 8)

14 Predominant General Land Use/Vegetation Type

Code	Class
ANNU	Annual Cropland
PAST	Pastureland which is Cultivated
GRAS	Grassland, which is Native
GRSH	Mixed, Grassland, Shrubland
SHIF	Shifting Cultivation in Forest Covered Land
FORE	Forestland, Closed Stand
PLAN	Plantation Land, perrenial
ORCH	Orchard Land
ROCK	Rockland or Rubble Land
DESE	Desert Land
ORGA	Organic Swamp, Bog, Fen
TUND	Tundra
IRRI	Irrigated Land
WOOD	Woodland (Open Stand of Trees)
SHRU	Shrubland
DWAR	Dwarf Shrubland
REFO	Reforested Land

15. Annex documenting aerial photograph, satellite and radar information (numbers, flight dates)

#	Not Applicable

SCHEMATIC CROSS SECTIONS SHOWING DIFFERENT REGIONAL LANDFORMS

(NOT TO SCALE)

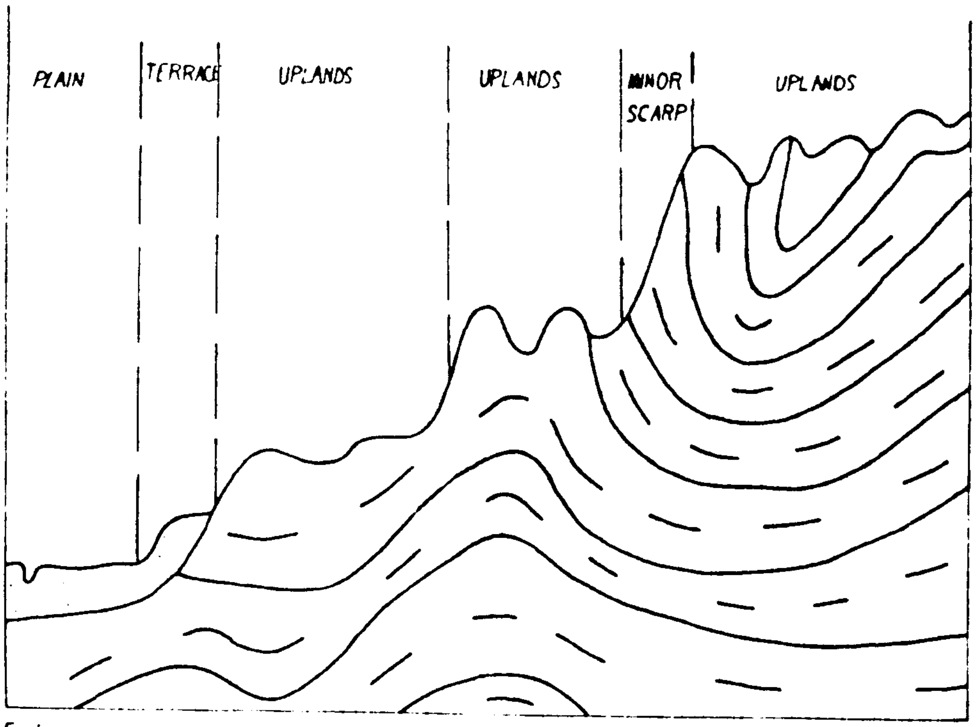


Fig 1

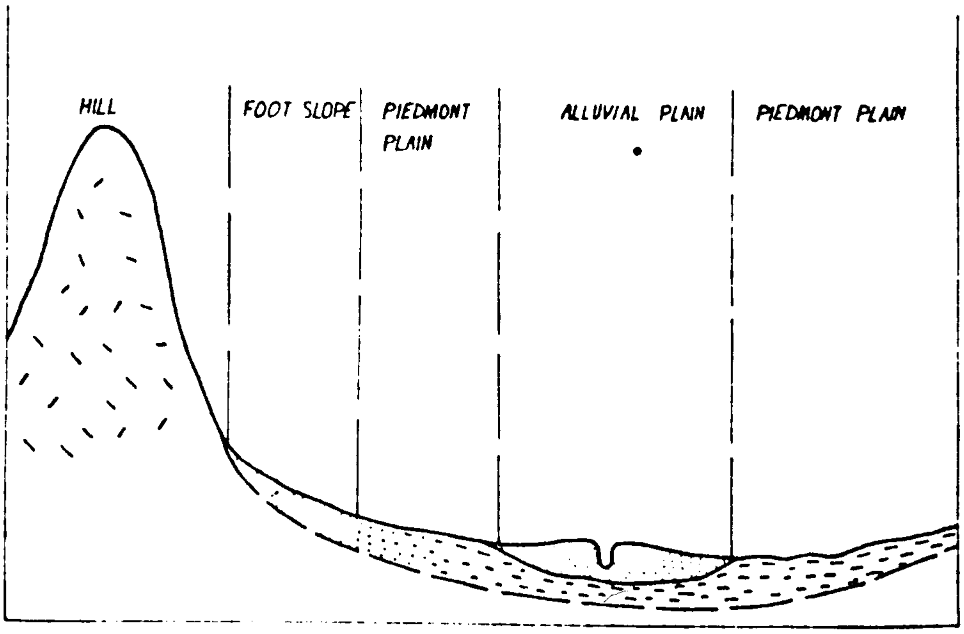


Fig 2

REGIONAL LANDFORMS

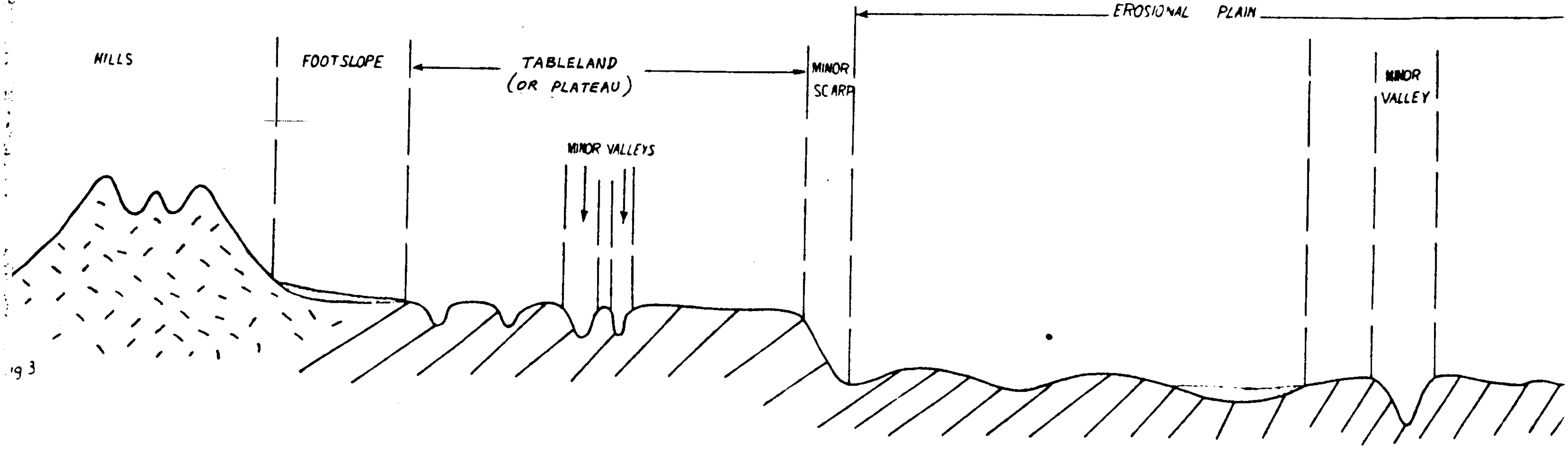


Fig 3

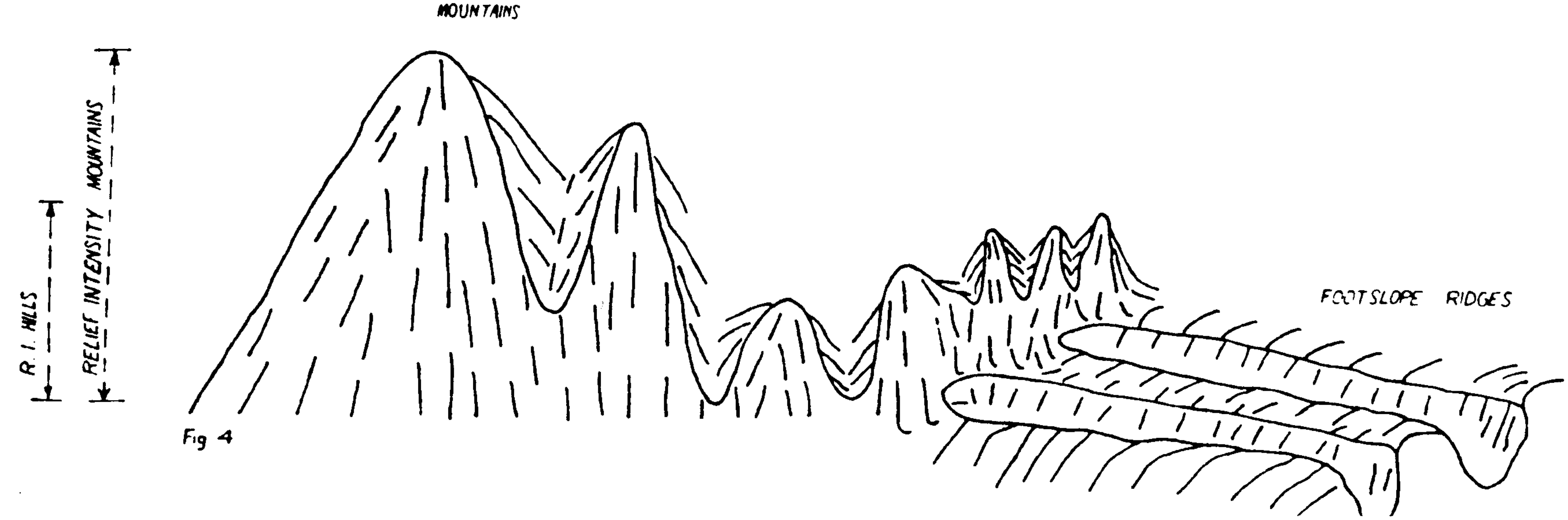


Fig 4

FROM KENYA SOIL SURVEY, 1978

REGIONAL LANDFORMS

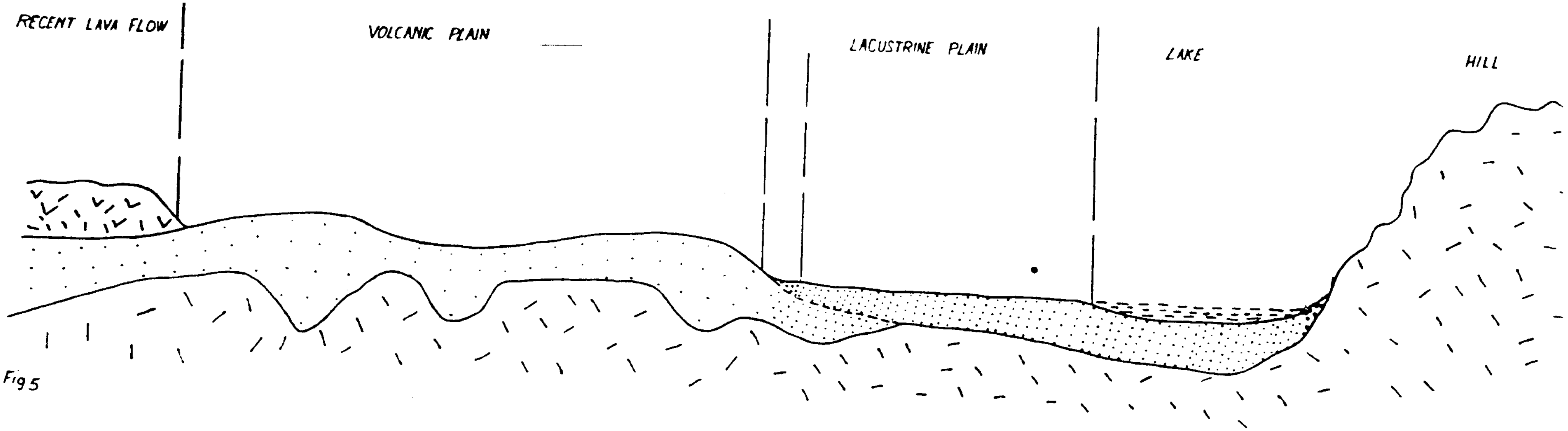


Fig 5

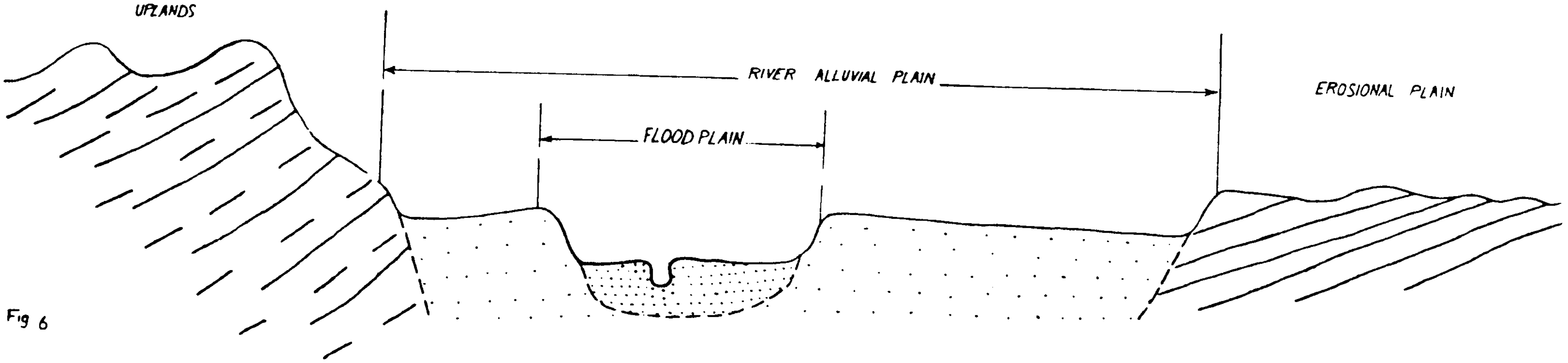
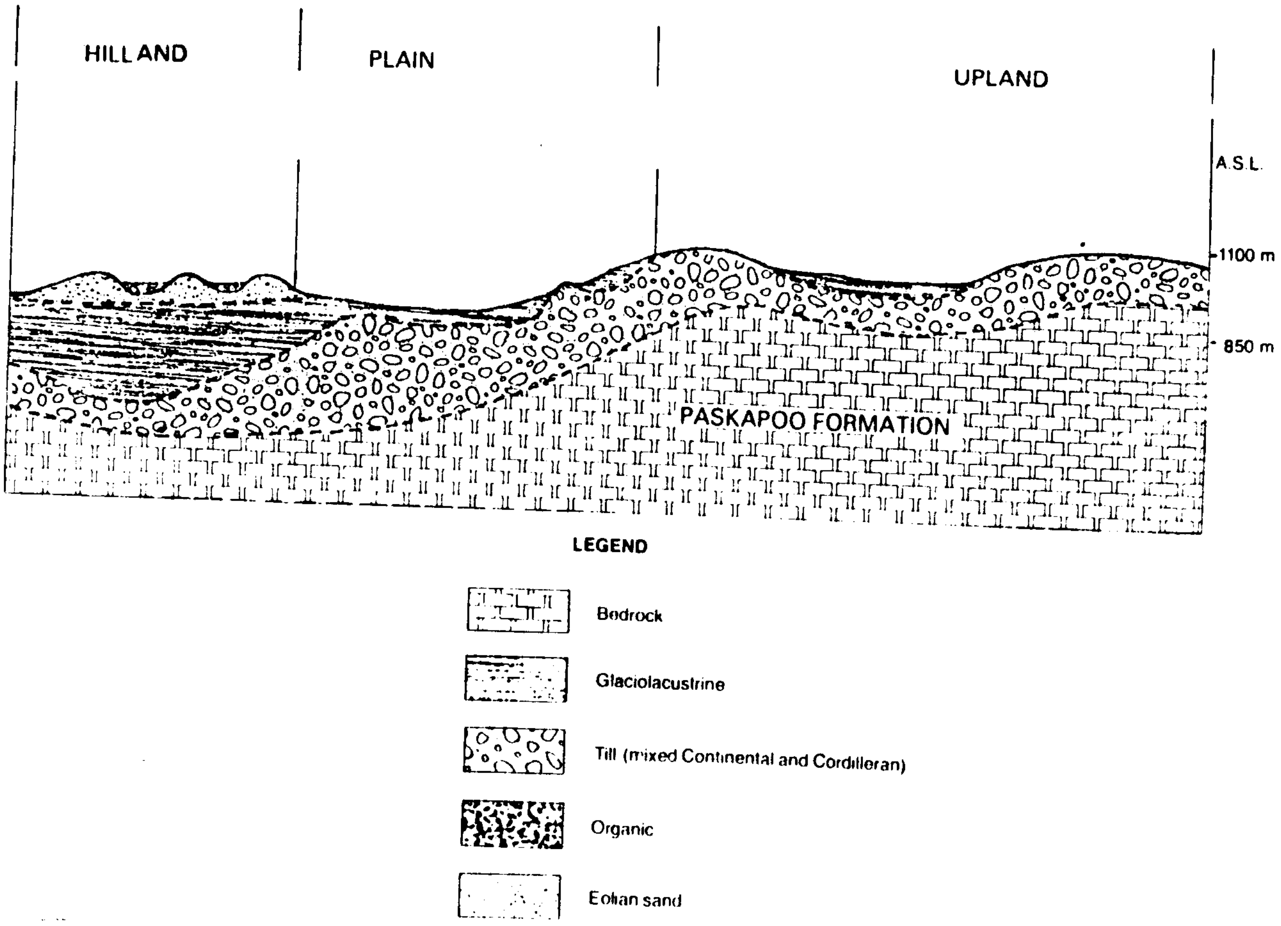


Fig 6

NOT TO SCALE

REGIONAL LANDFORMS



from Brazeau Dam

REGIONAL LANDFORMS

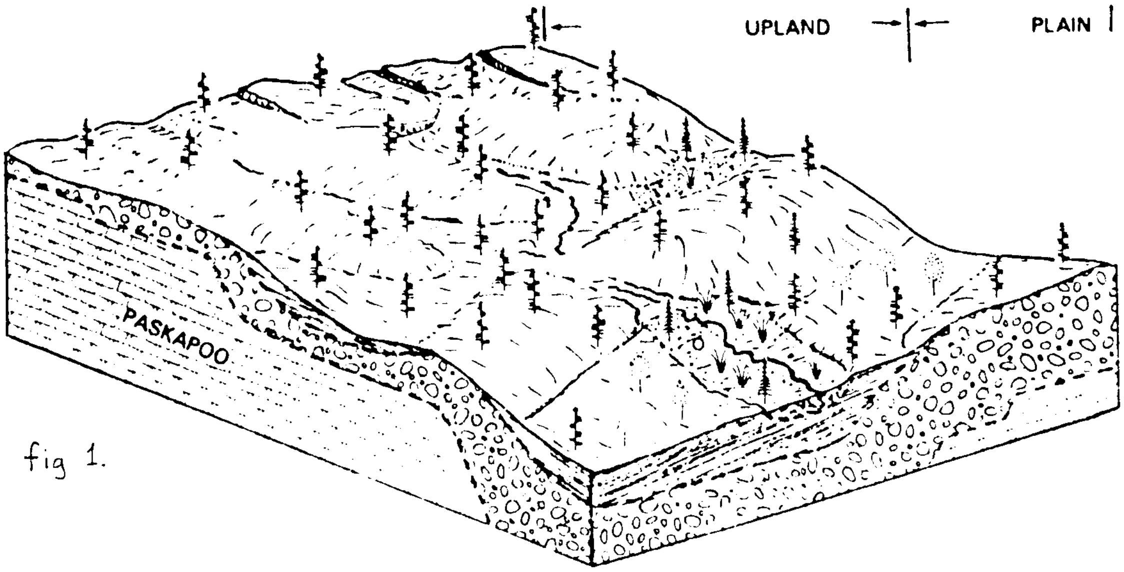


fig 1.

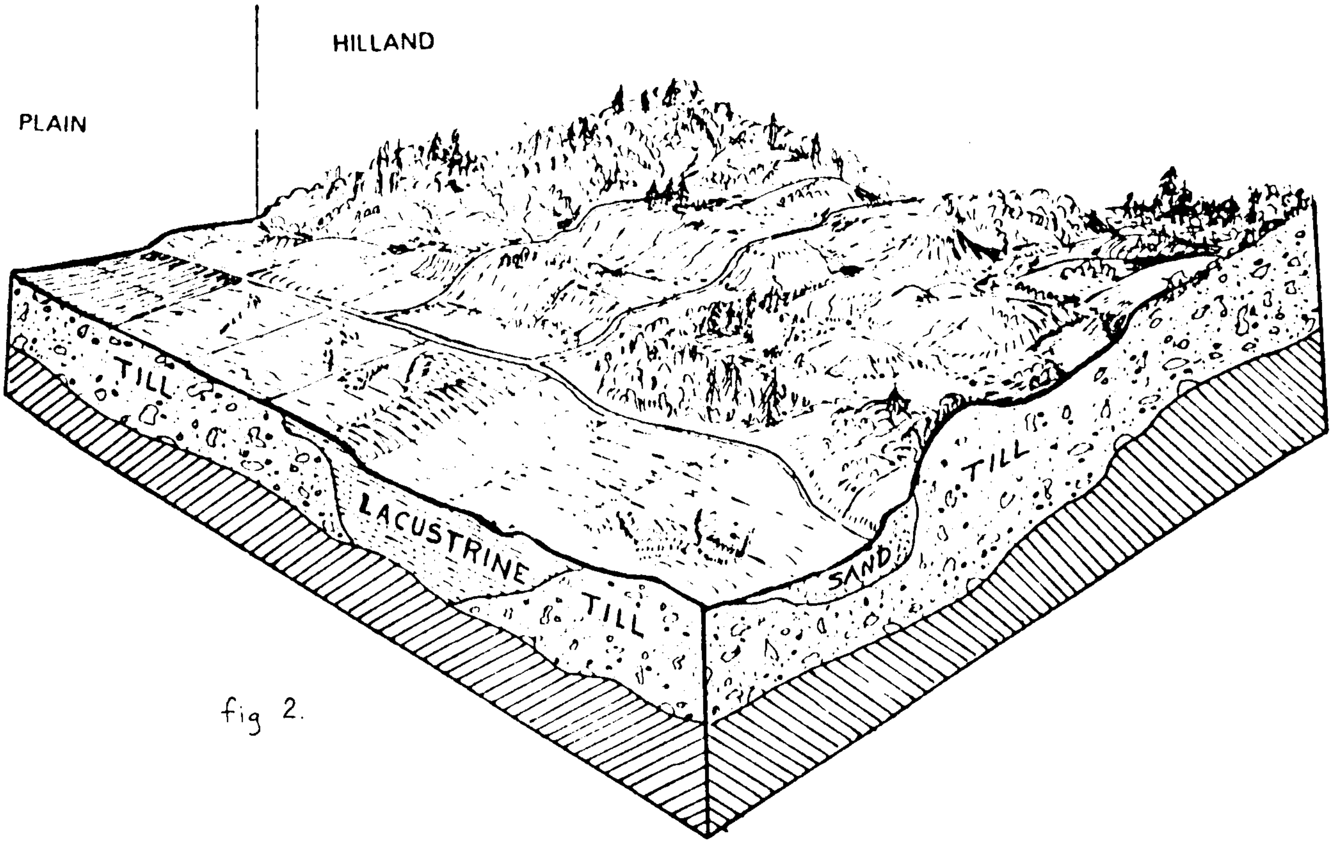
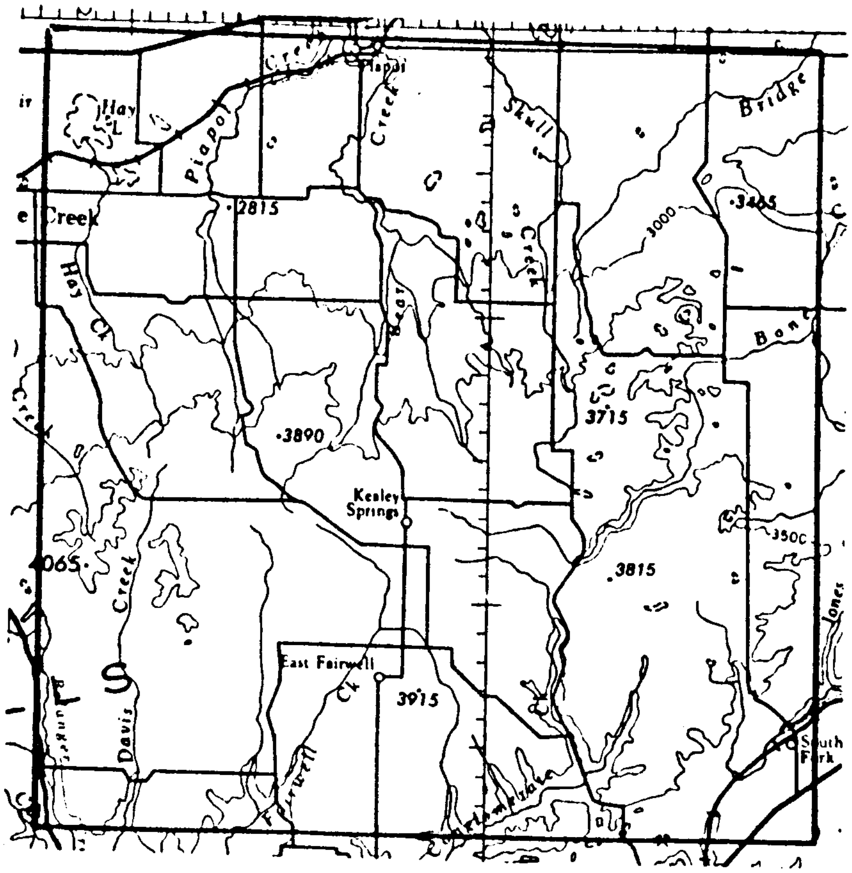


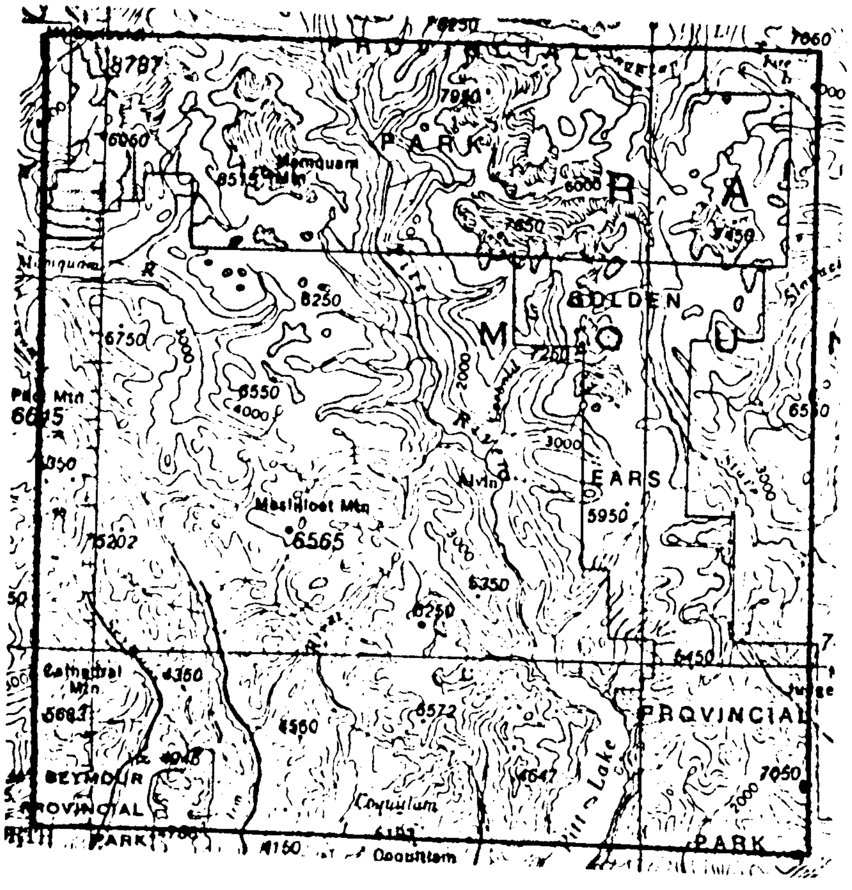
fig 2.

fig 1 from Brazeau Dam

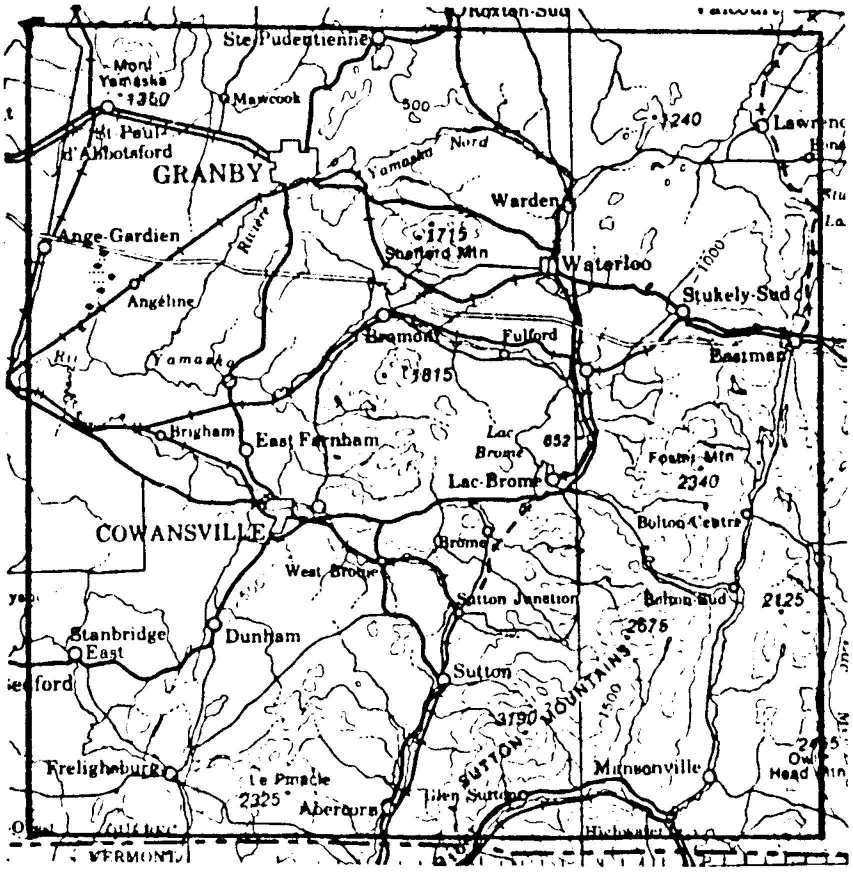
fig 2 from Kocaoglu

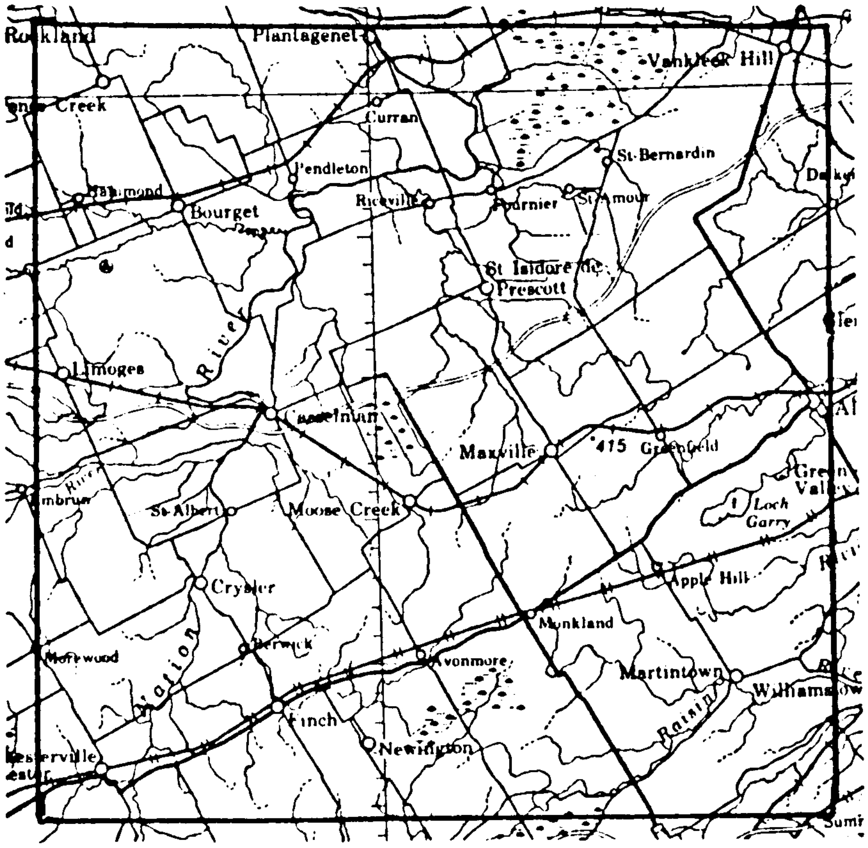
Low Density River and Stream Drainage



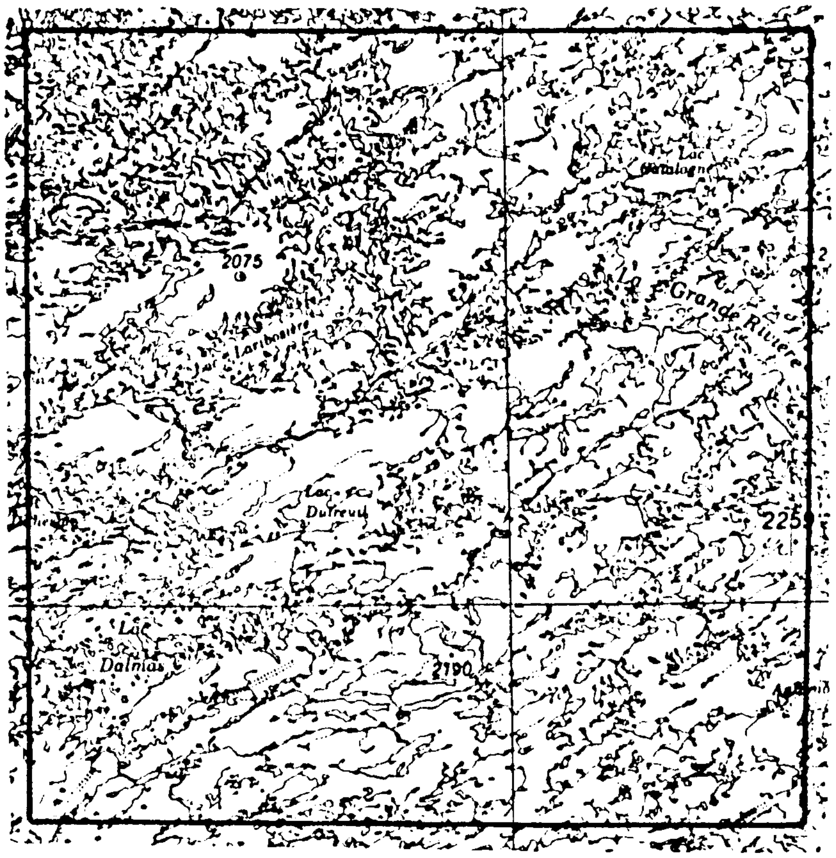


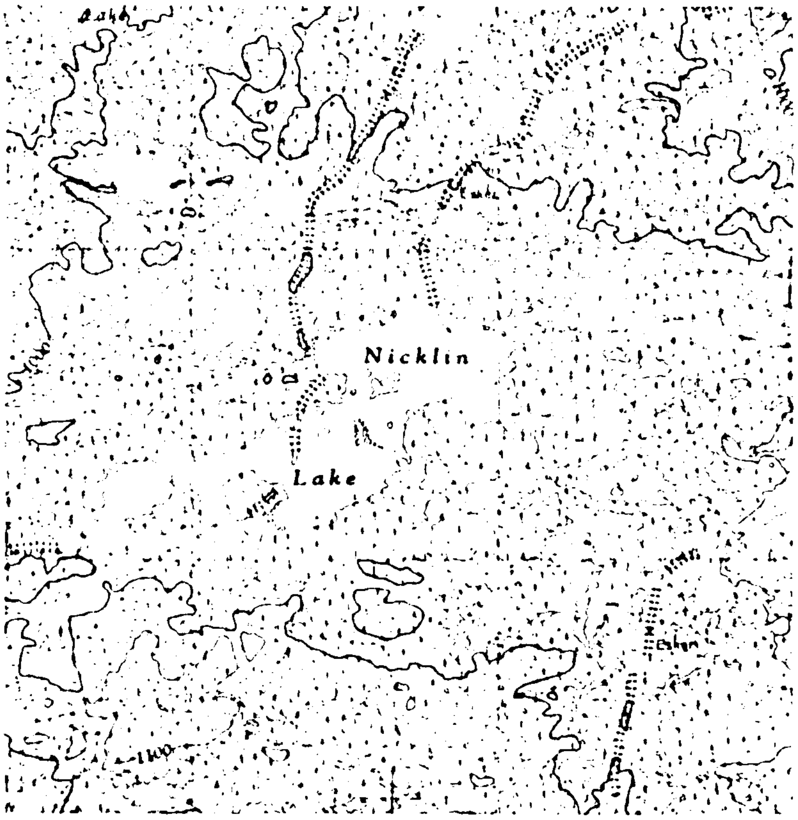
MEDIUM DENSITY RIVER AND STREAM DRAINAGE





HIGH DENSITY RIVER AND STREAM DRAINAGE





9. SOTER TERRAIN COMPONENT FILE ATTRIBUTE LIST AND STRUCTURE

No.	Attribute	Type	Width	Dec
01	Country Code	CHAR	4	
02	State/Province Code	CHAR	2	
03	Base Map Code	CHAR	4	
04	Report/Map Number Reference Code	CHAR	4	
05	Polygon Number (unique)	CHAR	4	
06	Proportion of Polygon to Which Following Attributes Apply, nearest 10% or 5% when needed	NUMERIC	2	
07	Terrain Component Number	CHAR	1	
08	Parent Material/Parent Rock	CHAR	2	
09	Texture Group of Soil Parent Material	CHAR	1	
10	Local Surface Form	CHAR	1	
11	Slope Gradient, %	CHAR	2	
12	Dominant Length of Slope (shoulder to footslope), m	CHAR	3	
13	Stoniness At Surface	CHAR	4	
14	Rockiness Outcrops	CHAR	3	
15	Depth to Ground Water, cm	CHAR	5	
16	Quality of Ground Water, micro semen	CHAR	4	
17	Rooting Depth Which Is Unrestricted, cm	CHAR	3	
18	Predominant Land Use/Vegetation Type	CHAR	2	
19	Surface Flooding Due to Inundation	CHAR	3	
20	Deleted from this version			

21	Surface Drainage	CHAR	4
22	Overwash with Recent Water Erosion Products	CHAR	2
23	Overblow with Recent Wind Erosion Products	CHAR	2
24	Deleted from this version		
25	Deleted from this version		
26	Complexity of Parent Material/Soil	CHAR	1
27	Permafrost Distribution	CHAR	1
28	Ice Content of Materials	CHAR	1
29	Previous Polygon Number	CHAR	4
30	Terrain Component of Previous Poly Number	CHAR	1
31	Depth to Parent Rock, m	CHAR	2

NOTE: Underlined four characters of attribite name key words are used to label attributes (or fields of information) on coding forms.

10. SOTER TERRAIN COMPONENT FILE ATTRIBUTE CLASSES, CODES AND DESCRIPTIONS

01 Country Code - 4 Number International Code

02 State or Province Code - 2 Number National Code

03 Base Map Code - 4 Character National Code

04 Report/Map Number Code - 4 Number State or Province Code
Not Applicable

05 Polygon Number - 4 Number Code, Unique for each map Polygon

06 Proportion of Polygon to Which the Following Attributes Apply, Nearest 10% (i.e. 50%, 30%), or 5% When Needed (i.e. 15%)

07 Terrain Component Number - A maximum of 3 per polygon (i.e. 1,2,3)

08 Soil Parent Material/Parent Rock - Parent rock or material derived from parent rock

Code	Class	Description
AL	Alluvial	- Sediment generally consisting of gravel and sand with a minor fraction of silt and clay. The gravels are typically rounded and contain interstitial sand. Alluvial sediments are commonly moderately to well sorted and display stratification. Examples: channel deposits, overbank deposits, terraces, alluvial fans, and deltas.
CO	Colluvial	- Massive to moderately well stratified, nonsorted to poorly sorted sediments with any range of particle sizes from clay to boulders that have reached their present position only by direct, gravity-induced movement (excepting snow avalanches). - Processes include slow displacements such as creep and solifluction and rapid movements such as earth flows,

		rockslides, avalanches, and falls.
EO	Eolian	- Sediment, generally consisting of medium to fine sand and coarse silt particle sizes, that is well sorted, poorly compacted, and may show internal structures such as cross bedding or ripple laminae, or may be massive. Individual grains may be rounded and show signs of frosting. These materials have been transported and deposited by wind action. - Examples: dunes, shallow deposits of sand and coarse silt, and loess but not tuffs.
FL	Fluvioglacial	- Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.
LA	Lacustrine	- Sediment generally consisting of either stratified fine sand, silt, and clay deposited on the lake bed or moderately well sorted stratified sand and coarser materials that are beach and other nearshore sediments transported and deposited by wave action. - These are materials that either have settled from suspension in bodies of standing fresh water or have accumulated at their margins through wave action. - Examples: lake sediments and beaches.
MO	Morainal	- Sediment generally consisting of well-compacted material that is nonstratified and contains a heterogeneous mixture of sand, silt and clay particle sizes in a mixture that has been transported beneath, beside, on, within, or in front of a glacier and not modified by any intermediate agent. - Examples: basal till (ground moraine), lateral and terminal moraines, rubbly moraines of cirque glaciers, hummocky ice-disintegration

		moraines, and preexisting, unconsolidated sediments reworked by a glacier so that their original character is largely or completely destroyed.
AN	Anthropogenic	- Man-made or man-modified materials, including those associated with mineral exploitation and waste disposal. - They include materials constructed by man or geological materials modified by man so that their physical properties (structure, cohesion, compaction) have been drastically altered. - Examples: areas of landfill, spoil heaps, open-pit mines, levelled irrigated areas.
UN	Undifferentiated	- A sequence of more than three types of genetic material outcropping on a steep erosional escarpment. This complex class is to be used where units relating to individual genetic materials cannot be delimited separately at the scale of mapping. It may include colluvium derived from the various genetic materials and resting upon the scarp slope.
MA	Marine	- Unconsolidated deposits of clay, silt, sand, or gravel that are well to moderately well sorted and well to moderately well stratified (in some places containing shells). They have settled from suspension in salt or brackish water bodies or have accumulated at their margins through shoreline processes such as wave action and longshore drift. Nonfossiliferous deposits may be judged marine, if they are located in an area that might reasonably be considered to have contained salt water at the time the deposits were formed.
MR	Marl	- An earthy, unconsolidated deposit consisting chiefly of calcium

		carbonate mixed with clay in approximately equal proportions.
RE	Residuum	- Unconsolidated, weathered, or partly weathered soil mineral material that accumulates by disintegration of bedrock in place.
OB	Organic, BOG	- Sphagnum or forest peat materials (>30% organic matter by weight) formed in an ombrotrophic environment due to the slightly elevated nature of the bog tending to be disassociated from nutrient-rich ground water or surrounding mineral soils. - Near the surface the materials are usually undecomposed (fibric), yellowish to pale brown in color, loose and spongy in consistence, and entire sphagnum plants are readily identified. These materials are extremely acid, with low bulk density and very high fiber content. At depths they become darker in color, compacted, and somewhat layered. - Bogs are associated with slopes or depressions with a water table at or near the surface in the spring and slightly below it during the remainder of the year. They are usually covered with sphagnum mosses, but sedges may also grow on them. Bogs may be treed or treeless and are frequently characterized by a layer of ericaceous shrubs.
OF	Organic, FEN	- Sedge peat materials (>30% organic matter by weight) derived primarily from sedges with inclusions of partially decayed stems of shrubs formed in a mineotrophic environment due to the close association of the material with mineral-rich waters. - It is usually moderately well to well decomposed, dark brown to black in color, with fine to medium sized fibers; decomposition often becomes greater at lower depths.

		- The materials are covered with a dominant component of sedges, but grasses and reeds may be associated in local pools.
OS	Organic, Swamp	- A peat-covered or peat-filled (>30% organic matter by weight) area with the water table at or above the peat surface. The dominant materials are forest and fen peat formed in a eutrophic environment due to strong water movement from the margins or other mineral sources. - It is usually moderately well to well decomposed and has a dark brown to reddish brown matrix; the more decomposed materials are black in color. It has an amorphous or very fine fibered structure containing a random distribution of woody fragments and trunks of coniferous tree species. - The vegetation cover may consist of coniferous or deciduous trees, tall shrubs, herbs, and mosses. In some regions sphagnum mosses may be abundant.
OU	Organic, Undifferentiated	- A layered sequence of more than three types of organic material.
IA	Rock Igneous, Acid	- Any igneous rock predominantly consisting of light-colored materials, having low specific gravity and having more than 65% silica (Si02) Examples: granite, granodiorite aplite, rhyolite
IB	Rock Igeneous, Basic	- Any igneous rock having a relatively low silica content, sometimes delimited arbitrarily as less than 54%. They are relatively rich in Fe-Mg minerals such as pyroxenes (augite), horneblend, nephelinite, gabbro, norite, dolerite, pyroxene, serpentine, peridotite.
II	Rock Igneous, Intermediate	- andesite

SN	Rock, Sandstone	- Sedimentary rock consisting of consolidated sands, grits, graywackes, and conglomerite.
SH	Rock, Shales	- Sedimentary rock consisting of shales (clays/silts with fine stratification), siltstones, mudstones (silt and clays).
LI	Rock, Limestone	- Sedimentary rock consisting of limestone, coral reef limestones or travertines.
TA	Rock Metamorphic, Acid	- Metamorphic rocks, from acid environment. i.e. quartzite
TB	Rock Metamorphic, Basic	- Metamorphic rocks from basic environment i.e. horneblende, gneiss
PA	Rock Pyroclastic, Acid	- Pyroclastic rocks from acid environment
PB	Rock Pyroclastic, Basic	- Pyroclastic rocks from basic environment.
RU	Rock Unspecified	- Rock of unspecified origin and properties
IC	ICE	- The ice component includes areas of snow and ice with evidence of active glacier movement. - Examples: cirque glaciers, mountain icefields, valley and piedmont glaciers.
WA	Water	
#	Not Applicable	

<u>References</u> for general surface lithology including parent material:
CanSIS Manual, 1982 Revised.
Kenya Soil Survey, 1978.
Canadian Wetland Classification System, 1987.

09 Texture Group of Soil Parent Material, or soil at 2 m if deeply developed.

Code	Class	Group of USDA Soil Texture Classes
X	Extremely Sandy	- Includes all sand texture classes.
S	Sandy	- Includes all loamy sand, and sandy loam texture classes and their gravelly or cobbly modifiers.

L	Loamy	Includes all loam and clay loam texture classes and their gravelly or cobbly modifiers.
C	Clayey	Includes clay texture class up to 60% clay and their gravelly or cobbly modifiers.
Y	Very Clayey	More than 60% clay.
#	Not Applicable	

10 Surface Form - A description of the physical surface form (assemblage of slopes) or recurring pattern of forms occurring at the earths surface. Form as applied to consolidated materials, form refers to the product of their modification by geological processes. (Canadian System of Soil Classification, 1978)

Surface Forms: (SEE DIAGRAMS AT THE END OF SECTION 10)

Code	Class	Description
G	Gullied	A well developed pattern of frequent, active deep gullies providing external drainage for the area.
H	Hummocky (or Irregular)	A very complex sequence of slopes extending from somewhat rounded depressions or kettles of various sizes to irregular conical knolls or knobs. There is a general lack of concordance between knolls or depressions. Slopes are generally 4-70%. Examples: hummocky moraine, hummocky glaciofluvial.
I	Inclined	A sloping, unidirectional surface with a generally constant slope not broken by marked irregularity or gullies. A weakly developed dissected pattern provides external drainage for the local area. Slopes are 4-60%. The form of inclined slopes is not related to the initial mode of origin of the underlying material.

L	Level	- A flat or very gently sloping, unidirectional surface with a generally constant slope not broken by marked elevations and depressions. Slopes are generally less than 2% (i.e. 1%). Examples: floodplain, lake plain.
R	Rolling	- A very regular sequence of moderate slopes extending from rounded, sometimes confined concave depressions to broad, rounded convexities producing a wavelike pattern of moderate relief. Slope gradients are generally greater than 5% but may be less. This surface form is usually controlled by the underlying bedrock.
E	Ridged	- A long, narrow elevation of the surface, usually sharp crested with steep sides. The ridges may be parallel, subparallel, or intersecting. Examples: eskers, crevasse fillings, washboard moraines, some drumlins.
S	Steep	- Erosional slopes greater than 60%, on both consolidated and unconsolidated materials. The form of a steep erosional slope on unconsolidated materials is not related to the initial mode of origin of the underlying material. Examples: escarpments
U	Undulating	- A very regular sequence of gentle slopes that extends from rounded, sometimes confined concavities to broad rounded convexities producing a wavelike pattern of low local relief. Slope length is generally less than 0.8 km and the dominant gradient of slopes is usually less than 6%, but may range up to 8%. It lacks an external drainage pattern. Examples: some ground moraine, lacustrine material of varying thickness over morainal deposits, peneplain.

N	Undulatingex	-	as for undulating but with external drainage pattern.
T	Terraced	-	Scarp face and the horizontal or gently inclined surface (tread) above it. Example: alluvial terrace.
C	Gilgai	-	A microrelief pattern consisting of a succession of enclosed micro-basins and micro-knolls less than 60 cms in nearly level areas or of micro-valleys and micro-ridges that run with the slope. Gilgai microrelief patterns occur on clay soils that have high coefficients of expansion and contraction with changes in moisture (USDA Handbook 18)
M	Mounded	-	A pattern including distinct mounds of varying relief rising above a planar surface. The mounds must occupy at least 40% of the area. Example: termite and ant mounds.
A	Apron	-	A relatively gentle slope at the foot of a steeper slope and formed by materials from the steeper, upper slope. Examples: two or more coalescing fans, a simple slope.
Z	Irregulary Dissected	-	A complex pattern of inclined, multi aspect facing apical shaped slopes with interlocking bases and rising to a series of inclined ridges.
#	Not Applicable		

ORGANIC Surface forms (Canadian Wetland Classification System, 1987)

Code	Class		Description
B	Blanket Bog	-	A bog consisting of extensive peat deposits that occur more or less uniformly over gently sloping hills and valleys. The peat thickness seldom exceeds 2 m.

D	Domed Bog	- A large (usually more than 500 m in diameter) bog with a convex surface, rising several metres above the surrounding terrain. The centre is usually draining in all directions. Small crescentic pools often form around the highest point. Peat development is usually in excess of 3 m.
F	Flat Bog	- A bog having a flat, featureless surface. It occurs in broad, poorly defined depressions. The depth of peat is generally uniform.
P	Plateau Bog	- A raised bog elevated 0.5-1 m above the surrounding fen. It is usually teardropshaped, with the pointed end oriented in the downslope direction.
V	Veneer Bog	- A bog occurring on gently sloping terrain generally underlain by discontinuous permafrost. Although drainage is predominantly below the surface, overland flow occurs in poorly defined drainage-ways during peak runoff. Peat thickness is usually less than 1.5 m.
J	Ribbed Fen	- A fen with parallel, low peat ridges ("strings") alternating with wet hollows or shallow pools, oriented across the major slope at right angles to water movement. The depth of peat exceeds 1 m.
K	Horizontal Fen	- A fen with a very gently sloping, featureless surface. This fen occupies broad, often ill-defined depressions, and may be interconnected with other fens. Peat accumulation is generally uniform.
Y	Delta Marsh	- A marsh occupying lowlands on deltas, usually with drainage connections to active river channels. It is subject to inundation at least once during a season, followed by a slow drawdown of the water levels. A high rate of sedimentation may occur in many parts of the marsh.

O Coastal Marsh - A marsh influenced by brackish or saline waters of tidal marine origin. It is located above mean high-water levels and is inundated only by flood tides. It occurs on marine terraces, flats, embayments, or lagoons.

Q Floodplain Marsh - A marsh occurring on fluvial floodplains adjacent to river channels. The marsh is subject to annual flooding and sedimentation for various lengths of time, with possibly some water impounded on the marsh following flooding.

W Floodplain Swamp - A swamp occurring in a valley which may be inundated by a seasonally flooding river. Slow drawdown after flooding preserves a high water table for most of the growing season. Shallow peat development may be encountered.

X Basin Swamp - A swamp developed in a topographically defined basin where the water is derived locally but may be augmented by drainage from other parts of the watershed. Accumulation of well-decomposed peat is shallow (less than 0.5 m) at the edge, and may reach 2 m at the centre.

11 Slope Gradient, %

Code	Class
01	1-3
04	4-9
10	10-15
16	16-29
30	30-59
60	60 +
#	Not Applicable

12 Dominant Length of slope, m (shoulder to toe slope)

001	1-49
050	50-149
150	150-299
300	300-599
600	600+
#	Not Applicable

13 Stoniness at Surface, m apart

Code	Class(m)	Coverage(%)
0.1	0 - 0.1	99 - 90 (Pavement)
0.2	0.2 - 0.7	90 - 15
0.8	0.8 - 1.5	15 - 3
1.6	1.6 - 9.0	3.0 - 0.1
10.0	10.0 - 30	0.1 - 0.01
30.0	30+	<0.01
#	Not Applicable	

14 Rockiness Outcrops - presence of hardrock(H) or softrock(S) outcrops, m apart.

Code	Class	Exposure (%)
H01	Hardrock outcrops 0 - 3m apart	50 - 90
H04	Hardrock outcrops 4 - 9m apart	25 - 50
H10	Hardrock outcrops 10 - 34m apart	10 - 25
H35	Hardrock outcrops 35 - 98m apart	2 - 10
H99	Hardrock outcrops 99 + m apart	<2
S01	Softrock outcrops 0 - 3m apart:	50 - 90
S04	Softrock outcrops 4 - 9m apart	25 - 50
S10	Softrock outcrops 10 - 34m apart	10 - 25
S35	Softrock outcrops 35 - 98m apart	2 - 10
S99	Softrock outcrops 99 + m apart	<2
#	Not Applicable	

15 Depth To Ground Water Table or Mottling, cm

AL100	Always less than 100
TL100	Temporarily less than 100
AG100	Always 100-200
TG100	Temporarily 100-200
AG200	Always greater than 200
ML50	Mottling less than 50
MG50	Mottling 50-99
MG100	Mottling greater than 100
#	Not Applicable

16 Quality of Ground Water, micro semens

Code	Class
0001	1 - 249
0250	250 - 749
0750	750 - 1499
1500	1500 - 2999
3000	3000+
#	Not Applicable

17 Rooting, Depth which is <u>unrestricted</u>, cm

Code	Class
001	1 - 24
025	25 - 49
050	50 - 99
100	100 - 149
150	150 +
#	Not Applicable

18 <u>Predominant</u> Land Use/Vegetation Type

Code	Class
HO	Horticultural Land
OR	Orchard Land
AN	Annual Cropland
MA	Multi-annual cropland (more than one annual crop per year)
BO	Bog, Fen
SW	Swamp
PA	Pastureland, Cultivated grassland
GR	Grassland, Native
PL	Plantation Land
MI	Mixed grazing, small trees (parque)
DT	Desertland
QU	Quaries, Mines, Pits
RO	Rockland or Rubbleland
RE	Outdoor Recreation, (Parks, Game Farms or Preserves)
SH	Shifting Cultivation in Forest Covered Land
UR	Urban
IC	Irrigated Annual Cropland
IO	Irrigated Orchard Land
IH	Irrigated Horticultural Land
SA	Salinity/Alkalinity Tolerant Plants
FT	Tropical Rain Forest
FG	Tropical semi-evergreen seasonal forest
FC	Tropical semi-deciduous seasonal forest
FU	Closed Forest, Unspecified (FAO, 1986)
FE	Closed Forest, Evergreen
FS	Closed Forest, Semi-deciduous
FD	Closed Forest, Deciduous
FX	Closed Forest, Xeromorphic
CA	Caatinga
FM	Submontane Forest

WU	Woodland, Unspecified (Open Stand of trees)
WE	Woodland, Evergreen
WS	Woodland, Semi-deciduous
WD	Woodland, Deciduous
WX	Woodland, Extremely Xerophytic
SU	Shrub, Unspecified
SE	Shrub, Evergreen
SS	Shrub, Semi-deciduous
SD	Shrub, Deciduous
SX	Shrub, Extremely Xerophytic
DU	Dwarf Shrub, Unspecified
DE	Dwarf Shrub, Evergreen
DS	Dwarf Shrub, Semi-deciduous
DD	Dwarf Shrub, Deciduous
DX	Dwarf Shrub, Extremely Xerophytic
DT	Dwarf Shrub, Tundra
HW	Savanna - Well drained
HP	Savanna - Poorly drained
HU	Herbaceous, Unspecified
HT	Herbaceous, Tall Grassland
HM	Herbaceous, Medium Grassland
HS	Herbaceous, Short Grassland
HF	Herbaceous, Forb
#	Not Applicable

19 Surface Flooding During Growing Season Due To Inundation (I) and/or heavy rainfall, or High Water Table (H) - months land surface covered

Code	Class
IH0	No flooding
I01	0 - 1 month of flooding by inundation and/or heavy rainfall
I02	2 - 3 months of flooding by inundation and/or heavy rainfall
I04	4 - 6 months of flooding by inundation and/or heavy rainfall
I07	7 - 9 months of flooding by inundation and/or heavy rainfall
I10	10 - 12 months of flooding by inundation and/or heavy rainfall
H01	0 - 1 month of flooding by high water table
H02	2 - 3 months of flooding by high water table
H04	4 - 6 months of flooding by high water table
H07	7 - 9 months of flooding by high water table
H10	10 - 12 months of flooding by high water table
#	Not Applicable

20 Deleted from this version

21 Surface Drainage or Run Off - rate of which water is drained from the terrain surface (Cochrane, ISIS)

Code	Class
POND	Water ponds at the surface, and the soil is waterlogged for periods of a month or more.
SLOW	Water drains slowly, the soil does not remain waterlogged for a period less than a month.
MEDI	Water drains at a medium rate, the soil is not waterlogged for more than 48 hours.
RAPI	Excess water drains rapidly, even during periods of prolonged heavy rainfall.
VERY	Excess water drains very rapidly, the soil cannot ensure adequate topsoil moisture for seed germination.
#	Not Applicable

22 Overwash With Recent Water Erosion Products, % Occupance

Code	Class
01	0 - 2%
03	3 - 9
10	10 - 39
40	40 - 74
75	75+
#	Not Applicable

23 Overblow With Recent Wind Erosion Products, % Occupance

Code	Class
01	0 - 2
03	3 - 9
10	10 - 39
40	40 - 74
75	75+
#	Not Applicable

24 Deleted from this version

25 Deleted from this version

26 Complexity of Parent Material and/or Soil

Code	Class	Description
L	Low	- A maximum of 2 parent materials and/or soils occurring over relatively long distance.

M	Medium	- 2 to 3 parent materials and/or soils occurring within relatively short distance
H	High	- At least 2 different materials on which are developed at least 2 different soils
#	Not Applicable	

27 Permafrost Distribution

Code	Class	Description
S	Sporadic	- Only a very few isolated areas of organic soils are permanently frozen.
D	Discontinuous	- Occurs in some areas beneath the ground surface throughout a geographic regional landform where other areas are free of permafrost.
C	Continuous	- Occurs everywhere beneath the exposed land surface throughout a geographic regional landform with the exception of widely scattered sites such as newly deposited unconsolidated sediments.
#	Not Applicable	

28 Ice Content of Material

Code	Class	Description
L	Low	- <60% by volume
M	Medium	- 60 - 80% by volume
H	High	- >80% by volume
#	Not Applicable	

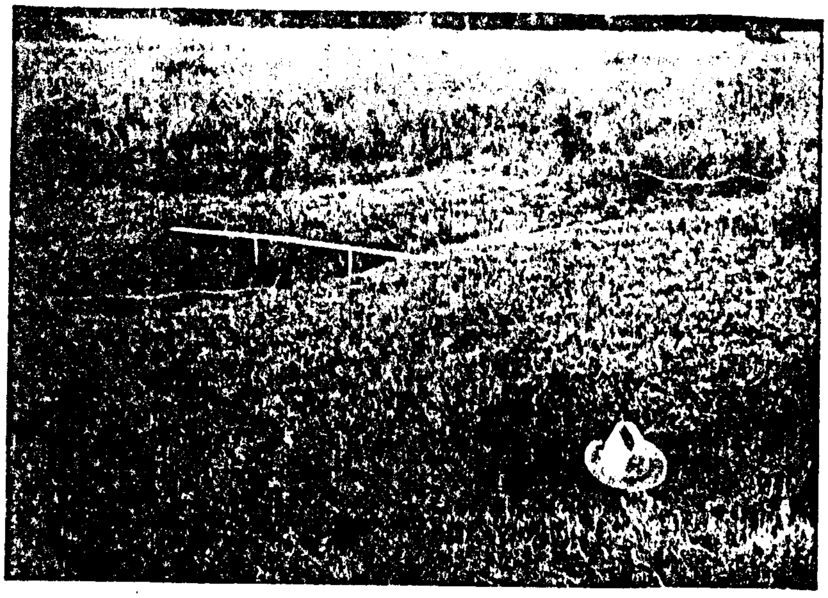
29 Previous Polygon Number with same terrain component data - refers to the polygon number in which the same terrain component occurs and has already been coded. Therefore, it is not necessary to code the same data again; it will be done by the computer.

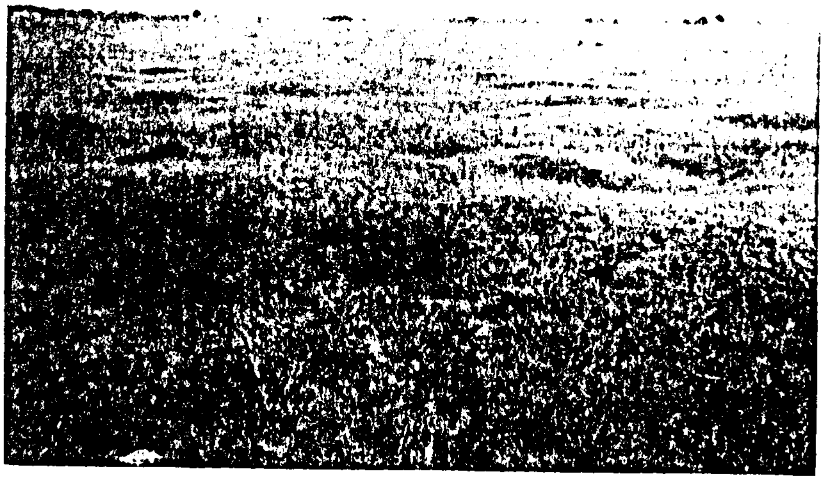
Not Applicable should be coded if the same terrain component data has not been recorded previously.

30\. Terrain Component Number of Above Polygon (See 29) with Same Soil Data - refers to the terrain component number of the above Polygon in which the same terrain component occurs so it is not necessary to code the data again.

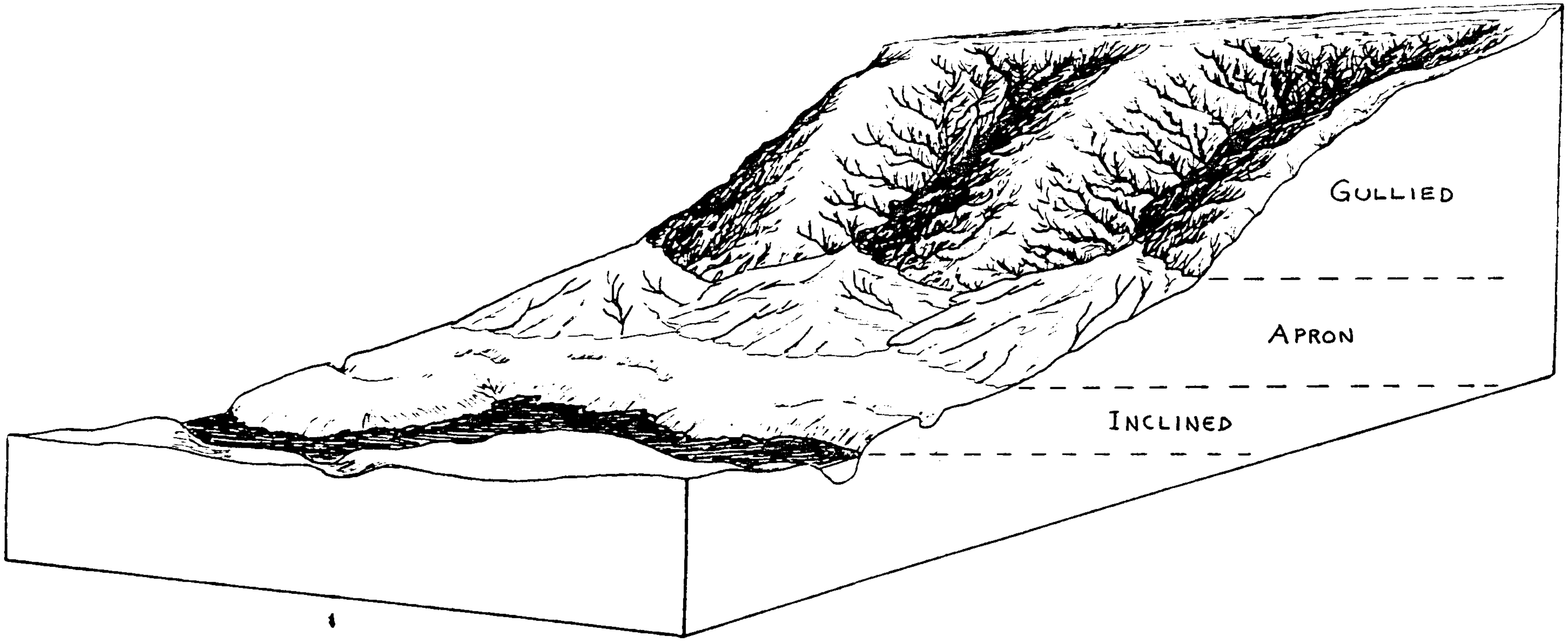
Not Applicable should be coded if the same terrain component data has not been recorded previously.

31\. Depth to parent rock (m)

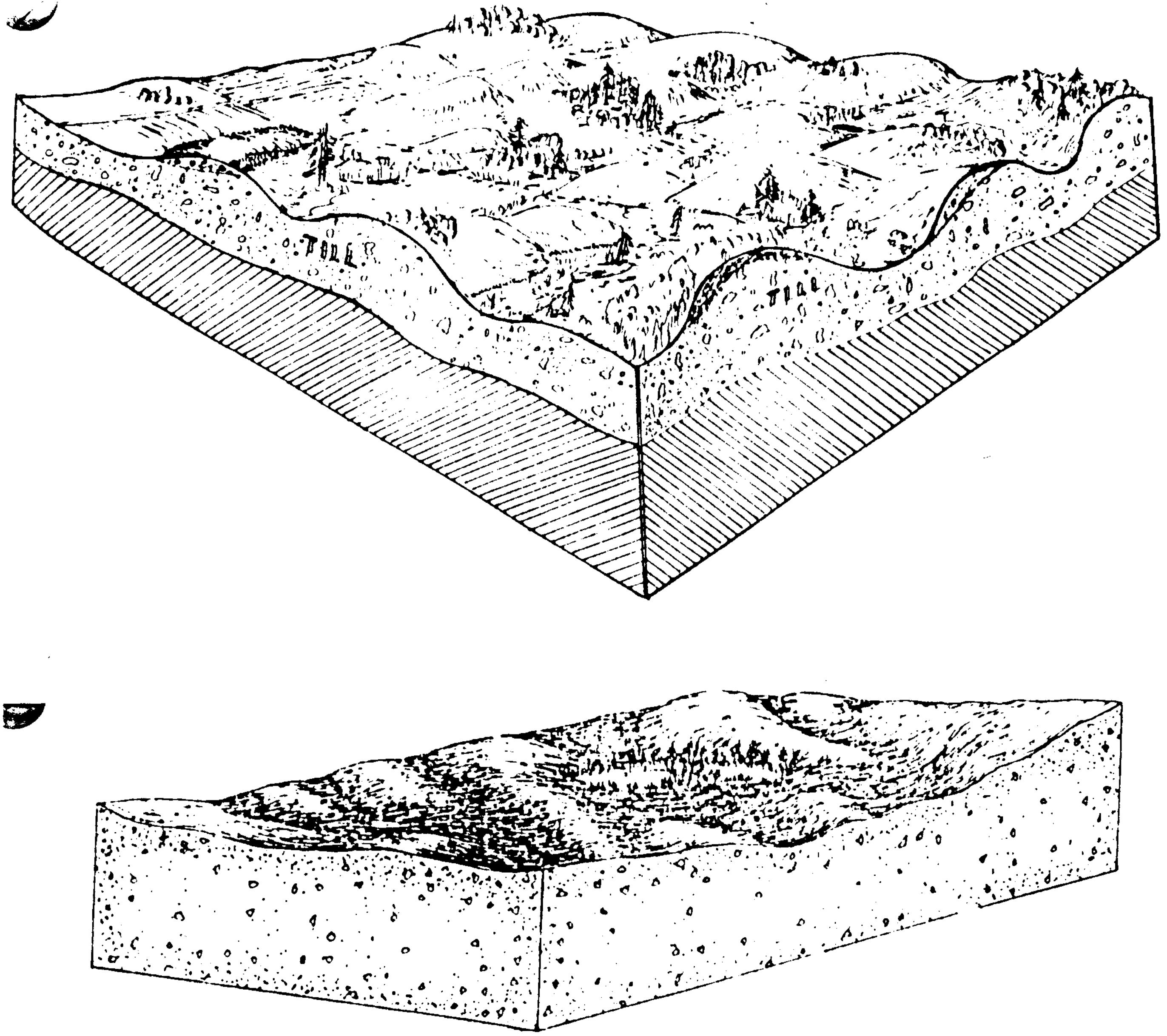




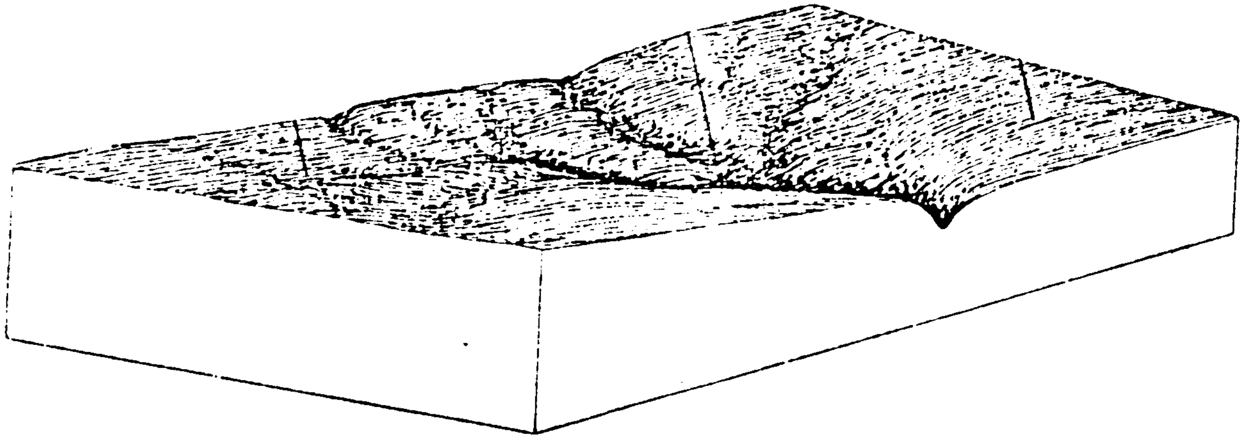
GILGAI SURFACE FORM



GULLIED SURFACE FORM



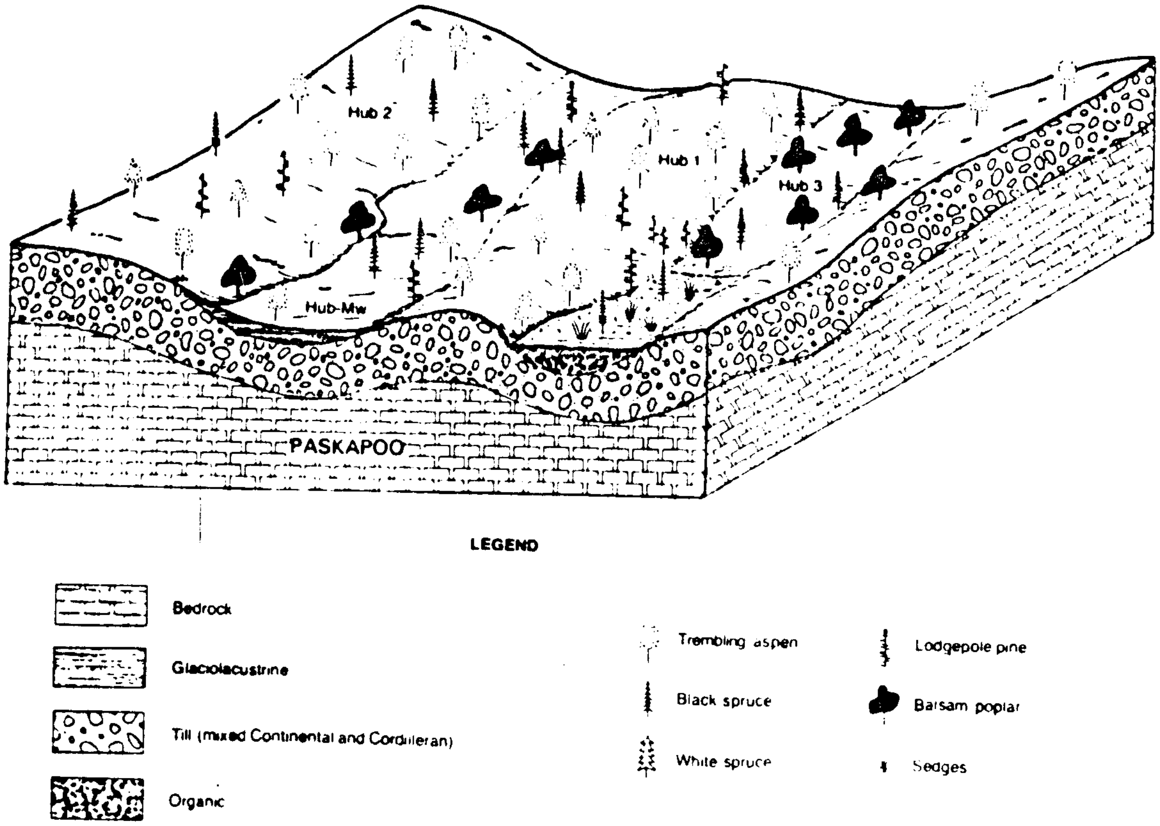
Hummocky surface form

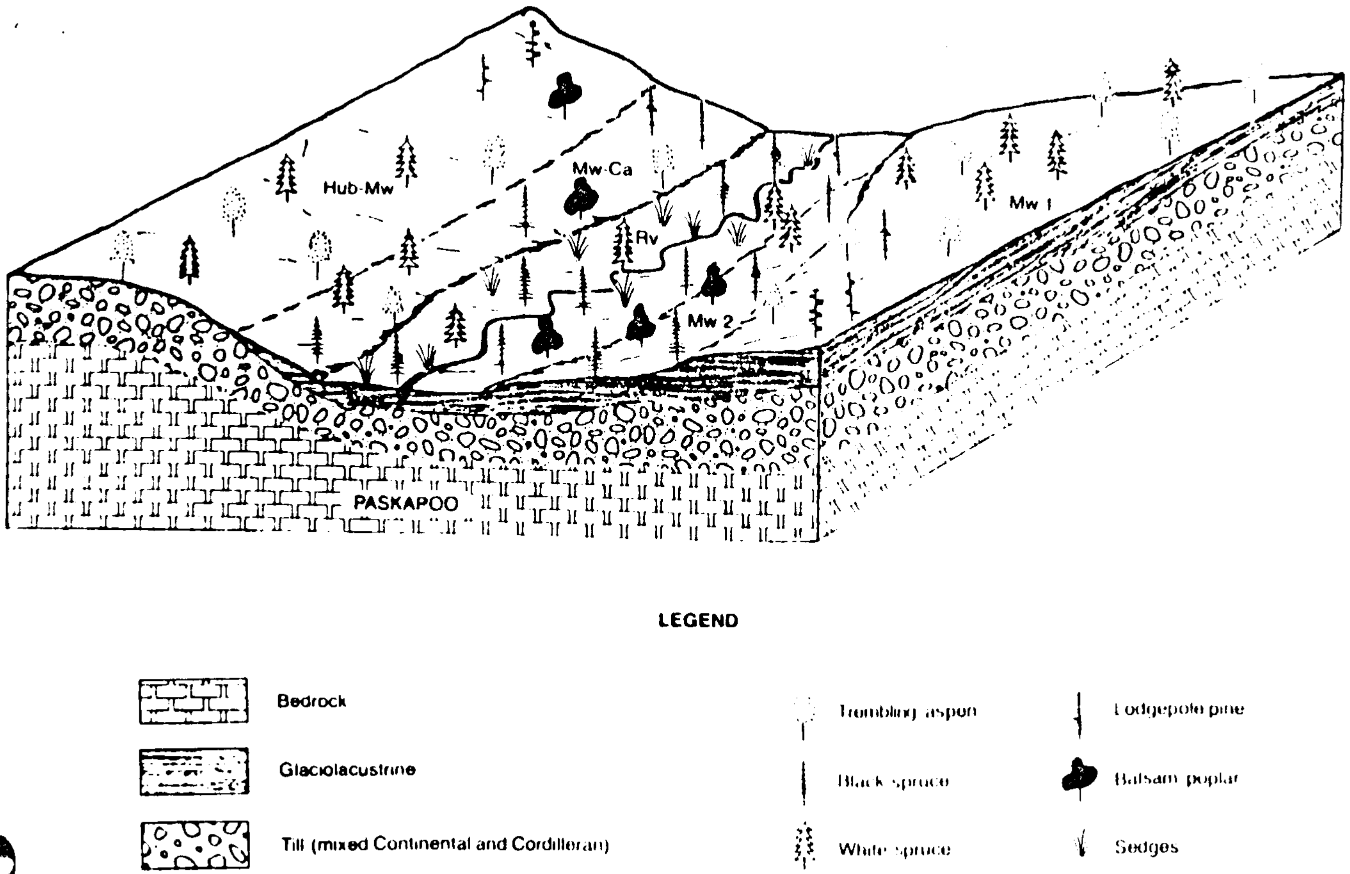


INCLINED SURFACE FORM

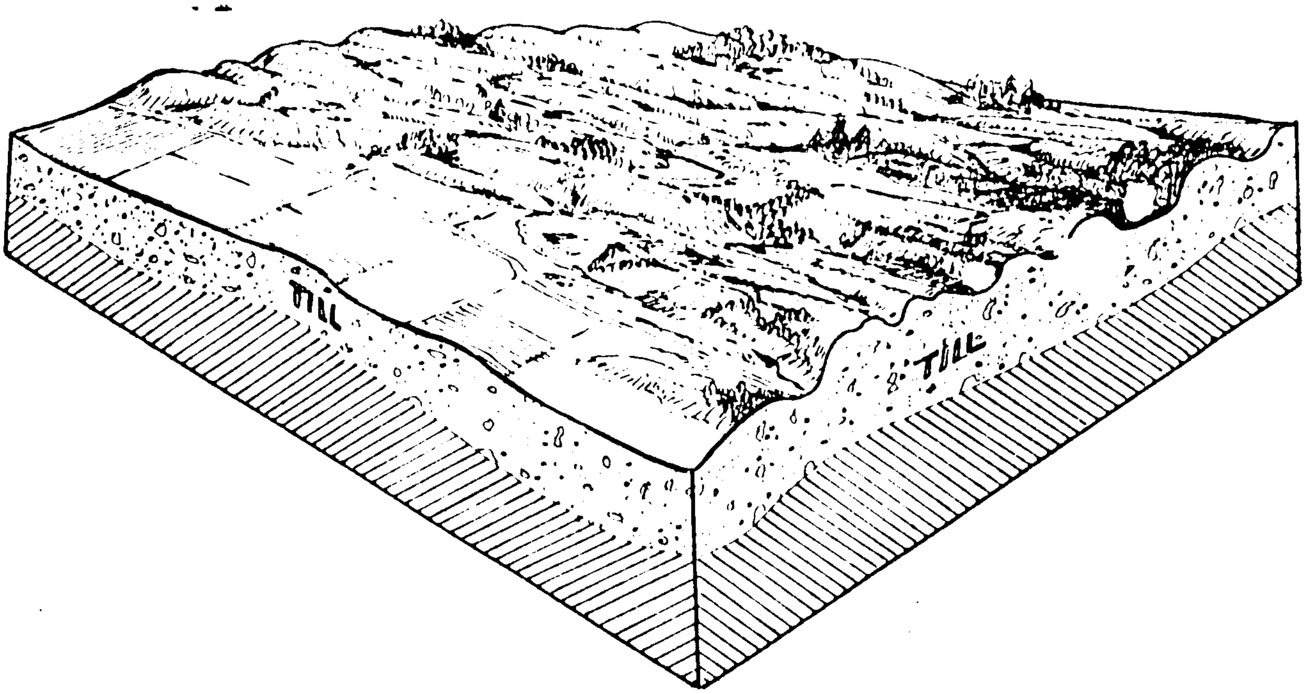
LEVEL

Steep surface form



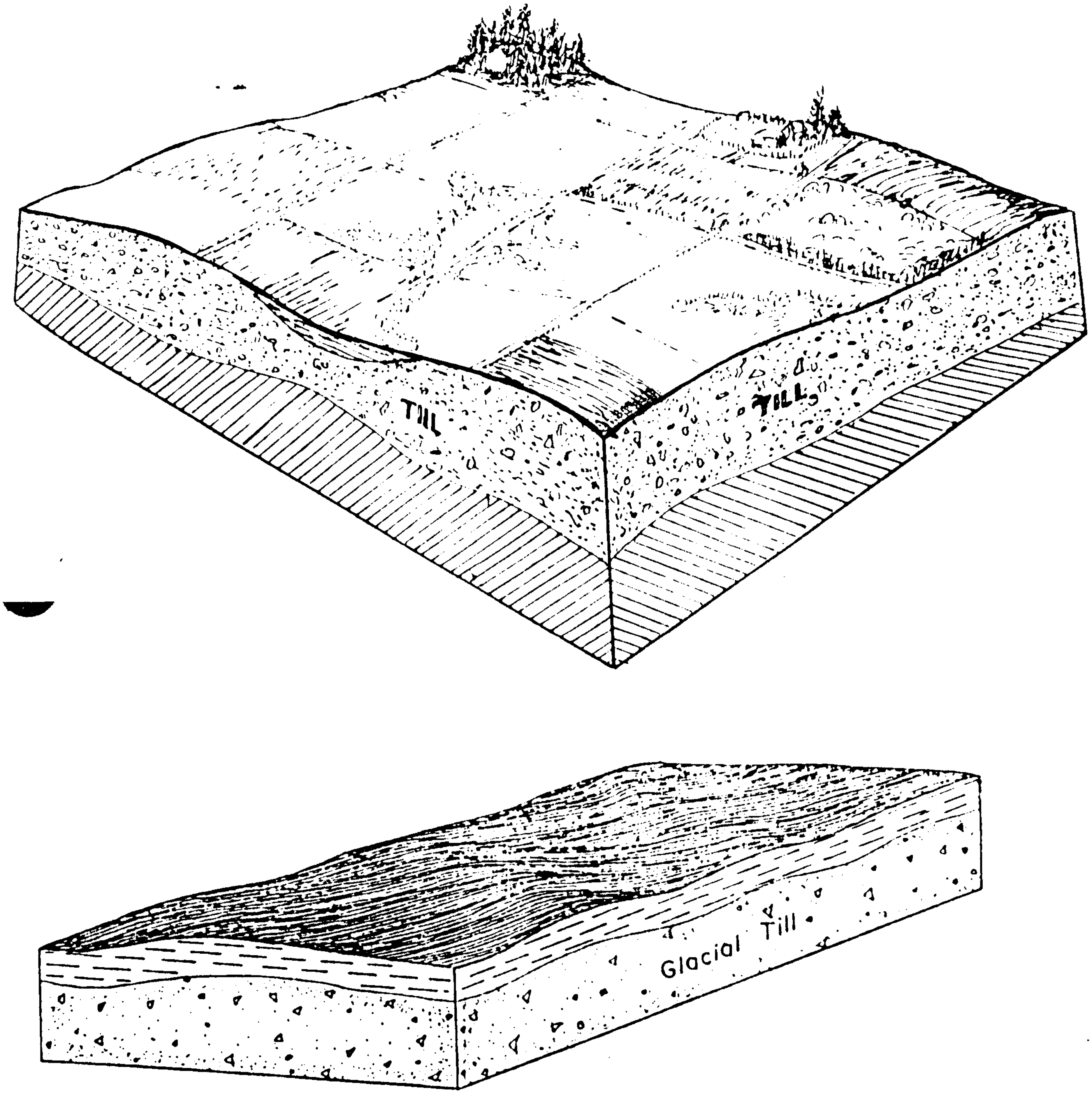


ROLLING SURFACE FORM



RIDGED SURFACE FORM

TERRACED SURFACE FORM



UNDULATING SURFACE FORM

11. SOTER SOIL LAYER FILE ATTRIBUTE LIST AND STRUCTURE

NOTE: CODED LAYERS SHOULD INCLUDE MASTER HORIZONS (A,B,C) AND OTHER HORIZONS AFFECTING SOIL MANAGEMENT.

Attribute		Type	Width	Dec	Necessity Requirement for Layer Data*			
					1	2	3	4
01	Country Code	CHAR	4					
02	State or Province Code	CHAR	2					
03	Base Map Code	CHAR	4					
04	Report/Map Number Code	CHAR	4					
05	Polygon Number	CHAR	4					
06	Terrain Component Number in Which Soil Occurs	CHAR	1					
07	Slope Position	CHAR	3					
08	Internal Soil Drainage	CHAR	4					
09	Proportion of Polygon To Which Following Attributes Apply; Nearest 10%, or 5% Where Needed	NUM	2					
10	Previous Polygon Number with Same Soil Layer Data	CHAR	4					
11	Soil Number of Previous Polygon	CHAR	1					
12	Soil Number (1-3)	CHAR	1					
13	Layer or Soil Horizon Number(1-4)	CHAR	1					
14	Lower Depth of Layer or Soil Horizon, cm	CHAR	3					
15	Abruptness of Layer/Horizon Boundary to Underlying Layer	CHAR	2		M	M	O	O
16	Soil Disturbance	CHAR	2		M	M	O	O

* Necessity requirements of data for the 4 soil layers identified are referred to as: M-Mandatory; D-Desirable; O-Optional

No.	Attribute	Type	Width	Dec	Necessity Requirement in Layers*			
					1	2	3	4
17	Moist Munsell Color Hue, Nearest Chart	CHAR	5		M	O	O	O
18	Moist Munsell Color Value, Nearest Unit	CHAR	1		M	O	O	O
19	Moist Munsell Color Chroma, Nearest Unit	CHAR	1		M	O	O	O
20	Dry Munsell Hue, Nearest Chart	CHAR	5		M	O	O	O
21	Dry Munsell Value, Nearest Unit	CHAR	1		M	O	O	O
22	Dry Munsell Chroma, Nearest Unit	CHAR	1		M	O	O	O
23	Organic Carbon, %	CHAR	4	1	M	D	O	O
24	Total Soil Nitrogen, %	CHAR	4	2	M	O	O	O
25	CEC, Total. meq/100g Soil	CHAR	2		M	M	M	O
26	CEC Clay, meq/100g Clay	CHAR	4	1	M	M	M	O
27	CEC Effective, meq/100 g Soil; at pH-Soil	CHAR	4	1	O	O	O	O
28	Anion Exchange Capacity meq/100g soil; at pH-Soil	CHAR	4	2	O	O	O	O
29	Exchangeable CA	CHAR	5	2	M	M	M	O
30	Exchangeable MG	CHAR	4	2	M	M	M	O
31	Exchangeable NA	CHAR	4	2	M	M	M	O
32	Exchangeable K	CHAR	4	2	M	M	M	O
33	Exchangeable MN	CHAR	4		D	D	D	D
34	Exchangeable AL	CHAR	4	2	M	M	M	O
35	Ca/Mg Ratio	CHAR	2		D	D	D	D
36	Ca/K Ratio	CHAR	2		D	D	D	D
37	Mg/K ratio	CHAR	3	1	D	D	D	D
38	Aluminum Saturation, %	CHAR	2		M	M	M	M

No.	Attribute	Type	Width	Dec	Necessity Requirement in Layers*			
					1	2	3	4
39	Available P	CHAR	1		M	M	O	O
40	P Fixation	CHAR	4		D	D	D	D
41	Available S	CHAR	4		D	D	D	D
42	Trace Element Deficiency	CHAR	4		D	D	D	D
43	Toxicity/Potential Toxicity	CHAR	4		D	D	D	D
44	Base Saturation, %	CHAR	2		M	M	M	O
45	pH in Water(1:1), One Decimal	CHAR	3	1	M	M	M	M
46	pH in $CaCl_2$ or Kcl, One Decimal	CHAR	3	1	M	M	M	M
47	Electrical Conductivity, ds/m (mmhos/cm)	CHAR	2		M	M	M	M
48	ESP	CHAR	2		M	M	M	M
49	Total $CaCO_3$ Equivalent, %; Primary, Secondary incl. Nodules	CHAR	3		O	O	O	O
50	Gypsum (CaS04.2H20)	CHAR	2		M	M	M	M
51	Clay Mineralogy	CHAR	4		O	O	O	O
52	Coarse Fragments,%	CHAR	2		M	M	O	O
53	Texture, Class, (USDA)	CHAR	4		M	M	M	M
54	Sand, Total, %	CHAR	2		O	O	O	O
55	Very Fine Sand,%	CHAR	2		M	M	M	M
56	Silt, Total,%	CHAR	2		O	O	O	O
57	Clay, Total,%	CHAR	2		O	O	O	O
58	Available Water Capacity, Upper Limit (i.e. field capacity) Definition kPA	CHAR	2		M	M	M	M

No.	Attribute	Type	Width	Dec	Necessity Requirement in Layers*			
					1	2	3	4
59	Available Water Capacity, Lower Limit (i.e. wilting point) Definition KPa	CHAR	4		M	M	M	M
60	Available Water Capacity, Upper Limit Volume %	CHAR	2		M	M	M	M
61	Available Water Capacity, Lower Limit Volume %	CHAR	2		M	M	M	M
62	Bulk Density, kg/m^3 (g/cm^3)	CHAR	4	2	M	M	M	M
63	Infiltration/Percolation, cm/H	CHAR	4		M	O	O	O
64	Saturated Hydraulic Conductivity, cm/H	CHAR	4		O	O	O	O
65	Structure	CHAR	2		M	M	M	M
66	Stable Soil Aggregates	CHAR	2		D	D	D	D
67	Decomposition Degree	CHAR	3		M	M	M	M
68	Biological Activity	CHAR	3		D	D	D	D
69	Contrasting Layer	CHAR	1		M	M	M	M
70	Diagnostic Horizon/Features	CHAR	4		M	M	M	O
71	Diagnostic Horizon;Defined Source	CHAR	3		M	M	M	M
72	Soil Development	CHAR	4		M			
73	Reference Pedon Name Code	CHAR	6		M	M	M	M

NOTE: The underlined four characters of the attribute name key words are used to label attributes (or fields of information) on coding forms.

12. SOTER SOIL LAYER ATTRIBUTE CLASSES, CODES AND DESCRIPTIONS

01	Country Code	-	4 Number International Code (ISIS)
02	State or Province Code	-	2 Number National Code
03	Base Map Code	-	4 Character National Code
04	Report/Map Ref. Code	-	4 Number State or Province Code
05	Polygon Number	-	4 Number, Unique for each map Polygon
06	Terrain Component Number In Which the Described Soil Occurs (1-3)		
07	Slope Position	-	position on local slope where described soil occurs (see diagram)

Code	Class	Description
SUM	Summit	See Diagram on next page
SHO	Shoulder	See Diagram on next page
MID	Midslope	See Diagram on next page
FOO	Footslope	See Diagram on next page
TOE	Toeslope	See Diagram on next page
DEP	Depression	See Diagram on next page
ALL	All Positions	See Diagram on next page
#	Not Applicable	

08 Internal Soil Drainage

Code	Class	Description
EXCE	Excessive	- Water is removed from the soil very rapidly in relation to supply. Excess water flows downward very rapidly if underlying material is pervious. There may be very rapid subsurface flow during heavy rainfall provided there is a steep gradient. Water source is precipitation.
RAPI	Rapid	- Water is removed from the soil rapidly in relation to supply. Excess water flows downward if underlying material is pervious. Subsurface flow may occur on steep gradients during heavy rainfall. Water source is precipitation.
WELL	Well	- Water is removed from the soil readily but not rapidly. Excess water flows downward readily into underlying pervious material or laterally as subsurface flow. These soils commonly retain optimum amounts of moisture for plant growth after rains or addition of irrigation water.

IMPE Imperfect - Water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season. Excess water moves slowly downward if precipitation is the major supply. If subsurface water or groundwater, or both, is the main source, the flow rate may vary but the soil remains wet for a significant part of the growing season.

POOR Poor - Water is removed so slowly in relation to supply that the soil remains wet for a comparatively large part of the time the soil is not frozen. Excess water is evident in the soil for a large part of the time. Subsurface flow or groundwater flow, or both, in addition to precipitation are the main water sources; there may also be a perched water table.

VPOO Very Poor - Water is removed from the soil so slowly that the water table remains at or on the surface for the greater part of the time the soil is not frozen. Groundwater flow and subsurface flow are the major water sources. Precipitation is less important except where there is a perched water table.

Not Applicable

09 Proportion of Polygon to which the following attributes apply, nearest 10%; where needed 5%, Right Justified

Not Applicable

10 Previous Polygon Number with Same Soil Data - refers to the polygon number in which the same soil occurs and has already been coded. Therefore, it is not necessary to code the same data again; it can be done by the computer.

Not Applicable should be coded if the same soil data has not been recorded previously.

11 Soil Number of Above Previous Polygon (see 10) with Same Soil Data - refers to the soil number from the above Polygon in which the same soil occurs so it is not necessary to code the data again.

Not Applicable should be coded if the same soil data has not been recorded previously.

12 Soil Number, Listed According to the Largest Proportion of Polygon to Which it Applies (see 09)

13 Layer or Soil Horizon Number, 1-4

14 Lower Depth of Layer or Soil Horizon, cm, Right Justified (Top of surface layer is 0 cm)
NOTE: Each soil may have a maximum of 4 layers in a continuum to a depth of 150 cm:
- 2 Layers to about 50 cm
- 2 Layers from about 50 cm up to 150 cm (200 cm in the case of oxisols and Paleudults)

15 Abruptness of Horizon/Layer Boundary to Underlying Horizon

Code	Class
AB	Abrupt
CL	Clear
GR	Gradual
DI	Diffuse
#	Not Applicable

16 Soil Disturbance (i.e. disturbed or natural)

Code	Class
DI	Disturbed by the activities of man
UN	Undisturbed
#	Not Applicable

17 Moist Munsell Color Hue, Nearest Chart, Left Justify

#	Not Applicable

18 Moist Munsell Color Value, Nearest Unit

#	Not Applicable

19 Moist Munsell Color Chroma, Nearest Unit

#	Not Applicable

20 Dry Munsell Color Hue, Nearest Chart, Left Justify

#	Not Applicable

21 Dry Munsell Color Value, Nearest Unit

#	Not Applicable

22 Dry Munsell Color Chroma, Nearest Unit

#	Not Applicable

23 Organic Carbon, %

Code	Class
00.1	0 - 0.2
00.3	0.3 - 0.6
00.7	0.7 - 1.9
02.0	2.0 - 2.9
03.0	3.0 - 7.9
08.0	8.0 - 16.9
17.0	17.0+
#	Not Applicable

NOTE: The numeric zero is not coded. Instead, the next smallest number with the same decimal placement is coded i.e. Class 0-0.2 is coded as 0.1

24 Total Soil Nitrogen - % of soil by weight

Code	Class
0.01	0 - 0.09
0.10	0.10 - 0.19
0.20	0.20 - 0.49
0.50	0.50 - 0.99
1.00	1.00+
#	Not Applicable

i.e. Class 0 - 0.09 is codes as 0.01

25 CEC, Total, meq/100g soil

Code	Class
01	0 - 2
03	3 - 5
06	6 - 12
13	13 - 29
30	30 - 35
36	36+
#	Not Applicable

i.e. Class 0 - 2 is coded as 01

26 CEC Clay, meq/100g Clay; pH 7.0

Code	Class
00.1	0 - 1.4
01.5	1.5 - 5.9
06.0	6.0 - 16
17.0	17 - 23
24.0	24 - 36
37.0	37+
#	Not Applicable

i.e. Class 0 - 1.4 is coded as 00.1

27 CEC Effective meq/100g Clay; pH of Acid Soil

Code	Class
0.1	0 - 1.4
1.5	1.5 - 1.9
2.0	2.0 - 4.9
5.0	5.0 - 9.9
10	10+
#	Not Applicable

28 Anion Exchange Capacity, meq/100g Soil and pH Soil

Code	Class
0.10	0 - 0.24
0.25	0.25 - 0.49
0.50	0.50 - 0.99
1.00	1.00+
#	Not Applicable

29 Exchangeable Ca, meq/100g Soil

Code	Class
0.01	0 - 0.03
0.04	0.04 - 0.99
1.00	1.00 - 2.99
3.00	3.00 - 5.99
6.00	6.00 - 11.99
12.00	12.00 - 19.99
20.00	20.00+
#	Not Applicable

30 Exchangeable Mg, meq/100g Soil

Code	Class
0.01	0 - 0.02
0.03	0.03 - 0.06
0.07	0.07 - 0.10
0.11	0.11 - 3.0
3.10	>3.0
#	Not Applicable

31 Exchangeable Na, meq/100g Soil

Code	Class
0.01	0 - 0.04
0.05	0.05 - 0.09
0.10	0.1 - 0.9
1.00	1.0 - 4.9

5.00	5.0+
#	Not Applicable

32 Exchangeable K, meq/100g Soil

Code	Class
0.01	0 - 0.05
0.06	0.06 - 0.19
0.20	0.20 - 0.29
0.30	0.30 - 7.99
8.00	8.00+
#	Not Applicable

33 Exchangeable Mn, meq/100g Soil

Code	Class
0.01	0 - 0.05
0.06	0.06 - 0.10
0.11	0.11 - 1.00
1.10	1.10 - 2.00
2.00	2.0+
#	Not Applicable

34 Exchangeable Al, meq/100g Soil

Code	Class
0.1	0 - 0.5
0.6	0.6 - 1.5
1.6	1.6 - 2.5
2.6	2.6+
#	Not Applicable

35 Ca/Mg Ratio

Code	Class
01	0 - 1.9
02	2+
#	Not Applicable

36 Ca/K Ratio

Code	Class
01	0 - 4.9
05	5+
#	Not Applicable

37 Mg/K

Code	Class
0.1	0 - 0.4
0.5	0.5+
#	Not Applicable

38 Al Saturation, %

Code	Class
01	0 - 9
10	10 - 49
50	50 - 74
75	75+
#	Not Applicable

39 Available P, ppm

CODE	Bray II	Truog	Olsen
A	<3	<2	<1
B	3-5	2-4	1-2
C	5-7	4-5	2-3
D	7-12	5-15	3-6
E	>12	>15	>6
#	Not Applicable		

40 P Fixation

Code	Class
PRES	Present
ABSE	Absent
POSS	Possible
UNLI	Unlikely
#	Not Applicable

41 Available S

Code	Class
DEFI	Deficient
SATI	Satisfactory
#	Not Applicable

42 Trace Element Deficiency

Code	Class
PROB	Probable
POSS	Possible
UNLI	Unlikely
#	Not Applicable

43 Toxicity/Potential Toxicity

Code	Class
PROB	Probable
POSS	Possible
UNLI	Unlikely
#	Not Applicable

44 Base Saturation, % (relative to CEC, pH 7)

Code	Class
01	0-09
10	10-24
25	25-49
50	50-74
75	75-100
#	Not Applicable

45 pH in Water

Code	Class
0.1	0.1 - 3.8
3.9	3.9 - 5.4
5.5	5.5 - 6.5
6.6	6.6 - 8.3
8.4	8.4 - 9.0
9.1	9.1+
#	Not Applicable

46 pH in $CaCl_2$/Kcl

Code	Class
0.1	0.1 - 3.5
3.6	3.6 - 5.0
5.1	5.1 - 6.5
6.6	6.6 - 8.4
8.5	8.5 - 9.0
9.1	9.1+
#	Not Applicable

47 Electrical Conductivity, dS/m (mmhos/cm, saturation extract)

Code	Class
01	0 - 1.9
02	2.0 - 3.9
04	4.0 - 7.9
08	8.0 - 15.9
16	16 - 25
26	26 - 49
50	50+
#	Not Applicable

48 ESP, %

Code	Class
01	0 - 8
09	09 - 15 (limit for natric horizon)
16	16 - 25
26	26 - 39
40	40+
#	Not Applicable

49 Total $CaCO_3$ Equivalent, % (P-Primary; S-Secondary)

Code	Class
P00	P 0
P01	P 1 - 5
P06	P 6 - 14
P15	P 15 - 39
P40	P 40+
S00	S 0
S01	S 1 - 5
S06	S 6 - 14
S15	S 15 - 39
S40	S 40+
#	Not Applicable

50 Gypsum, $CaSO_4.2H20$, %

Code	Class
01	0 - 2
03	3 - 5 (Limit of Gypsic Horizon)
06	6 - 9
10	10 - 24
25	25 - 39
40	40+
#	Not Applicable

51 CLAY Mineralogy

Code	Class
KAOL	Kaolinitic
MONT	Montmorillonitic
ILLI	Illitic
VERM	Vermiculitic
CHLO	Chloritic
MIXE	Mixed
ALLO	Allophane
CARB	Carbonitic
OXID	Oxidic (Fe_2O_3)
GYPS	Gypsic
#	Not Applicable

52 Coarse Fragments, % volume

Code	Class
01	0 - 2
03	3 - 14
15	15 - 39
40	40 - 79
80	80+
#	Not Applicable

53 Texture, Classes (USDA) as defined in CanSIS Manual

Code	Class
S	Sand
GLS	Gravelly loamy sand
LS	Loamy sand
LFS	Loamy fine sand
FS	Fine sand
VS	Very fine sand
LVFS	Loamy very fine sand
GS	Gravelly sand
VGS	Very Gravelly sand
CB	Cobbly
CBSL	Cobbly sandy loam
SL	Sandy loam
FSL	Fine sandy loam
GFSL	Gravelly fine sandy loam
GSL	Gravelly sandy loam
VGSL	Very gravelly sandy loam
GL	Gravelly loam
CBGL	Cobbly gravelly loam
CBL	Cobbly loam
L	Loam
GSIL	Gravelly silt loam
VFSL	Very fine sandy loam
SIL	Silt loam
GCL	Gravelly clay loam
SCL	Sandy clay loam
VCL	Very fine sandy clay loam
CL	Clay loam
SILT	Silty
SICL	Silty clay loam
SC	Sandy clay
GSIC	Gravelly silty clay
SIC	Silty clay
C	Clay
HC	Heavy clay
?	Unknown
#	Not Applicable

54 Sand, Total %
Not Applicable

55 Very Fine Sand, Total %
Not Applicable

56 Silt, Total %
Not Applicable

57 Clay, Total %
Not Applicable

58 Available Water Capacity, Upper Limit, KPa
(i.e. field capacity) Definition KPa
Not Applicable

59 Available Water Capacity, Lower Limit, KPa
(i.e. wilting point) Definition KPa
Not Applicable

60 Available Water Capacity, Upper Limit, Volume%
Not Applicable

61 Available Water Capacity, Lower Limit, Volume%
Not Applicable

62 Bulk Density, kg/m^3 (g/cm^3)

Code	Class
0.10	0.1 - 0.7
0.80	0.8 - 0.95
0.96	0.96 - 1.19
1.20	1.20 - 1.49
1.50	1.50 - 1.79
1.80	1.80+
#	Not Applicable

63 Infiltration/Percolation, cm/hr

Code	Class
0.1	0 - 0.5
0.6	0.6 - 14
15	15+
#	Not Applicable

64 Saturated Hydraulic Conductivity, cm/hr

Code	Class
0.1	0 - 0.5
0.6	0.6 - 14
15	15+
#	Not Applicable

65 Structure

Code	Class
01	Single grain; weak fine subangular blocky; weakly coherent porous massive.
02	Moderate fine to medium subangular blocky; weak fine to medium, angular blocky; weak to moderate crumb; moderate to strongly coherent porous massive.
03	Moderate, coarse subangular blocky; moderate fine to medium angular blocky; strong crumb; weak fine to medium prismatic; moderate coarse platy, strong very fine granular (i.e. crumb).
04	Strong, coarse, subangular blocky; strong fine to medium, angular (+ nutty/polyhedric) blocky; moderate coarse angular blocky; moderate fine to medium prismatic; weak coarse prismatic; non-porous massive.
05	Strong coarse angular blocky; moderate to strong coarse prismatic; columnar; moderate to strong platy.
#	Not applicable

66 Stable Soil Aggregates Retained by US Standard Seive Number 20 (0.8 mm grain size), %;

Not Applicable

67 Decompostion Degree

Code	Class
FIB	Fibric
MES	Mesic (hemic)
HUM	Humic (sapric)
#	Not Applicable

68 Biological Activity

Code	Class	Description
NON	None	- None
FEW	Few	- Few observable roots and/or biopores
COM	Common	- Readily observable roots and/or biopores
MAN	Many	- Many readily observable roots and/or biopores
#	Not Applicable	

69 Contrasting Layers to the Overlying Layer

Code	Class
A	Clay
B	Clay loam to loam
C	Sand
D	Gravel cemented by gibsite
E	Compacted man made
F	Compacted basal morainal
G	Consolidated acid rock
H	Consolidated basic rock
I	Saturated
J	Indurated
P	Plinthite
K	Thin Cemented
L	Cemented by organic matter, Fe, Al
M	Fragipan
N	Clay pan
X	Not present
W	Plow Pan
#	Not Applicable

70 Diagnostic Horizon/Features

Code	Class
MOLL	Mollic like A
FIMI	Fimic like A
HIST	Histic like A
UMBR	Umbric like A
OCHR	Ochric like A
ARGI	Argillic like B
NATR	Natric like B
CAMB	Cambic like B
SPOD	Spodic like B (Podzolic B)
OXIC	Oxic like B
CALC	Calcic like
GYPS	Gypsic like
SULP	Sulphuric like
ALBI	Albic like
CRYI	Frozen Permanently (Cryic)
GLEY	Strongly gleyed or reduced
VERM	Vermic
VERT	Vertic
ANDI	Andic
#	Not Applicable

71 Diagnostic Horizon Defined in:

Code	Class
TAX	Soil Taxonomy Classification System
FAO	FAO System
NAT	National System of Project Area
#	Not Applicable

72 Soil Development (International Reference Base Group of ISSS Commission V, Jan/88 Lenven - Belgium)

Code	Class		Description
	HISTIC	-	Thick surface accumulation of non or only partial decomposed organic materials associated with waterlogging.
	VERTIC	-	Churning of soil material as a result of swelling and shrinking.
	ANDIC	-	Weathering of volcanic material resulting in the formation of amorphous alumino-silicates
	PODZIC	-	Illuvial accumulation of amorphous compounds of organic matter, often with iron and/or aluminum
	FERRALIC	-	Residual accumulation of sesquioxides as a result of strong weathering
	STAGNIC	-	Reduction as a result of surface or subsurface waterlogging
	NITIC	-	Accumulation of clay, (illuvial and/or residual) in the presence of active iron oxides
	LUVIC	-	Illuvial accumulation of high activity clays
	LIXIC	-	Illuvial accumulation of low activity clays
	GLEYIC	-	Reduction as a result of groundwater influence
	HALIC	-	Accumulation of soluble salts

CHERNIC	-	Surface accumulation of saturated organic matter
CALCIC	-	Accumulation of calcium carbonate
GYPSIC	-	Accumulation of gypsum
CAMBIC	-	Weathering in situ leading to a change in color, texture or consistence without important translocations
SODIC	-	Accumulation of sodium (and magnesium) leading to dispersed soil material
MODIC	-	Surface accumulation of desaturated organic matter
ANTHRIC	-	Pronounced human influence
PRIMIC	-	Absence of distinct attributes due to soil formation, non-stratified.
FLUVIC	-	Absence of distinct attributes due to soil formation, but with sedimentary stratification
#	-	Not Applicable

73 Reference Pedon Name Code or Number - From National Soil Names file

13. SOTER CODING FORMS

Coding (or recording) data in attribute files is an integral part of SOTER Map and attribute compilation procedures. Data is usually coded on specially designed hard copy coding forms and then input to similar computer data file structure created according to dBASE or INFO commercial software packages. Alternatively, data can be input directly to the computer database files. However, data compilation usually requires considerable time to acquire information from legends, reports and other sources which necessitates having a personal computer dedicated especially to the project. Consequently, it is considered more practical to initially record data on hard copy.

Two coding forms are proposed for inclusion in this Manual, one on which to record polygon attributes plus the terrain component attributes (SOTER Coding Form 1, See attached) and one on which to record soil layer attributes (SOTER Coding Form 2, See attached). Attributes from the polygon and terrain component files are conveniently combined on Form 1. There is some repetitious coding involved when more than one terrain component occurs per polygon. However, if two separate forms were used, the first four fields would also have to be repeated on each form. Coding Forms 1 and 2 are intended as examples to provide insight as to what format is considered convenient and what is involved in the coding exercise.

Obviously, there are many ways the legend files and coding forms can be organized. For example, the soil attribute file could be reorganized into 3 or 4 smaller files (morphological, chemical, physical) as suggested by P. Brabant (personal communication). Alternately, the attributes required by priority interpretation could be organized into a smaller special file. In fact, attribute organization into a number of smaller files is recommended as a general principle of most database management systems including INFO. However, experience has shown that using multiple files requires the client to be very knowledgeable with the software commands and to be able to do some programming.

To retrieve (or select) attributes from two or more different files (morphology, chemical, physical) one has to temporarily relate or combine these files on each occasion, or program a join. If it is necessary to join, it may be more convenient to have one large file depending on the software package. Large files of 100 fields are no problem for dBASE, but have undesirable implications for INFO which cannot readily "pan" across files that exceed 80 columns in width. The capabilities of INFO are still being reviewed.

Coding Form Format

Each form is created according to the structure (sequence of field widths) documented in the respective attribute file.
Attributes are entered from left to right in the same order as listed in their respective files (see Polygon, Terrain Component and Soil

File Attribute Lists). In the case of Coding Form 1, the Polygon Attributes are listed first, followed by Terrain Component Attributes commencing at attribute 06 (Proportion of Polygon to which the following attributes apply). The fields are also numbered according to the numbering sequence provided in the respective attribute listings. Columns are provided for decimals.
Attribute names are abbreviated to a field name (or label) with a maximum of 4 characters, usually the first 4 characters of the Attribute Name Key Word (See underlined characters in File Attribute Lists in Sections 7, 9 and 11).

The field name is unique among all files. Since many of the fields on the coding forms are less than 4 columns wide, it is necessary that the labels (or names) are oriented vertically within each field of the coding form. This vertical label of 4 characters can also be conveniently retrieved by the dBase III Plus Report Generator. These abbreviated attribute field names become easier to remember connotatively as one becomes more familiar with the coding form. The short label also saves many key strokes when copying selected fields or generating reports with selected fields of information.

The attached coding forms are prepared on standard 80 column data coding paper joined end to end as required. This format, although physically wide, provides a better option than coding this data on 2 to 3 separate pages which only increases the number of pages of coded data to organize and keep track of.

It is important that the file structures and coding forms be finalized before any project data is compiled and input to the computer.

Summary of SOTER File Attribute Lists and Class Codes

To expedite the coding procedure, each file attribute list (Polygon, Terrain, Soil) and their respective class codes were summarized as briefly as possible to one or two pages (see attached Summary). These summaries provide the map and data compiler with rapid access to the appropriate attribute class codes for data derived from map legends and reports. To use the summary file efficiently, it is essential that the compiler be very familiar with the more detailed description of the attribute classes documented previously in the Manual.

Immediately following the coding procedure, data should be input to dBase III installed on a personal computer; a report can then be generated. As indicated previously, the dBase III Report Generator can accommodate field labels of up to 4 lines (or 4 vertical characters). Thereby, a Report of the data coded can be quickly printed out in the same format as it occurred on the coding form. This provides for convenient editing. Corrections or revisions can then be made interactively at the terminal.

Reports of attribute subsets from any file can also be generated and outputed to print. Alternatively, files can be combined (or related, or joined, etc.) and attributes from any of the 3 files can be selected for a Report.

SUMMARY POLYGON FILE ATTRIBUTE LISTS AND CLASS CODES

01 COUNTRY CODE:
02 STATE/PROVINCE CODE:
03 BASE MAP CODE:
04 REPORT/MAP NUMBER CODE:
05 POLYGON NUMBER
06 REGIONAL LANDFORM:

M	MOUNTAIN
H	HILLAND
T	TABLELAND (OR PLATEAU)
P	PLAIN
V	VALLEY
U	UPLAND (FOOTHILL)
F	FOOTSLOPE

07 RELIEF, MEDIAN, M (NEAREST 50M):
08 ELEVATION, MEDIAN, M (NEAREST 100M):
09 LITHOLOGY:

IGNE	IGNEOUS ROCK	ALLU	ALLUVIAL DEPOSIT
META	METAMORPHIC ROCK	EOLI	EOLIAN DEPOSIT
SEDI	SEDIMENTARY ROCK	GLAC	GLACIAL DRIFT DEPOSIT
SAND	SANDSTONE ROCK	COLL	COLLUVIAL DEPOSIT
SHAL	SHALE ROCK	RESI	RESIDUUM DEPOSIT
PYRO	PYROCLASTIC ROCK	UNDI	UNDIFFERENTIATED DEPOSIT
MIXE	MIXED ROCK	ORGA	ORGANIC DEPOSIT
UNSP	UNSPECIFIED ROCK	ICE	ICE
MARI	MARINE DEPOSIT		

10 PERMANENT LAKE SURFACE, %:
11 SEASONALLY INUNDATED LANDS, %:
12 MEDIAN DISTANCE BETWEEN RIVERS, OR STREAMS, KM:
13 DENSITY OF RIVER AND STREAM DRAINAGE (SEE STANDARD REFERENCE AREAS):
14 PREDOMINANT GENERAL LAND USE AND VEGETATION

ANNU	ANNUAL CROPLAND	DESE	DESERTLAND
PAST	CULTIVATED PASTURELAND	ORGA	ORGANIC SWAMP, BOG OR FEN
GRAS	GRASSLAND, NATIVE	TUND	TUNDRA
GRSH	MIXED GRASSLAND, SHRUBLAND	IRRI	IRRIGATED LAND
SHIF	SHIFTING CULTIVATION ON FOREST COVERED LAND	WOOD	WOODLAND (OPEN STAND)
FORE	FORESTLAND (CLOSED STAND)	SHRU	SHRUBLAND
PLAN	PLANTATION LAND, PERRENIAL	DWAR	DWARFSHRUBLAND
ORCH	ORCHARD LAND	REFO	REFORESTED LAND
ROCK	ROCKLAND OR RUBBLELAND		

SUMMARY TERRAIN COMPONENT ATTRIBUTE LIST AND CLASS CODES

01 COUNTRY CODE:
02 STATE/PROVINCE CODE:
03 BASE MAP CODE:
04 REPORT/MAP NUMBER CODE:
05 POLYGON NUMBER:
06 PROPORTION OF POLYGON:
07 TERRAIN COMPONENT (1-3):
08 PARENT MATERIAL ORIGIN/ROCK:

AL	ALLUVIAL
CO	COLLUVIAL
EO	EOLIAN
FL	FLUVIOGLACIAL
LA	LACUSTRINE
MO	MORAINAL
AN	ANTHROPOGENIC
UN	UNDIFFERENTIATED
MA	MARINE
MR	MARL
RE	RESIDUUM
OB	ORGANIC BOG
OF	ORGANIC FEN
OS	ORGANIC SWAMP
OU	ORGANIC UNDIFFERENTIATED
IA	IGNEOUS ROCK, ACID
IB	IGNEOUS ROCK, BASIC
II	IGNEOUS ROCK, INTERMEDIATE
SN	SANDSTONE ROCK
LI	LIMESTONE ROCK
SH	SHALE ROCK
TA	METAMORPHIC ACID
TB	METAMORPHIC BASIC
PA	PYROCLASTIC ACID
PB	PYROCLASTIC BASIC
RU	ROCK UNSPECIFIED
IC	ICE
WA	WATER

09 TEXTURE GROUP OF SOIL PARENT MATERIAL, OR SOIL AT 2 M IF DEEPLY DEVELOPED:

X	EXTREMELY SANDY
S	SANDY
L	LOAMY
C	CLAYEY
Y	VERY CLAYEY

10 SURFACE FORM:

G	GULLIED
H	HUMMOCKY
I	INCLINED(4-60%)
L	LEVEL
R	ROLLING
E	RIDGED
N	UNDULATINGEX
S	STEEP (> 60%)
U	UNDULATING
T	TERRACED
C	GILGAI
M	MOUNDED
A	APRON
Z	IRREGULAR DISSECTED
B	BLANKET BOG
D	DOMED BOG
F	FLAT BOG
P	PLATEAU BOG
V	VENEER BOG
J	RIBBED FEN
K	HORIZONTAL FEN
Y	DELTA MARSH
O	COASTAL MARSH
Q	FLOODPLAIN MARSH
W	FLOODPLAIN SWAMP
X	BASIN SWAMP

11 SLOPE GRADIENT, %: 01, 04, 10, 16, 30, 60,
12 SLOPE LENGTH, M: 001, 050, 150, 300, 600
13 STONINESS, M APART: 00.1 00.2 00.8 01.6 10.0 30.0
14 ROCKINESS OUTCROPS, M APART:
H01, H04, H10, H35, H99
S01, S04, S10, S35, S99
15 DEPTH TO GROUND WATER, CM:

AL100	ALWAYS <100
TL100	TEMPORARILY <100
AG100	ALWAYS 100 - 200
TG100	TEMPORARILY 100 - 200
AG200	ALWAYS >200
ML50	MOTTLING <50
MG50	MOTTLING 50 - 100
MG100	MOTTLING >100

16 QUALITY OF GROUND WATER, MICROSEMEN: 0001, 0250, 0750, 1500, 3000
17 ROOTING DEPTH WHICH IS UNRESTRICTED, CM: 001, 025, 050, 100, 150

18 PREDOMINANT LAND USE/VEGETATION TYPE:

HORTICULTURAL
ORCHARD
ANNUAL CROP
MULTI-ANNUAL
BOG, FEN
SWAMP
PASTURE, CULTIVATED
GRASS NATIVE
HW-SAVANNA WELL DRAINED
HP-SAVANNA POORLY DRAINED

CA CAATINGA
PLANTATION
FOREST, NATURAL
DESERT
QUARIES, MINES
ROCK, RUBBLE
URBAN
MIXED GRAZING, SMALL TREES(PARQUE)
FT-TROPICAL RAIN FOREST
FG-TROPICAL SEMI EVERGREEN SEASONAL FOREST
FC - TROPICAL SEMI DECIDUOUS SEASONAL FOREST

SALINITY/ALKALINITY TOLERANT PLANTS
SHIFTING CULTIVATION
IRRIGATED CROP
IRRIGATED HORTICULTURAL
IRRIGATED ORCHARD
RECREATION, OUTDOOR

FM - SUBMONTANE FOREST

CLOSED FOREST - UNSPECIFIED(FU), EVERGREEN(FE), SEMI-DECIDUOUS(FS)
- DECIDUOUS(FD), XEROMORPHIC(FX)

WOODLAND - UNSPECIFIED(WU), EVERGREEN(WE), SEMI-DECIDUOUS(WS)
- DECIDUOUS(WD), XEROMORPHIC(WX)

SHRUB - UNSPECIFIED(SU), EVERGREEN(SE), SEMI-DECIDUOUS(SS)
- DECIDUOUS(SD), XEROMORPHIC(SX)

DWARF/SHRUB - UNSPECIFIED(DU), EVERGREEN(DE), SEMI-DECIDUOUS(DS)
- DECIDUOUS(DD), XEROMORPHIC(DX), TUNDRA(DT)

HERBACEOUS - UNSPECIFIED(HU), TALL GRASS(HT), MEDIUM(HM)
- SHORT(HS), FORB(HF)

19 FLOODING ON SURFACE DUE TO INUNDATION(I) AND/OR HEAVY RAINFALL OR HIGH WATER TABLE(H), MONTHS
IH0, I01, I02, I04, I07, I10
H01, H02, H04, H07, H10

21 SURFACE DRAINAGE OR RUN OFF: POND, SLOW, MEDIUM, RAPID, VERY RAPID
22 OVERWASH OF EROSION PRODUCTS, % OCCUPANCE: 01, 03, 10, 40, 75
23 OVERBLOW OF EROSION PRODUCTS, % OCCUPANCE: 01, 03, 10, 40, 75
26 COMPLEXITY OF PARENT MATERIAL/SOIL: LOW, MEDIUM, HIGH
27 PERMAFROST DISTRIBUTION: SPORADIC, DISCONTINUOUS, CONTINUOUS
28 ICE CONTENT OF MATERIALS: LOW, MEDIUM, HIGH
29 PREVIOUS POLYGON NUMBER WITH SAME TERRAIN COMPONENT DATA
30 TERRAIN COMPONENT NUMBER OF PREVIOUS POLY NUMBER (SEE 26)
31 DEPTH TO PARENT ROCK (m)

SUMMARY SOIL LAYER ATTRIBUTE LIST AND CLASS CODES

GUIDELINE: CODE MASTER HORIZONS PLUS HORIZONS AFFECTING SOIL MANAGEMENT

01 COUNTRY CODE:
02 STATE/PROVINCE CODE:
03 BASE MAP CODE:
04 REPORT/MAP NUMBER CODE:
05 POLYGON NUMBER:
06 TERRAIN COMPONENT NUMBER IN WHICH DESCRIBED SOIL OCCURS(1-3):
07 POSITION ON SLOPE: SUMMIT, SHOULDER, MIDSLOPE, FOOTSLOPE, TOESLOPE, DEPRESSION, ALL
08 DRAINAGE: EXCESSIVE, RAPID, WELL, IMPERFECT, POOR, VERY POOR
09 PROPORTION OF POLYGON TO WHICH ATTRIBUTES APPLY, NEAREST 10%, OR 5% WHERE NEEDED:
10 PREVIOUS POLYGON NUMBER WITH SAME SOIL LAYER DATA ALREADY CODED:
11 SOIL NUMBER OF ABOVE PREVIOUS POLYGON RECORDED IN 10:
12 SOIL NUMBER WITHIN CURRENT POLYGON LISTED ACCORDING TO PROPORTIONS FROM 09:
13 LAYER/HORIZON NUMBER OF DESCRIBED SOIL (1-4):
14 LOWER DEPTH OF LAYER/HORIZON TO AT LEAST 150 CM (TOP OF SURFACE LAYER IS 0 CM):
15 ABRUPTNESS OF LAYER/HORIZON BOUNDARY: ABRUPT, CLEAR, GRADUAL, DIFFUSE
16 DISTURBANCE OF SOIL: DISTURBED, UNDISTURBED
17 MOIST HUE COLOR (LEFT JUSTIFY):
18 MOIST VALUE COLOR:
19 MOIST CHROMA COLOR:
20 DRY HUE COLOR (LEFT JUSTIFY):
21 DRY VALUE COLOR:
22 DRY CHROMA COLOR:

23	ORGANIC CARBON, %:	0.1	0.3	0.7	2.0	3.0	8.0	17.0
24	NITROGEN TOTAL, %:	0.01	0.1	0.2	0.5	1.0		
25	CEC TOTAL:	01	03	06	13	30	36	
26	CEC CLAY:	0.1	1.5	6.0	17.0	24.0	37.0	
27	CEC EFFECTIVE:	0.1	1.5	2.0	5.0	10.0		
28	ANION EXCHANGE CAPACITY;	0.10	0.25	0.50	1.0			
29	CA EXCHANGEABLE:	0.01	0.04	1.0	3.0	6.00	12.00	20.00
30	MG EXCHANGEABLE:	0.01	0.03	0.07	0.11	3.10		
31	NA EXCHANGEABLE:	0.01	0.05	0.10	1.00	5.00		
32	K EXCHANGEABLE:	0.01	0.06	0.20	0.30	8.00		
33	MN EXCHANGEABLE:	0.01	0.06	0.11	1.10	2.00		
34	AL EXCHANGEABLE	0.1	0.6	1.6	2.6			
35	CA/MG RATIO:	01	02					
36	CA/K RATIO:	01	05					
37	MG/K RATIO:	0.1	0.5					
38	AL SATURATION:	01	10	50	75			

39	AVAILABLE P	BRAY II	TRUOG	OLSEN
	A	<3	<2	<1
	B	3-5	2-4	1-2
	C	5-7	4-5	2-3
	D	7-12	5-15	3-6
	E	>12	>15	>6

40 P FIXATION: PRESENT, ABSENT, POSSIBLE, UNLIKELY
41 AVAILABILITY S: DEFICIENT, SATISFACTORY
42 TRACE ELEMENT DEFICIENCY: PROBABLE, POSSIBLE, UNLIKELY
43 TOXICITY POTENTIAL: PROBABLE, POSSIBLE, UNLIKELY

44	BASE SATURATION, %:	01	10	25	50	75		
45	PH WATER:	0.1	3.9	5.5	6.6	8.4	9.1	
46	PH CACL:	0.1	3.6	5.1	6.6	8.5	9.1	
47	ELECTRICAL CONDUCTIVITY dS/m (i.e.MMHOS/CM):	01 02	04	08	16	26	50	
48	ESP, %:	01	09	16	26	40		
49	CACO3 EQUIV: PRIMARY(P)	P00	P01	P06	P15	P40		
	SECONDARY(S)	S00	S01	S06	S15	S40		

14. STATUS OF SOIL DEGRADATION

The status of soil degradation is a QUALITATIVE evaluation of the present type, degree and rate of soil degradation. It corresponds to that used for the World Soil Degradation Map being prepared by the Global Assessment of Soil Degradation (GLASOD) project. The assessment has to be qualitative because no measurement of soil degradation in the field can distinguish between long-term geologic processes, historical human intervention that may no longer be relevant, and the effects of recent human activities that are continuing today. It is the latter that is of prime importance in this evaluation, though geologic and historic degradation of soils should also be noted. Identifying these different conditions can usually only be done by interpretation of the situation observed in the field.

For the application of the SOTER database to the GLASOD project, an evaluation is needed of the status of soil degradation. An estimate is also required of the rate of recent soil degradation and, where possible, of the causative factors. These must also be assessed subjectively. Each of these assessments will be recorded on coding forms (see Appendix A).

For definitions of soil degradation, and an explanation of the rationale for the GLASOD project, the reader is referred to: "Guidelines for general assessment of the status of human-induced soil degradation", 1988, edited by L.R. Oldeman, International Soil Reference and Information Centre (ISRIC), Wageningen, The Netherlands, Working Paper No. 88/3. Most of the material in this chapter has been drawn from these guidelines.

Soil degradation types have been broadly divided into two categories:

- degradation by displacement of soil material (water and wind erosion), including off-site effects
- degradation by internal soil deterioration (chemical, physical and biological deterioration)

The causative factors of soil degradation are expected to fit one of the following three categories:

f - deforestation, caused by burning or logging; "slash and burn" system

g - overgrazing, when extensive areas of land have been completely cleared of its original vegetation

i - overly-intensive annual cropping

(In each of the above process there is a loss of biological diversity, often leading to a secondary type of vegetation with predominantly obnoxious and unpalatable weeds and shrubs.)

The present degree of soil degradation must be expressed in one of five classes:

None	- there is no sign of present degradation from water or wind erosion, or from chemical, physical or biological deterioration; all original biotic functions are intact. Such land is considered stable.
Slight	- the terrain is suitable for use in local farming systems, but with somewhat reduced agricultural productivity. Restoration to full productivity is possible by modifications of the management system. Original biotic functions still largely intact.
Moderate	- the terrain is still suitable for use in local farming systems, but with greatly reduced agricultural productivity. Major structural alterations are required to restore productivity (eg. draining for water logging or salinity; contour banks if the land is eroding). Original biotic functions partly destroyed.
Severe -	the terrain is unreclaimable at the farm level. Major engineering works are required for terrain restoration. Orignial biotic functions largely destroyed.
Extreme -	the terrain is unreclaimabale and impossible to restore. Original biotic functions fully destroyed. The terrain has become a non-vegetated and non-used wasteland.

The recent-past (approximately 5 to 10 years) average rate of soil degradation must be expressed in three classes:

1 - slow; 2 - medium; and 3 - rapid

This will generally be a qualitative assessment, and may involve discussion with local experts (inhabitants, farmers, etc.). The reasons for selecting the indicated rate should be explained in an accompanying report.

Historical man-induced soil degradation should be identified under one of the following eras (a,b,c or d) only if it is now stabilized and not currently active.

(a) Early civilization (more than 250 years ago)

(b) Era of European expansion (50-250 years ago)

(c) Post-World War II development period, up to the "recent-past" (10 to 50 years ago)

(d) Currently active (within last 10 years)

The extent of soil degradation is to be recorded as the percent of the land area within the mapping unit that is affected:

0 - absent : 0%
1 - infrequent : 1-5% of the terrain affected
2 - common : 6-10% of the terrain affected
3 - frequent : 11-25% of the terrain affected
4 - very frequent : 26-50% of the terrain affected
5 - dominant : 51-100% of the terrain affected

The following sub-sections describe in more detail how the assessments apply to each of the soil degradation processes.

14.1 Status of water erosion

On-site (in situ) water erosion can be described as follows:

Wt - loss of topsoil - a uniform loss by surface wash and sheet erosion
Wd - terrain deformation - an irregular displacement of soil materials, characterized by major rills, gullies or mass movement

Off-site water erosion effects can be described as follows:

Wr - reservoir, harbour or lake sedimentation

Wf - flooding, including riverbed filling, riverbank erosion, and excessive siltation of basin land

Wc - coral, shellfish bed, and seaweed destruction

14.1.1 Degree of present degradation due to water erosion

Code	Degree	Description
Wt/Wd 0	None	
Wt/Wd 1	slight	- In deep soils (rooting depth more than 50 cm): part of the topsoil removed, and/or with shallow rills 20-50 m apart. - In shallow soils (rooting depth less than 50 cm): some shallow rills at least 50 m apart. - In pastoral country: groundcover of perennials of the original/optimal vegetation is in excess of 70%*.

Wt/Wd 2	moderate	- In deep soils: all top soil removed, and/or shallow rills less than 20 m. apart or with moderately deep gullies 20-50 m. apart. - In shallow soils: part of topsoil removed, and/or shallow rills 20-50 m apart. - In pastoral country: groundcover of perennials of the original/optimal vegetation ranges from 30-70%*.
Wt/Wd 3	severe	- In deep soils: all topsoil and part of subsoil removed, and/or with moderately deep gullies less than 20 m apart. - In shallow soils: all topsoil removed: lithic or lepthic phases or with exposed hardpan. - In pastoral country: groundcover of perennials of the original/ optimal vegetation is less than 30%*.
Wt/Wd 4	extreme	- The terrain has become devastated by water erosion, and is unreclaimable and impossible to restore.

---

* Known maximum coverage of perennials under good management as practiced during some time in the past

** N/a = not applicable

14.1.2 Degree of present off-site degradation due to water erosion

There has not yet been a set of criteria developed for assessing the degree of off-site degradation due to water erosion. Where such degradation is evident, it is necessary to estimate the degree by following the guidelines, described above, for the general assessment of the degree of degradation.

14.2 Status of wind erosion

On-site (in situ) wind erosion can be described as follows:

Et - Loss of topsoil, a uniform displacement by deflation
Ed - Terrain deformation, an uneven displacement characterized by major hollows, hummocks or dunes

Off-site wind erosion can be described as follows:

Eo - Overblowing, such as encroachment on structures such as roads and buildings, or sand-blasting of vegetation.

14.2.1 Degree of present degradation due to wind erosion

Code	Degree	Description
Et/Ed 0	none	
Et/Ed 1	slight	- In deep soils: topsoil partly removed and/or with few (10-40% of the area) shallow (0-5 cm) hollows.
		- In shallow soils: very few (10% of the affected area) shallow (0-5 cm) hollows.
		- In pastoral country: groundcover of perennials of the original/optimal vegetation is in excess of 70%*.
Et/Ed 2	moderate	- In deep soils: all topsoil removed; and/or with common (40-70% of the area) shallow (0-5 cm) or few (10-40% of the area) moderately deep (5-15 cm) hollows.
		- In shallow soils: topsoil partly removed and/or few (10-40% of the area) shallow (0-5 cm) hollows.
		- In pastoral country: groundcover of perennials of the original/optimal vegetation ranges from 30-70%*.
Et/Ed 3	severe	- In deep soils: all topsoil and part subsoil removed and/or many (>70% of the area) shallow (0-5 cm) or common (40-70% of the area) moderately deep (5-15 cm) or few (10-40% of the area) deep (>15 cm) hollows/blowouts.

		- In shallow soils: all topsoil removed: lithic or leptic phases or with exposed hardpan. - In pastoral country: groundcover of perennials of the original/optimal vegetation is less than 30%*.
Et/Ed 4	extreme	The terrain has been devastated by wind erosion, and is unreclaimable and impossible to restore.

---

* Known maximum coverage of perennials under good management as practiced during some time in the past.

** N/a = not applicable

14.2.2 Degree of present off-site degradation due to wind erosion

There has not yet been a set of criteria developed for assessing the degree of off-site degradation due to wind erosion. Where such degradation is evident, it is necessary to estimate the degree by following the guidelines, described above, for the general assessment of the degree of degradation.

14.3 Status of degradation due to chemical deterioration

Soil degradation due to chemical deterioration can be described by six categories of processes:

Cn - loss of nutrients, often leading to seriously reduced production (eg accelerated leaching of soils in the humid tropics)

Ca - acidification from fertilizer use and from bio-industrial sources (acid rain, oxidation of soil sulphur, etc.)

Cp - pollution and contamination from bio-industrial sources, excessive addition of chemicals (manures, wastes, atmospheric deposition, etc.)

Cs - salinization, caused by human-induced activities such as irrigation

Cd - discontinuation of flood induced fertility, which may occur as a result of a conservation practice or an impoundment that controls flooding and leads to a reduction in the natural replenishment of nutrients by flooding

Co - other chemical problems, such as "catclay" formation following drainage of certain coastal swamps; negative chemical changes and development of toxicities in paddy fields.

14.3.1 Degree of present degradation due to loss of nutrients

Criteria to assess the degree of present degradation are the organic matter content, the parent material, and the climatic conditions. The nutrient decline by leaching or by extraction by plant roots without adequate replacement is identified by a decline in organic matter, P, CEC (Ca, Mg, K).

Code	Degree		Description
Cn0	none		
Cn1	slight	-	Cleared and cultivated grassland or savannas on inherently poor soils in tropical regions. Cleared or cultivated formerly forestland in temperate regions on sandy soils, or in tropical (humid) regions on soils with rich parent materials.
Cn2	moderate	-	Cleared and cultivated grassland or savannas in temperate regions, on soils high in inherent organic matter, when organic matter has declined markedly by mineralization (oxidation). Cleared and cultivated formerly forested land on soils with moderately rich parent materials in humid tropical regions, where subsequent annual cropping is not being sustained by adequate fertilization.
Cn3	severe	-	Cleared and cultivated formerly forestland in humid tropical regions on soils with inherently poor parent materials (soils with low CEC), where all above-ground biomass is removed during clearing and where subsequent crop growth is poor or non-existent and cannot be improved by N fertilizer alone.
Cn4	extreme	-	Cleared formerly forested land with all above ground biomass removed during clearing, on soils with inherently poor parent materials, where no crop growth occurs and forest regeneration is not possible

14.3.2 Degree of present degradation due to acidification

Acidification should be considered as the relative change in pH over the last 5 to 10 years. The present status of acidity can be defined as follows:

Present status	Description	Corresponding SOTER soil layer file attributes: surface pH in	
		water (45)	CaCl (46)
Non acidic	pH neutral, or above that at which any acidity-related nutrient or toxicity problems occur	6.5 +	6.6 +
Slightly acidic	some nutrient availability problems, but generally no acidity-related toxicity	5.5,6.5	5.1,6.6
Moderately acidic	pH in range in which nutrient availability is moderately affected by acidity and toxicity problems may occur	3.9	3.6
Severely acidic	crop growth severely limited by acidity due to poor nutrient availability and/or toxicity	0.1,3.9	0.1,3.6
Extremely acidic	crop growth prevented by acidity and toxicity	0.1,3.9	0.1,3.6

The present degree of soil degradation by human-induced acidification can now be identified as a change in acidity status as follows:

Code	Degree	Description
Ca 0	none	
Ca 1	slight	- from non to slightly acidic; from slightly to moderately acidic; or from moderately to severly acidic
Ca 2	moderate	- from non to moderately acidic, or from slightly to severely acidic

Ca 3	severe	- from non to severly acidic, or from slightly to extremely acidic
Ca 4	extreme	- from non, slightly or moderately acidic to extremely acidic

14.3.3 Degree of present degradation due to salinization

Salinization should be considered as the relative change over the last +/- 10 years in salinity status of the soil, the latter being defined primarily on surface soil chemistry, but with subsoil conditions providing secondary criteria, as follows:

Present status	Description	Corresponding SOTER soil layer file attributes: EC (47)		
		0-50 cm Upper layers		50 cm + Lower layers
Non-saline	Electrical conductivity (EC) less than 2 dS m-1; E.S.P. <15%; pH <8.5	01		01, 02
Slightly saline	EC of 2-8 dS m-1; E.S.P. <15%; pH <8.5 Unevenness of growth and reduced crop vigour.	02,04		01, 02, 04
			or	
		01		04, 08, 16
Moderately saline	EC of 8-16 dS m-1; E.S.P. <15%; pH <8.5 White or grey salt precipitates visible in the soil; presence of salt-tolerant native vegetation or weeds; abnormal leaves such as tip-burn, firing along the margins, stunted plants and deep blue-green foliage.	08		01, 02, 04, 08, 16
			or	
		02,04		16, 26, 50
			or	
		01		26, 50
Severely saline	EC of more than 16 dS m-1; E.S.P. <15%; pH <8.5 Presence of white salt crusts on the soil surface, barren areas in fields, or only salt-tolerant native vegetation can grow.	16		all
			or	
		08		26, 50
Extremely saline	EC more than 25 dS m-1; E.S.P. <15%; pH <8.5 Surface completely covered with salt, no vegetation ("salt flats").	26 or more		all

The present degree of human-induced salinization can now be identified as a change in salinity status as follows:

Code	Degree	Description
Cs0	none	
Cs1	slight	from non-saline to slightly saline, from slightly to moderately saline, or from moderately saline to severely saline.
Cs2	moderate	from non-saline to moderately saline, or from slightly saline to severely saline.
Cs3	severe	from non-saline to severely saline, or from slightly to extremely saline.
Cs4	extreme	from non, slightly or moderately saline to extremely saline.

14.3.4 Degree of soil degradation due to discontinuation of flood induced fertility (Cd), or other chemical problems (Co)

These problems have not yet been defined in terms that permit the separation of degrees. If these problems are identified during field work, the general descriptions of the degrees of present degradation should be used as a guide.

14.4 Status of degradation due to physical deterioration

Soil degradation due to physical deterioration can be described by six categories of processes:

Pk - sealing and crusting of topsoil

Pc - compaction, caused by heavy machinery working on soils with weak structural stability, or on soils in which humus is depleted

Ps - deterioration of soil structure due to dispersion of soil particles by sodium (or magnesium) salts (sodication)

Pw - waterlogging, human-induced soil hydromorphism, flooding or submergence (except paddy soils)

Pa - aridification, human-induced changes in the soil moisture regime towards greater aridity, caused by lowering the local base water level (excluding deep aquifers)

Pl - subsidence of organic soils, by drainage and oxidation

14.4.1 Degree of present degradation due to soil physical deterioration

At present the criteria for separating degrees of soil degradation by physical deterioration into classes are poorly defined. The following guidelines are suggested for estimating the degree of Pk, Pc, Ps, and Pl. The general descriptions of degrees of soil degradation, listed above, should also be used as a guide in making these estimates, and are the only guidelines presently available for waterlogging (Pw) and aridification (Pa).

14.4.1.1 Degree of present degradation due to crusting/sealing of topsoil

It is the relative degree of human-induced crusting that is important in this assessment. Such a change is difficult to define as crusting is often a cyclical process that returns at certain seasons of the year. The following descriptions can be used as a guide to assessing the present degree of crusting that is being observed.

Code	Degree	Description
Pk 0	none	
Pk 1	slight	- visible round smooth aggregates, some cracking around emerging seedlings.
Pk 2	moderate	- surface soil particles slaked, sorted sand and silt and/or some clay films, emergence of seedlings reduced with successful emergence accompanied by cracking.
Pk 3	severe	- soil has strong, firm crust when dry, seedling emergence almost eliminated, infiltration very low when wet, through polygonal cracks when dry.
Pk 4	extreme	- surface cemented, no vegetation growth.

14.4.1.2 Degree of present degradation due to compaction

It is the relative change in soil compaction that is human-induced that is important in this assessment. Some soils are naturally compact or contain naturally compact layers such as ortstein or fragipans. It is important to distinguish between soil compaction that has been induced by human activity, and that which has a natural origin. The following guide to soil compaction classes must be considered in relation to the frequency of tillage operations and the management of the soil.

Code	Degree	Description
Pc 0	none	- coarse textured soils loose and friable, others have strong, fine structure, many voids, cracks and channels >2mm wide, most extending through horizon boundaries, rapid saturated hydraulic conductivity K_{sat}
Pc 1	slight	- coarse textured soils structureless, others moderate to strong fine to medium blocky structure; some voids, cracks and channels extending through horizons, most < 2mm wide but still visible to the naked eye; fewer voids than in similar, but uncultivated, soils in same region; moderate to low K_{sat}.
Pc 2	moderate	- weakly developed stratified or platy structure in medium and coarse textured soils, tightly packed adherent peds in fine textured soils; few visible voids, and none appear to cross horizons; low K_{sat}; higher bulk density compared with similar, but uncultivated, soils in same region.
Pc 3	severe	- cemented or strongly packed medium and coarse textured soils with bulk densities of 1.6 +, massive fine textured soils with Bd 1.4 + ; bulk densities higher than similar, but uncultivated, soils in same region; no visible voids or channels; very low K_{sat} (<0.1 cm/h).
Pc 4	extreme	- soil has massive structure and may be strongly cemented; it is essentially impermeable; tillage is no longer possible without special machinery; no vegetation will grow.

14.4.1.3 Degree of soil degradation due to structure deterioration from dispersing action of salts in subsoil

As noted above for salinity, it is the relative change of the soil structure as a result of human-induced sodication that is important in this degradation assessment. The following guidelines can be used to define the sodication status:

Present status	Description	Corresponding SOTER soil layer file attributes pH(45)	ESP(48)
Non sodic	No excess sodium salts	< 8.4	01
Slightly sodic	Some dispersion of clay soils, reduced infiltration	8.4	09 +
Moderately sodic	Clay soils dispersed and crusted on surface, very low permeability in subsoil, crop growth severly reduced	8.4	16 +
Severly sodic	Hard, columnar structure in subsoil, permeability very low, rain water ponds in many shallow, barren pits on soil surface ("black alkali" soils).	9.1	26 +
Extremely sodic	Soil crusted or structureless at surface, dense columnar subsoil structure close to soil surface, no vegetation growth.	9.1	26 +

The present degree of human-induced soil structure deterioration due to dispersion by salts in the subsoil can now be identified as a change in alkalinity status as follows:

Code	Degree	Description
Ps 0	None	
Ps 1	Slight	- from non-sodic to slightly sodic, from slightly to moderately sodic or from moderately to severely sodic
Ps 2	Moderate	- from non-sodic to moderately sodic, or from slightly to severely sodic

Ps 3	Severe	from non-sodic to severely sodic, or from severely to extremely sodic
Ps 4	Extreme	from non, slightly or moderately sodic to extremely sodic

14.4.1.4 Degree of organic soil degradation by subsidence

Organic soil degradation due to subsidence can often be measured as a loss of surface elevation as soils shrink from loss of water content following drainage, oxidize because of aeration, sink from loss of buoyancy, and become compacted during cultivation. Local reference points can often be found that indicate the loss of surface elevation of an organic soil. The management of drainage and cultivation of organic soils can also be interpreted in terms of rate of soil subsidence. The following guidelines apply to loss of surface elevation in the recent past - i.e. the last 5 to 10 years:

Code	Degree	Description
Pl 0	None	
Pl 1	slight	Most of the depth of organic soil present 10 years ago is still remaining; loss of elevation <2 cm per year; drainage poor with frequent inundation; low intensity agriculture with little tillage, mostly by hand.
Pl 2	moderate	60% or more of the depth of organic soil present 10 years ago is still remaining; loss of elevation 2 - 10 cm per year; drainage by ditches or pipes that keep water table below root zone all year; intensive cultivation uses mulching, cover crops and reduced tillage practices; small, light equipment employed.
Pl 3	severe	<30% of organic soil depth present 10 years ago is still remaining; loss of elevation >10 cm per year; drainage by deep ditches or pipes (well below root zone); frequent tillage without mulching or cover crops; heavy equipment used.

Pl 4	extreme	- organic material essentially lost; tillage brings up mineral soil from below; can no longer be considered an organic soil.

14.5 Status of degradation due to biological deterioration

Soil degradation due to biological deterioration has so far only been described in one form (Bb). This is as an imbalance of biological or microbiological activity in the topsoil. This can be caused by deforestation in the humid tropics, or by over-emphasis of chemical fertilizer applications. The degree and recent rate of biological deterioration must be assessed qualitatively using the general guidelines presented at the beginning of this chapter.

14.6 Status of stable lands with no active soil degradation

Two types of stable land are recognized:

- SN - soils that are natural and unaffected by human intervention, such as natural forests, tundra, icefields etc.
    - SNf - naturally stable under undisturbed native forest
    - SNi - naturally stable under icefields or glaciers
    - SNt - naturally stable under undisturbed tundra
- SH - terrain that has been stabilized by human intervention:
    - SHc - stabilized as a consequence of soil conservation practices for rainfed crops, or other forms of permanent conservation measures such as structures for erosion control
    - SHe - stabilized as a consequence of empoldering
    - SHp - stabilized as a consequence of paddy field terracing (bunding)
    - SHr - stabilized as a consequence of reforestation, permanent plantation crops, etc.

14.7 Non-used wastelands

Land that is at its ultimate state of degradation, is unvegetated, and for which the original process resulting in that degradation may be obscure, can be identified under one or more of the following classes:

A - deserts
D - active dunes
I - ice caps
R - rock outcrops
Z - salt flats

14.8 Recording information on the present status of soil degradation

Coding forms have been prepared which allow the storage of soil degradation information as an extension of the SOTER terrain component file. Soil degradation information should be recorded for each terrain component of each polygon.

The coding forms are shown at the end of this Section. The first 23 columns are used for recording the polygon and terrain component identifiers. The next part of this coding form (and its continuation sheet) provides six columns for each of the seventeen in situ soil degradation processes and the four off-site degradation processes that can be encountered. These six columns should be completed as follows:

1st column - degree of recent human-induced degradation
    0 - none (< 1% of area affected)
    1 - slight
    2 - moderate
    3 - severe
    4 - extreme

2nd column - extent of the terrain component affected
    1 - infrequent
    2 - common
    3 - frequent
    4 - very frequent
    5 - dominant

3rd column - rate of recent-past soil degradation
    1 - slow
    2 - medium
    3 - rapid

4th column - historical soil degradation by this process
    a - ancient soil degradation, more than 250 years ago
    b - era of European expansion, from 50 to 250 years ago
    c - post World War II period, from 10 to 50 years ago

5th and 6th columns - most probable causes of this soil degradation process, up to two of the following symbols can be used
    f - deforestation

g - overgrazing
i - overly intesive annual cropping
o - other

Following the twenty one sets of soil degradation records on the coding form, there are four columns assigned to stable terrain, two each for naturally stable land and land stabilized by human-intervention, as follows:

SN - naturally stable terrain
  f - forest
  i - ice
  t - tundra

SH - land stabilized by human-intervention
  c - conservation practices
  e - empoldering
  p - paddy
  r - reforestation

Up to two of the above symbols may be used in the columns assigned to each of the two types of stable terrain.
Finally on the soil degradation status coding form, up to four columns may be used to record non-used wasteland that is severly degraded as follows:

A - deserts
D - dunes
I - ice
R - rock
Z - salt flats

An estimate of the present rate of soil degradation is also required in the preparation of the SOTER terrain component files for the pilot project areas. This requirement is discussed in the next chapter.

SUMMARY SOIL DEGRADATION TYPES AND CLASS CODES FOR DEGREE, EXTENT, RATE, HISTORICAL, CAUSES AND OTHER ATTRIBUTES

	CODES
PRESENT DEGREE:	0(NONE); 1(SLIGHT); 2(MODERATE); 3(SEVERE); 4(EXTREME)
EXTENT AFFECTED, %:	1(1-5%); 2(6-10%); 3(11-25%); 4(26-50%); 5(51-100%)
RATE IN RECENT PAST 5-10 YRS:	1(SLOW); 2(MEDIUM); 3(RAPID)
HISTORICAL SOIL DEGRADATION (YRS. AGO):	A(>250); B(250-50); C(50-10)
CAUSES (UP TO 2 CAN BE USED):	F(DEFORESTATION); G(OVERGRAZING); I(INTENSIVE ANNUAL CROPPING); O(OTHER)
NATURALLY STABLE TERRAIN (SN):	F(FOREST); I(ICE); T(TUNDRA)
LAND STABILIZED BY HUMAN INTERVENTION(SH):	C(CONSERVATION); E(EMPOLDERING); P(PADDY); R(REFORESTATION)
NON USED WASTELAND (WAST): UP TO 4 CAN BE USED	A(DESERTS); D(DUNES); I(ICE); R(ROCK); Z(SALT FLATS)
CURRENT RATE OF SOIL DEGRADATION:	0(NONE); 1(SLOW); 2(MEDIUM); 3(RAPID); 4(EXTREMELY RAPID)

14.1.1 STATUS OF DEGRADATION DUE TO WATER EROSION (WT/WD)

DEGREE	SOIL DEPTH (CM)	SOIL REMOVED		SHALLOW RILLS DISTANCE APART(M)		MOD. DEEP GULLIES, DISTANCE APART(M)	PASTORAL COUNTRY ORIGINAL GROUND COVER %
0(NONE)							
1(SLIGHT)	>50	PART TOP	&/OR	20-50			>70
	<50	?		>50			
2(MODERATE)	>50	ALL TOP	&/OR	<20	OR	20-50	30-70
	<50	PART TOP	&/OR			20-50	
3(SEVERE)	>50	ALL TOP PART SUB	&/OR			<20	<30
	<50	ALL TOP LITHIC PHASE EXPOSED HARDPAN					
4(EXTREME)	TERRAIN DEVISTATED, UNRECLAIMABLE, IMPOSSIBLE TO RESTORE						

14.2.1 STATUS OF DEGRADATION DUE TO WIND EROSION (ET/ED)

DEGREE	SOIL DEPTH (CM)	SOIL REMOVED		SHALLOW HOLLOWS 0-5 CM DEEP (% OF AREA)		MODERATELY DEEP HOLLOWS 5-15 CM DEEP (% OF AREA)		DEEP HOLLOWS >15 CM (% OF AREA)	PA CO OR GR CO
0(NONE)									
1(SLIGHT)	>50	PART TOP	&/OR	10-40					
	<50	PART TOP		<10					
2(MODERATE)	>50	ALL TOP	&/OR	40-70	OR	10-40			3
	<50	PART TOP	&/OR	10-40					
3(SEVERE)	>50	ALL TOP PART SUB	&/OR	>70	OR	40-70	OR	10-40	
	>50	ALL TOP LITHIC PHASES EXPOSED HARDPAN							
4(EXTREME)	- TERRAIN DEVASTATED, UNRECLAIMABLE, IMPOSSIBLE TO RESTORE								

14.3.2 PRESENT STATUS OF DEGRADATION DUE TO ACIDIFICATION, CA (PH IN WATER)

STATUS		DESCRIPTION
NON ACIDIC	-	PH RANGE (6.6+) ABOVE THAT AT WHICH ANY ACIDITY-RELATED NUTRIENT OR TOXICITY PROBLEMS OCCUR
SLIGHTLY ACIDIC	-	PH RANGE (5.5 - 6.5) WHERE SOME NUTRIENT AVAILABILITY PROBLEMS, BUT GENERALLY NO ACIDITY-RELATED TOXICITY
MODERATELY ACIDIC	-	PH RANGE (3.9 - 5.4) IN WHICH NUTRIENT AVAILABILITY IS MODERATELY AFFECTED BY ACIDITY AND TOXICITY PROBLEMS MAY OCCUR
SEVERELY ACIDIC	-	PH RANGE (0.1 - 3.9) IN WHICH CROP GROWTH IS SEVERELY LIMITED BY ACIDITY DUE TO POOR NUTRIENT AVAILABILITY AND/OR TOXICITY
EXTREMELY ACIDIC	-	(PH RANGE (0.1 - 3.9) AND CROP GROWTH PREVENTED BY ACIDITY AND TOXICITY

THE PRESENT DEGREE ON HUMAN-INDUCED ACIDIFICATION IS IDENTIFIED AS THE CHANGE IN ACIDIFICATION STATUS OCCURRING OVER THE LAST 10 YRS. (APPROX):

CAD (NO CHANGE, Δ0); CA1(Δ 1 CLASSES)
CA2 (Δ 2 CLASSES); CA3(Δ 3 CLASSES OR FROM SEVERE TO EXTREME)
CA4 (Δ TO EXTREMELY EXCEPT SEVERE TO EXTREME)

14.3.1 STATUS OF DEGRADATION DUE TO LOSS OF NUTRIENTS (CN)

DEGREE	CLEARED AND CULTIVATED LAND IN DIFFERENT REGIONS			
	TROPICAL GRASSLAND OR SAVANNAS	HUMID TROPICAL FORESTLAND	TEMPORATE GRASSLAND OR SAVANNAS	TEMPORATE FORESTLAND
0(NONE) -	NO SIGN OF PRESENT DEGRADATION			
1(SLIGHT)	POOR SOILS WITH LOW CEC	RICH SOIL P.M.		SANDY SOIL
2(MODERATE)		SOIL PM MODERATELY RICH ANNUAL CROPPING NOT SUSTAINED BY ADEQUATE FERTILIZER	SOIL INHERENTLY HIGH IN OM WHICH HAS DECLINED MARKEDLY	
3(SEVERE)		SOIL INHERENTLY POOR WITH LOW CEC. ABOVE GROUND BIOMASS REMOVED DURING CLEARING CROP GROWTH POOR, AND NOT IMPROVED BY N FERT		
4(EXTREME)	- FORMERLY FORESTED LAND WITH INHERENTLY POOR P.M WHERE NO CROP GROWTH OCCURS AND FOREST REGENERATION IS NOT POSSIBLE.			

14.3.3 STATUS OF DEGRADATION DUE TO SALINZATION ON SOILS (CS) WITH ESP <15% AND PH <8.5

PRESENT STATUS CLASS		E.C. (DSM-1) TO APPROX DEPTH: 0 - 50 CM	50 + CM	OBSERVATIONS
NON-SALINE		<5	<9	
SLIGHT		5-8	<16	UNEVEN GROWTH;
	OR	<5	<26	REDUCED CROP VIGOR
MODERATE		9-15	<26	WHITE OR GRAY SALT PRECIPITATE ON SURFACE;
	OR	5-8	<50	ONLY SALT TOLERANT PLANTS PRESENT;
	OR	<5	<50)	STUNTED PLANTS AND DEEP BLUE-GREEN FOLIAGE
SEVERE		>15	50+	WHITE SALT CRUST PRESENTS ON SOIL SURFACE;
	OR	9-15	26+	BARREN AREAS IN FIELDS; ONLY SALT TOLERANT NATIVE VEGETATION CAN GROW.
EXTREMELY		>25	50+	SURFACE COMPLETELY COVERED WITH SALTS, NO VEGETATION ("SALT FLATS")

THE PRESENT DEGREE OF HUMAN-INDUCED SALINIZATION IS IDENTIFIED AS THE CHANGE IN SALINITY STATUS OCCURRING OVER THE LAST 10 YRS(APPROX):

CS0(NO CHANGE, Δ0); CS1(Δ1 CLASS); CS2(Δ2 CLASSES);
CS3(Δ3 CLASSES OR FROM SEVERE TO EXTREME); CS4(Δ TO EXTREMELY EXCEPT SEVERE TO EXTREME)

14.4.1.1 STATUS OF CRUSTING/SEALING DETERIORATION OF TOPSOIL:
PK0; PK1; PK2; PK3; PK4

14.4.1.2 STATUS OF DEGRADATION DUE TO COMPACTION:
PC0; PC1; PC2; PC3; PC4

15.4.1.3 STATUS OF DEGRADATION DUE TO SOIL STRUCTURE DETERIORATION FROM DISPERSING ACTION OF SALTS IN SUBSOIL (SEE PAGE 14-13)

THE PRESENT DEGREE OF HUMAN INDUCED STRUCTURE DEGRADATION DUE TO SOIL STRUCTURE DETERIORATION IS IDENTIFIED AS THE CHANGE IN ALKALINITY STATUS AS FOLLOWS:

PS1	FROM NON SODIC TO SLIGHTLY SODIC, FROM SLIGHTLY TO MODERATELY SODIC OR FROM MODERATELY TO SEVERELY SODIC
PS2	FROM NON SODIC TO MODERATELY SODIC, OR FROM SLIGHTLY TO SEVERELY SODIC
PS3	FROM NON SODIC TO SEVERELY SODIC, OR FROM SEVERELY TO EXTREMELY SODIC
PS4	EXTREMELY SODIC FROM NON, SLIGHTLY OR MODERATELY SODIC TO EXTREMELY SODIC

14.4.1.4 STATUS OF DEGRADATION DUE TO SUBSIDENCE:
statue PL0; PL1; PL2; PL3; PL4

15.4.1.3 STATUS OF DEGRADATION DUE TO SOIL STRUCTURE DETERIORATION FROM DISPERSING ACTION OF SALTS IN SUBSOIL (SEE PAGE 14-13)

THE PRESENT DEGREE OF HUMAN INDUCED STRUCTURE DEGRADATION DUE TO SOIL STRUCTURE DETERIORATION IS IDENTIFIED AS THE CHANGE IN ALKALINITY STATUS AS FOLLOWS:

PS1	FROM NON SODIC TO SLIGHTLY SODIC, FROM SLIGHTLY TO MODERATELY SODIC OR FROM MODERATELY TO SEVERELY SODIC
PS2	FROM NON SODIC TO MODERATELY SODIC, OR FROM SLIGHTLY TO SEVERELY SODIC
PS3	FROM NON SODIC TO SEVERELY SODIC, OR FROM SEVERELY TO EXTREMELY SODIC
PS4	EXTREMELY SODIC FROM NON, SLIGHTLY OR MODERATELY SODIC TO EXTREMELY SODIC

14.4.1.4 STATUS OF DEGRADATION DUE TO SUBSIDENCE:

statue PL0; PL1; PL2; PL3; PL4

SOTER CODING FORM — TERRAIN COMPONENT FILE - DEGRADATION SUBFILE SHEET #1

	POLYGON IDENTIFIER						WATER EROSION											WIND EROSION										CHEMICAL DETERIORATION																								
	COUN	STAT	BASE	REPO	POLY	PPOL	TNUM	WtDE	WtEX	WtRA	WtHI	WtCA	WdDE	WdEX	WdRA	WdHI	WdCA	EtDE	EtEX	EtRA	EtHI	EtCA	EdDE	EdEX	EdRA	EdHI	EdCA	CnDE	CnEX	CnRA	CnHI	CnCA	CpDE	CpEX	CpRA	CpHI	CpCA	CaDE	CaEX	CaRA	CaHI	CaCA	CsDE	CsEX	CsRA	CsHI	CsCA	CdDE	CdEX	CdRA	CdHI	CdCA
	1 2 3 4	5 6	7 8	11 12 13 14	15 16 17 18	19 20 21 22	23	24	25	26	27	28	30	31	32	33	34	36	37	38	39	40	42	43	44	45	46	48	49	50	51	52	54	55	56	57	58	60	61	62	63	64	66	67	68	69	70	72	73	74	75	76
1	01	02	03	04	05	06	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
2																																																				
3																																																				
4																																																				
5																																																				
6																																																				
7																																																				
8																																																				
9																																																				
10																																																				
11																																																				
12																																																				
13																																																				
14																																																				
15																																																				
16																																																				
17																																																				
18																																																				
19																																																				
20																																																				
21																																																				
22																																																				
23																																																				
24																																																				
25																																																				

con't

SHEET #2

	Chem. Deter. con't						Physical Deterioration																																				Biological Deterioration						Off-site Effects																								Stable Terrain				Non-Used Wasteland			
	C	C	C	C	C		P	P	P	P	P		P	P	P	P	P		P	P	P	P	P		P	P	P	P	P		P	P	P	P	P		P	P	P	P	P		B	B	B	B	B		W	W	W	W	W		W	W	W	W	W		W	W	W	W	W		E	E	E	E	E		S		S		W			
	o	o	o	o	o		K	k	k	k	k		c	c	c	c	c		s	s	s	s	s		w	w	w	w	w		a	a	a	a	a		l	l	l	l	l		b	b	b	b	b		r	r	r	r	r		f	f	f	f	f		c	c	c	c	c		o	o	o	o	o		N		H		A			
	D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C		D	E	R	H	C						S			
	E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A		E	X	A	I	A						T			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	53	54	55	56	57		58	59	60	61	62		63	64	65	66	67		68	69	70	71	72		73	74	75	76	77		78	79	80	81	82		83	84	85	86	87		88	89	90	91	92		93	94	95	96	97		98	99	100	101	102		103	104	105	106	107		108	109	110	111	112		113		114		115			
2																																																																																
3																																																																																
4																																																																																
5																																																																																
6																																																																																
7																																																																																
8																																																																																
9																																																																																
10																																																																																
11																																																																																
12																																																																																
13																																																																																
14																																																																																
15																																																																																
16																																																																																
17																																																																																
18																																																																																
19																																																																																
20																																																																																
21																																																																																
22																																																																																
23																																																																																
24																																																																																
25																																																																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

15. ASSESSMENT OF THE PRESENT RATE OF SOIL DEGRADATION

The assessment in the field, by observation, of the present rate of soil degradation is essential as a comparison and verification step for the quantitative rate estimates that will be made from SOTER data.

The "present rate" estimates made in the field during compilation of the SOTER database will be compared with those computed from analysis of SOTER terrain and soil layer file data. Significant differences (defined here as more than one class difference) between the observed and the computed soil degradation rate estimates will be investigated in detail in an attempt to improve both approaches.

15.1 Classes of present rate of soil degradation

The preceding chapter presents the guidelines for the assessment in the field of the status of human-induced soil degradation during the last 5 to 10 years. It also indicates the need for an estimate of the rate of soil degradation over the same time period, to be recorded as slow, medium or rapid. The guidelines request a written explanation of the reasons for the choice of rate.

The same observations can be used to estimate the PRESENT rate of soil degradation for comparison with the rate estimates that are described in the following chapters. Five classes are suggested:

0 - None
1 - Slow
2 - Medium
3 - Rapid
4 - Extremely rapid.

The first applies when there is no evidence of soil degradation occurring at the present time; the last should be reserved for unusual conditions that exceed the most rapid soil degradation that might be expected as a result of even very poor soil management - i.e. a disasterous climatic event or human intervention. The three intermediate rates should correspond closely to those used for the rate assessment over the recent past - i.e. 5 - 10 years.

These present rate estimates should be made for all of the following soil degradation processes:

water erosion
wind erosion
salinization
loss of soil structure by dispersion due to sodication
chemical and nutrient decline

These are the processes chosen for the first stage of the pilot area evaluation project. They are the only processes analysed in the remaining chapters of this procedures manual.

15.2 Recording information on present rate of soil degradation

A special coding form has been added to those that have been developed for recording the status of soil degradation. This will also form part of the SOTER terrain component file. Each of the 21 possible in situ and off-site soil degradation processes is listed with one column each to enter the estimated present rate from 0 to 4. Only those identified soil degradation processes that are to be covered in the first pilot project area must be completed. They have been grouped into the first eight columns following the polygon and terrain component identifiers. Present rate estimates for the other soil degradation processes may be completed by option. The coding form is shown at the end of this section.

15.3 Recording information for use in the SOTER-GLASOD soil degradation rate and risk analyses

As will be discussed in subsequent chapters of this procedures manual, certain of the SOTER terrain component attributes and soil layer file attributes will be used in the GLASOD 1:1 million scale soil degradation analyses to determine the rate and risk of soil degradation. Although only mandatory information will be used in these analyses, these attributes are listed here as a reminder that they will be needed early in the GLASOD project, and that it is essential that this information be recorded.

SOTER terrain component attributes:

08 - parent material/rock : for nutrient/chemical decline
10 - surface form : for water erosion and nutrient/chemical decline
11 - slope gradient : for water erosion
12 - slope length : for water erosion
15 - depth to groundwater : for salinization, sodication, and nutrient/chemical decline
16 - quality of groundwater: for salinization
17 - rooting depth : for water erosion and nutrient/chemical decline
18 - predominant land use : for water erosion, wind erosion, and nutrient/chemical decline

SOTER soil layer file attributes:

07 - position on slope : for water erosion and salinization
08 - internal drainage : for water erosion and nutrient/chemical decline
23 - organic carbon : for water erosion and nutrient/chemical decline
25 - CEC total : for nutrient/chemical decline
28 - AEC : " " " "
38 - Al saturation : " " " "
44 - base saturation : " " " "
45 - pH in water : for sodication and nutrient/chemical decline
47 - electrical cond. : for salinity
52 - coarse fragments : for water erosion
53 - texture (USDA) : for water erosion, wind erosion, sodication and nutrient/chemical decline
65 - structure : for water erosion
66 - stable aggregates : for wind erosion
68 - biological activity : for nutrient/chemical decline
70 - diagnostic horizon : for water erosion, sodication and nutrient/chemical decline

This list is not final; as the methodology develops for improving estimates of current rate of risk of soil degradation this list will almost certainly be expanded.

SOTER CODING FORM

TERRAIN COMPONENTS - DEGRADATION SUBFILE

SHEET • 3

	POLYGON IDENTIFIER							CURRENT RATE																				
								Mandatory								Optional												
	COUN	STAT	BASE	REPO	POLY	PPOL	TNuM	Wtcu	Wdcu	Etcu	Edcu	Cncu	Cscu	Pscu	Wrcu	Cpcu	Cacu	Cdcu	Cocu	Pkcu	Pccu	Pwcu	Pacu	Plcu	Bbcu	Wfcu	Wccu	Eocu
	1 2 3 4	5 6	7 8 9 10	11 12 13 14	15 16 17 18	19 20 21 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
1	01	02	03	04	05	06	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
2																												
3																												
4																												
5																												
6																												
7																												
8																												
9																												
10																												
11																												
12																												
13																												
14																												
15																												
16																												
17																												
18																												
19																												
20																												
21																												
22																												
23																												
24																												
25																												

16. ASSESSMENT OF THE RATE AND RISK OF WATER EROSION FROM SOTER DATA

Although several methodologies have been used in different countries to assess soil erosion potential, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) is one of the best known and most extensively tested. It was the method chosen by the Food and Agriculture Organization of the United Nations for their "Provisional Methodology for Soil Degradation Assessment" (FAO 1979). This is not to suggest that it is necessarily superior to other methods, but its widespread use and acceptance makes it preferable to other methods - provided that modifications are made where needed to accomodate some of the significant global variability that affects erosion risk.

The USLE is a simple linear model of the form:

$$A = R_tKLSC_vP \qquad (16.1)$$

where each factor is determined separately, and the product (A) is annual soil loss in tons ha^{-1}. The driving component is the factor "R_t", the total or equivalent rainfall energy (or erosivity). It is therefore important that this factor be consistent globally if comparisons between maps are to be meaningful. Each of the other factors are modifiers that relate the soils, slopes and crop cover conditions at the sites under consideration to those of the original plots studied by Wischmeier and Smith (1978).

Water erosion risk assessment is usually done in two stages:

i. Computation of erosion risk assuming a "bare soil" condition; and
ii. Computation of likely erosion risk under the present vegetation cover, be it agricultural crops or natural vegetation.

The first provides the opportunity for a comparison of one soil polygon with another while holding vegetative cover constant at its "worst case" condition. Such comparisons are valuable in determining the most sensitive soils for clearing or for agricultural development. The second provides an estimate of the present rate of soil erosion.

16.1 Erosion risk for bare, unprotected soil

16.1.1 Estimation of R_t values for soil polygons

The climate database for the SOTER project will be used to compute the annual R_t values for the map sheet, using the most appropriate method according to the availability of data in the region. The computed R_t values can be provided as point data corresponding to the locations of climate stations within the map sheet area. From these data, isolines of equal R_t value can be drawn using linear interpolation.

Using an overlay of R_t isolines, each soil polygon on the 1:1M soil map should be assigned an R_t value estimated from the nearest isolines. Local knowledge should also be used to advantage at this stage so that lnown differences in the climatic conditions between soil polygons can be reflected in the choice of a "representative" R_t value for each polygon.

Alternatively, if map polygons are coded to fit the spacial capabilities of the climatic data handling system, R_t values can be assigned directly to polygons without the necessity of estimating them from an overlay of isolines.

16.1.2 Estimation of slope-landform effects

The slope-length factor (LS) developed for use with the USLE is not readily applied at the scale of 1:1M. The published procedure requires that slopes are segmented into lengths of equal slope angle, and that computations are made for each segment, apportioned among the segments of each slope sequence, then a weighted-mean LS value can be calculated for each slope. Although this procedure may be applicable for slopes within a plot or field, it cannot be applied to complex landscape units such as those mapped at a scale of 1.1M.

Where slopes are relatively uniform and an estimate has been made of the most representative slope length, values of L and S can be computed as follows:

16.1.2.1 Calculation of the effect of length-of-slope (L)

Soil loss has been found to be related to the length of slope by the following equation (Wischmeier and Smith 1978):

$$L = (D/22)^a \qquad (16.2)$$

where L is the slope length factor
D is the length of slope (m)
and a is an exponent with the value 0.3 for slopes in the 0-3% class, 0.4 for slopes in the 4-9% class, and 0.5 for slopes >9%.

16.1.2.2 Slope angle effect (S)

The relationship between soil loss and slope angle has been calculated as follows (Wischmeier and Smith 1978):

$$S = 65.41 \sin\sigma^2 + 4.56 \sin \sigma\nu + 0.065 \qquad (16.3)$$

where S is a dimensionless multiplier applied to R_t,
and σ is slope angle in degrees.

16.1.2.3 Estimation of LS for slope gradient and slope length classes:

Using equations 16.2 and 16.3 above, Table 16.1 has been prepared to provide estimates of LS values when slope and slope length classes are available in the soil attributes file.

Table 16.1 Slope-length factors (LS) for slope gradient and slope length classes estimated for soil map polygons at a scale of 1:1M.

Slope class (%)	(code)	Slope length class, m (code) 1 - 30 (001)	31-150 (031)	151-300 (151)	301+ (301)
		---------------------- LS factor		---------	
1- 3	(01)	0.14	0.23	0.29	0.33
4- 9	(04)	0.67	1.5	1.8	2.2
10-15	(10)	1.5	3.5	5.6	7.3
16-29	(16)	4.5	10	16	21
30-59	(30)	13	30	45	60
60+	(60)	26	58	92	120

16.1.3 Soil erodibility factor (K)

Soil erodibility (K) has long been used as a constant determined for each soil from organic matter, texture, structure and permeability. The equation has been formulated into a nomograph for ease of application (Wischmeier et al. 1971). The procedure described in the next 3 subsections provides an estimate of the mean annual K factor.

Recent research has demonstrated that K is subject to considerable seasonal variation, which is particularly important where freezing and thawing occurs in wet soils. Where freezing occurs in wet soils, a modification is proposed for adjusting K during periods of thaw so that determinations can be made of the effectiveness of vegetation cover in preventing erosion.

16.1.3.1 Estimation of soil erodibility (K) when particle size, structure and permeability data are available

The nomograph of Wischmeier et al (1971) is presented in Figure 16.1. Percent sand greater than very fine sand (0.10-2.0 mm), percent very fine sand (0.05-0.10 mm), percent silt (0.001-0.01 mm), and percent organic matter are required for estimation of the "1st approximation" of K. To complete the estimate, soil structure and permeability codes are required. These can be estimated from the SOTER extended legend attribute classes for structure and internal drainage as shown in Table 16.2.

Table 16.2 Estimated soil structure and permeability codes from structure and internal drainage classes.

SOTER soil layer file internal drainage class (08) code	SOTER soil layer file structure class (65) code for surface layer				
	01	02	03	04	05
	---- Structure/permeability codes * ----				
EXCE	1;6	2;6	3;6	4;6	4;6
RAPI	1;5	2;5	3;5	4;5	4;5
WELL	1;4	2;4	3;4	4;4	4;4
IMPE	1;3	2;3	3;3	4;3	4;3
POOR	1;2	2;2	3;2	4;2	4;2
VPOO	1;1	2;1	3;1	4;1	4;1

* Soil structure code; soil permeability code - for use with Figure 16.1.

16.1.3.2 Adjustment of erodibility factor (K) due to coarse fragments

Coarse fragments (stones) reduce soil erodibility because they provide protection from raindrop impact in a manner similar to that provided by surface mulch. When data are available for the coarse fragment content of the soil, the erodibility factor (K) can be adjusted to account for this reduced erodibility. Table 16.3 presents the correction factor for coarse fragments (F) according to the classes of coarse fragments recorded in the SOTER extended legend.

Table 16.3 Correction factor for coarse fragments (F) to be applied to the soil erodibility factor (K) by coarse fragment classes.

SOTER soil layer file coarse fragments class (52) for surface layer	Erodibility (K) correction factor - F
0 - 2 % (01)	1.0
3 - 14 % (03)	0.85
15 - 49 % (15)	0.48
50 - 89 % (50)	0.18
90+% (90)	0.05

16.1.3.3 Estimation of the erodibility factor (K) in the absence of soil particle size data:

In the absence of soil particle size information, it is necessary to rely on soil texture classes as the only source of information on particle size distribution from which to estimate soil erodibility. Table 16.4 presents the estimates of soil erodibility (K) by texture class and by organic carbon class. A second line of values has been included where appropriate as a correction to account for the lower erodibility of 'oxic' soils because of their strong structural characteristics.

16.1.4 Estimating the class of water erosion risk on bare, unprotected soil

The value of A obtained from the USLE when C_v and P are set equal to 1.0 (i.e. no effects from vegetation or conservation practices) can be assumed to be representative of the water erosion RISK if the soil is left bare and unprotected by vegetation or conservation practices. The computed value of the water erosion soil loss (A) from the USLE is in tonnes $ha^{-1}a^{-1}$. This is not a value that should be recorded permanently on a map as it is only an estimate and one that is particularly subject to quantitative inaccuracies. Rather, it is preferable that these values of A be grouped into classes.

Table 16.5 presents a suggested set of class limits for water erosion.

These may require re-assessment after values are determined under a wide range of soil and climatic conditions. They are slightly different from those proposed in the FAO (1979) provisional methodology, because five classes are proposed rather than four.

16.2. Computation of present water erosion RATE under present land use and vegetation

16.2.1 Vegetation cover soil loss correction factor (C_v)

Computation of the vegetation soil loss correction factor (C_v) requires that the seasonal vegetation pattern be estimated. For perennial crops such as hay or pasture, or for forest, there is little need of seasonal computations unless overgrazing or seasonal drought result in a significant reduction of the effectiveness of the vegetation in protecting the soil surface from erosion. This evaluation must be made locally by those familiar with the local vegetation conditions.

Table 16.4 Erodibility factor (K) estimates by soil texture class and organic carbon class (surface layer), using estimated status and permeability classes.

Texture class	(code)	Str; perm*	Organic carbon class (code)				
			0-0.3	0.3-0.6	0.7-1.9	2.0-2.9	3.0+
Sand	(S)	1;1	0.0025	0.0025	0.0025	0.0025	0.0025
Loamy sand	(LS)	1;1	0.0169	0.0157	0.0123	0.0076	0.0025
Loamy fine sand	(LFS)	2;2	0.0245	0.0233	0.0199	0.0152	0.0068
Fine sand	(FS)	1;1	0.0025	0.0025	0.0025	0.0025	0.0025
Very fine sand	(VS)	1;2	0.0767	0.0730	0.0627	0.0484	0.0118
Loamy v. f. sand	(LVFS)	2;3	0.0735	0.0720	0.0629	0.0500	0.0173
Sandy loam	(SL)	2;3	0.0255	0.0244	0.0213	0.0169	0.0059
Fine sandy loam	(FL)	2;3	0.0280	0.0244	0.0213	0.0186	0.0064
Loam	(L)	3;3	0.0515	0.0495	0.0437	0.0357	0.0152
(oxic)		2;3	0.0472	0.0452	0.0394	0.0314	0.0109
V. f. sandy loam	(VFSL)	3;4	0.0561	0.0538	0.0437	0.0387	0.0162
(oxic)		2;3	0.0518	0.0495	0.0394	0.0344	0.0119
Silt loam	(SIL)	3;4	0.0754	0.0725	0.0642	0.0527	0.0232
(oxic)		2;3	0.0678	0.0649	0.0566	0.0451	0.0156
Sandy clay loam	(SCL)	3;3	0.0238	0.0230	0.0206	0.0173	0.0088
(oxic)		2;3	0.0195	0.0187	0.0163	0.0130	0.0045
V. f. sandy c. l.	(VCL)	3;4	0.0401	0.0387	0.0347	0.0292	0.0151
(oxic)		2;3	0.0325	0.0311	0.0271	0.0216	0.0075
Clay loam	(CL)	3;3	0.0341	0.0328	0.0292	0.0232	0.0112
(oxic)		2;3	0.0298	0.0285	0.0249	0.0189	0.0069
Silty clay loam	(SICL)	3;4	0.0490	0.0472	0.0421	0.0351	0.0171
(oxic)		2;3	0.0414	0.0396	0.0345	0.0275	0.0095
Sandy clay	(SC)	3;5	0.0195	0.0191	0.0181	0.0166	0.0129
(oxic)		2;3	0.0086	0.0082	0.0072	0.0057	0.0020
Clay	(C)	4;5	0.0191	0.0189	0.0184	0.0177	0.0160
(oxic)		2;3	0.0040	0.0038	0.0033	0.0026	0.0009
Heavy clay	(HC)	4;6	0.0200	0.0199	0.0197	0.0195	0.0188
(oxic)		2;3	0.0016	0.0015	0.0013	0.0011	0.0004

* Structure code; permeability code - assumed in preparation of this table.

Table 16.5 Class limits for water erosion risk maps using the USLE

Water erosion risk class	Map Symbol	Computed value of soil loss 'A' (tonnes $ha.^{-1}a^{-1}$)
None	N	< 2.0
Low	L	2.0 - 9.9
Moderate	M	10.0 - 49.9
Severe	S	50.0 - 199.9
Extreme	E	200.0 +

For cultivated crops such as wheat, maize, cotton, sugar cane, etc., there is usually a marked seasonal variation in vegetation cover. This is especially evident for annual crops that must be re-seeded following a seasonal seedbed preparation. The minimum number of vegetation seasons for these crops will be:

i. a seedbed to crop cover establishment period;
ii. a full vegetation cover period; and
iii. a fallow (or no-crop) period in which various amounts of crop residue will be present on the soil surface depending on local harvesting, fallowing and tillage practices.

For crops requiring a lesser number of vegetation-cover seasons, only the most appropriate need be used, and extended to include the entire year. Where two or more crops are grown each year, each crop should be considered separately, and the length of each vegetation season should be adjusted to fit the portion of the year that applies to that crop.

The SOTER database provides only limited information on soil cover. This information should be augmented at the local level to the greatest extent possbile. Table 16.6 presents a minimum set of estimates that can be applied in the absence of better local information.

Table 16.6 Estimated vegetation cover soil loss factor (C) values for ground or plant cover classes.

Ground or Plant Vegetation cover soil loss factor (C) by season Cover Class

		Planting	Growing	Fallow	Wet	Dry
Horticultural	(HO)	0.80	0.35	0		
Orchards	(OR)	-	0.15	-	-	-
Annual cropland	(AN)	0.70	0.30	0.50	-	-
Perennial forage	(PE)	-	0.10	-	0.10	0.10
Perennial grazing	(GR)	-	0.20	-	0.10	0.30
Bushland grazing	(BU)	-	0.10	-	0.05	0.20
Productive woodland	(WO)	-	0.05	-	0.05	0.05
Arctic tundra	(AR)	-	-	0.10(frozen)	0.00(thawed)	
Unvegetated *		1.00	1.00	1.00	1.00	1.00

* Unvegetated includes sand, salt, rubble, rockland etc.

16.2.2 Estimation of seasonal "R" factor

From the data provided from the climate data file, the rainfall/runoff erosivity "R_t" factor should be divided into seasonal proportions that match the three seasons indicated in Table 16.5. If a greater or lesser number of seasons are used then the annual R_t factor should be apportioned accordingly.

The climate database should be used to prepare seasonal distributions of the R_t factor. Where the capability exists, these seasonal values may be provided by individual polygon. If the seasonal R_t cannot be provided on a polygon by polygon basis, then the approximate seasonal percentages of the R_t values for the map sheet should be estimated, and these applied to each of the polygon R_t values.

16.2.3 Estimation of seasonal "K" factor

For most climatic regions it is not yet possible to estimate seasonal variation in "K". The estimate obtained from section 16.1.3 above must serve as the only "K" value available, and it must be used in all seasons. This is not because there is no seasonal variation in "K", rather it is due to a lack of information on which to base seasonal estimates.

In regions with distinct seasonal changes in soil conditions, such as where there is a frozen winter period, it is possible to make a simple adjustment to "K" to better reflect the likely erodibility appropriate to the seasonal vegetation cover.

16.2.3.1 Adjustments to "K" where a frozen winter season exists

In climates where the soil is frozen for part of the year, "K" values should be increased by a factor of 2 for the season immediately following the principal thaw period (Coote et al. 1988; Wall et al. 1988). If this is part of the "fallow" vegetation period, then the "R" value for this period should be separated into that following harvest and before soil freezing, and that immediatly following spring thaw and prior to the planting period. Soil "K" factors during the "growing" season should be reduced by a factor of 2 (50%) compared with the initial "K" estimate, which now applies only during the "planting" season.

16.2.4 Effect of conservation practices on present rate of water erosion

The Universal Soil Loss Equation has a conservation practices factor (P) that is intended to correct estimates of water erosion for the presence of conservation practices (terraces, contouring, strip cropping, etc.). The 'P' factor can range from 0 (complete protection) to 1.00 (no protection). It simply reduces the estimated erosion rate by a proportionality constant determined by the type of conservation practice (distance between terraces, widths of crop strips, etc.).

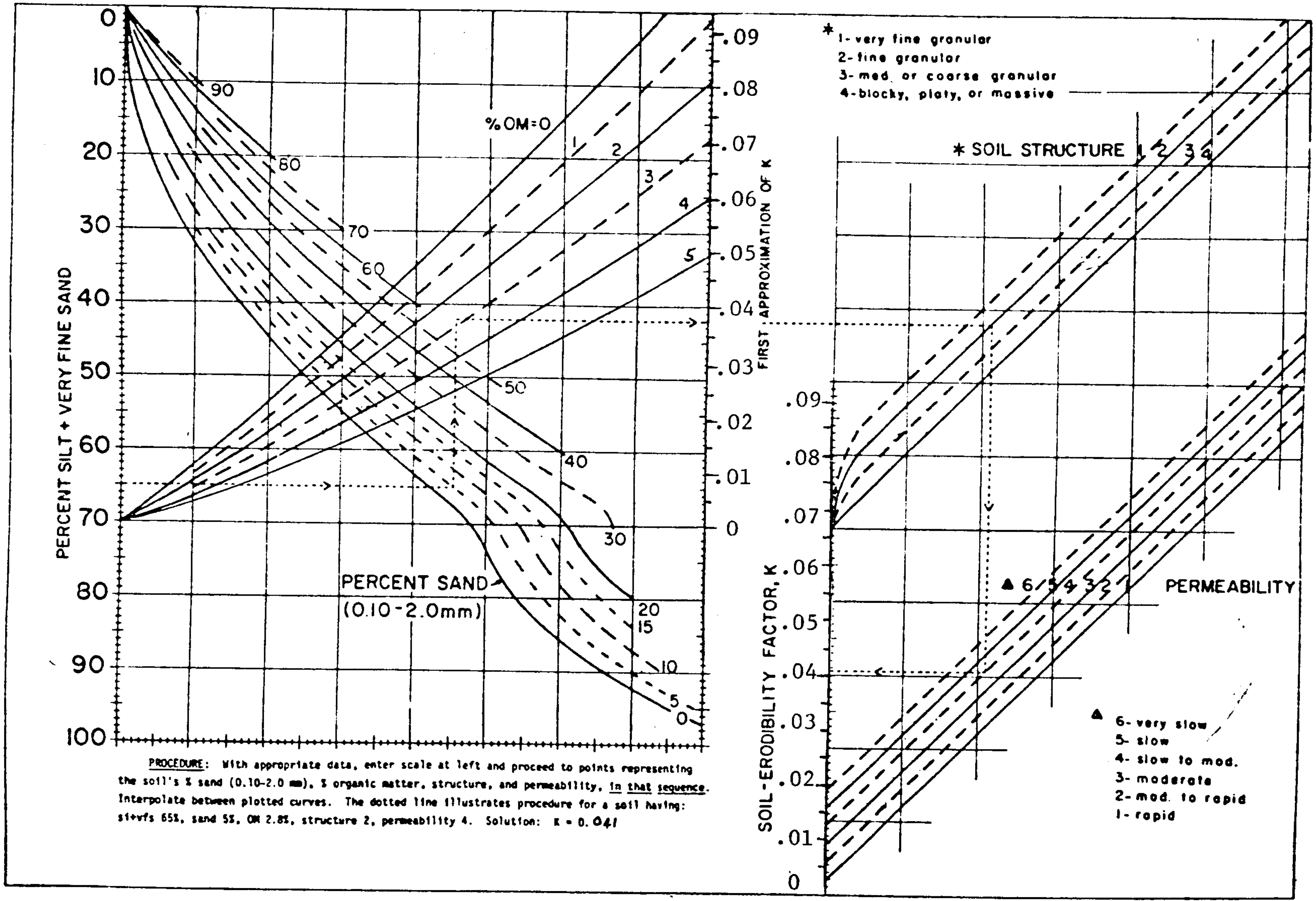
It is beyond the scope of this study to attempt to estimate 'P' factors that can be applied universally. They must be determined by local experience, and pro-rated according to the proportion of each map polygon that has been treated with various types of conservation practice.

16.2.5. Estimating water erosion rate classes

The values of A obtained from the USLE for each season can be summed to provide an annual rate. These can be compared with Table 16.7 to fit the computed erosion rate into classes. These are very subjective, and will require re-evaluation as data are collected from different regions and soil types.

Table 16.7 Class limits for present rate of water erosion

Water erosion rate class	Map symbol	Computed annual value of soil loss 'A' ($t.ha^{-1}.a^{-1}$)
None	0	< 1.0
Slow	1	1.0 - 4.9
Medium	2	5.0 - 24.9
Rapid	3	25.0 - 99.9
Extremely rapid	4	100 +



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.041

The soil-erodibility nomograph. Where the silt fraction does not exceed 70 percent, the equation is $100\ K = (2.1\ M^{1.14}\ (10^{-4})\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3)) \times 0.1317$ where M = (percent si + vfs) (100 — percent c), a = percent organic matter, b = structure code, and c = profile permeability class.

Figure 16.1 The soil erodibility nomograph (adapted from Wischmeier and Smith 1978)

17. ASSESSMENT OF THE RATE AND RISK OF WIND EROSION FROM SOTER DATA

Wind erosion assessment must be sensitive to wind speed, the erodibility of the soil by wind, the resistance to wind erosion that results from soil moisture, and the protection of the soil from wind erosion provided by vegetation or surface residue. There is no "universal" wind erosion equation such as has been developed for water erosion.

The Wind Erosion Equation developed in the USA (Woodruff and Siddoway 1965) is difficult to apply to map scales as small as 1:1M. The validity of the climate factor (C_W) outside of the continental USA is also questionable. An improved version of the C_W-factor estimation procedure proposed by Bondy et al.(1980) suggests the use of monthly or seasonal wind energy distributions applied to seasonal vegetation and soil conditions and accumulated for the year, rather than mean annual wind speeds applied to the soil and vegetation conditions in the most susceptible period.

The provisional methodology for soil degradation assessment proposed by FAO (1979) selected the US Wind Erosion Equation, with the simple annual climate factor based on mean annual wind speed and Thornthwaite's PE index. Regrettably, there are strong indications that Thornthwaite's PE index is not suitable for use in much of the tropical region of the world.

Work in Canada indicates that maximum 1-hour wind speeds during periods when the soil is dry and poorly protected by vegetation may provide better estimates of wind erosion risk (Coote et al. 1988). Maximum wind speeds in some regions, however, occur during intense rainstorms when wind erosion would not be expected, and for this reason the maximum wind speed may not be a suitable index for use in rating wind erosion on a global scale. The scarcity of maximum wind speed data for many regions is also a barrier to the use of this methodology for a global wind erosion assessment.

Protection of soils from wind erosion by vegetation is generally more critical than soil dryness, since even relatively wet soils can be dried sufficiently at the surface by strong, dry winds to create a wind erosion event. Soils well protected by vegetation, on the other hand, do not tend to erode even when the soil is dry.

The method proposed here for the global assessment of wind erosion risk at the 1:1 million scale is a modification of the US Wind Erosion Equation, with Hargreave's Moisture Availability Index providing the "precipitation effectiveness" estimate that was formerly obtained by Thornthwaite's method.

17.1 Wind erosion risk on bare, unprotected soils

17.1.1 Modified Wind Erosion Equation

The US Wind Erosion Equation is a function of a climate factor that combines wind and soil moisture considerations, a soil erodibility index that is related to expected wind-erodible aggregates, a surface roughness factor, and a field length (along prevailing wind direction) factor. The field length factor has been omitted from this assessment as it is not reasonable to apply it to polygons at the scale of 1:1M.

The wind erosion equation can be written as:

$$E = C_W . I_s . U . \qquad (17.1)$$

where: E = wind erosion rate in t $ha^{-1}a^{-1}$
C_W= wind erosion climate factor (dimensionless)
I_s= soil erodibility in t $ha^{-1}a^{-1}$
U = soil ridge roughness factor (dimensionless)

This simple equation provides an estimate of wind erosion on bare, unprotected soil.

17.1.2 The climate factor (C_W)

The climate factor can be computed from the climate data file for stations having wind speed data. Values can be plotted for individual stations, then isolines of equal C_W value drawn on a transparent overlay. Alternatively, the climate file can be used to estimate polygon C_W values directly if the data handling system has this capability.

17.1.3. The soil erodibility "I_s" factor

The "I_s" factor of the Wind Erosion Equation can be estimated from Table 17.1 if the % aggregates >0.84 mm are known. These can be measured by dry sieving. The units of "I_s" are in tonnes ha^{-1} per annum of soil loss.

Table 17.1 Soil erodibility factor (I_s) for soils with different percentages of non-erodible aggregates (tonnes $ha^{-1}a^{-1}$)

Percentage of dry soil fraction > 0.84 mm	Units									
	0	1	2	3	4	5	6	7	8	9
Tens	Tonnes/ha									
0	-	695	561	493	437	404	381	359	336	314
1	300	294	287	280	271	262	253	244	238	229
2	220	213	206	202	197	191	186	182	177	170
3	166	161	159	155	150	146	141	139	135	130
4	126	121	117	114	112	108	105	100	96	92
5	85	81	74	70	65	61	56	54	52	49
6	47	45	43	40	38	36	35	34	31	29
7	27	25	22	18	16	13	9	7	6	5
8	4	-	-	-	-	-	-	-	-	-

When data are not available on the percentage of dry aggregates > 0.84 mm, it is necessary to estimate the I_s factor value from soil texture.

Table 17.2 provides an estimate that can be used as a guide for selecting an appropriate value for I_s. There is no method currently available for adjusting the I_s value to account for organic matter content.

Table 17.2 Estimated values of % dry aggregates >0.84mm, wind erodibility factor "I_s" ($t\ ha^{-1}a^{-1}$), and roughness "U" for soil texture groups

SOTER soil layer file texture class (53) surface layer	code	% aggregates >0.84 mm	"I_s" ($t\ ha^{-1}a^{-1}$)	"U" (dimensionless)
Sand	(S)	1	695	1.00
Loamy sand	(LS)	10	300	1.00
Loamy fine sand	(LFS)	10	300	1.00
Fine sand	(FS)	1	695	1.00
Very fine sand	(VS)	1	695	1.00
Loamy very fine sand	(LVS)	10	300	1.00
Sandy loam	(SL)	25	181	0.75
Fine sandy loam	(FL)	25	181	0.75
Loam	(L)	25	181	0.75
Very fine sandy loam	(VFSL)	25	181	0.75
Silt loam	(SIL)	40	126	0.75
Sandy clay loam	(SCL)	40	126	0.75
V. f. sandy clay loam	(VCL)	25	181	0.75
Clay loam	(CL)	25	181	0.75
Silty clay loam	(SICL)	45	108	0.75
Sandy clay	(SC)	25	181	0.50
Clay	(C)	25	181	0.50
Heavy clay	(HC)	25	181	0.50

17.1.4 The ridge roughness factor "U"

This factor is supposed to reflect the effect of tillage, and the resistance of the soil to the collapse of the ridges formed by tillage. It is a rather subjective qualifier attached to the erodibility for a soil type. The values shown in Table 17.2 can be applied where tillage is normal for crop production. Where tillage is not usually practiced, the value of "U" can be set equal to 1.0.

17.1.5 Estimating wind erosion risk classes

The computed value of the wind erosion risk on bare, unprotected soil (E) has nominal units of $t.ha^{-1}.a^{-1}$. As with water erosion, these values are extremely unreliable in the quantitative sense. Rather, they serve a useful role for comparison purposes between one polygon and another, and between one region or continent and another. It is therefore preferable that these values be grouped into classes, where inaccuracies of estimation will be partly buffered by the breadth of the class, and where the risk of their use in an unreasonably quantitative procedure will be reduced.

Table 17.3 provides an initial grouping of values of E into classes of risk of wind erosion on bare, unprotected soils. It will likely be revised as information is accumulated from various regions, so that it can serve as a relative index of the severity of wind erosion risk on a global scale.

Table 17.3 Class limits for wind erosion risk on bare, unprotected soil

Wind erosion risk class	Map symbol	Computed value of soil loss 'E' (t. ha .a)
None	N	< 2.0
Low	L	2.0 - 9.9
Moderate	M	10.0 - 49.9
Severe	S	50.0 - 199.9
Extreme	E	200.0 +

17.2 Computation of present wind erosion RATE with present land use and vegetation cover

To compute the present rate of wind erosion it is necessary to adjust the risk of wind erosion on bare, unprotected soil to account for the effect of vegetetion and crop residues. The vegetation and residue factor, V_r, is used as a proportionality constant as follows:

$$E_r = E.V_r \qquad (17.2)$$

where: E_r is present erosion rate $(t.ha^{-1}.a^{-1})$
V_r is the vegetation and residue factor (dimensionless)
E is the erosion rate for bare soil from eq. 17.1

17.2.1 The vegetation and residue factor "V_r"

The vegetation and residue factor "V_r" is the most difficult to estimate from the complex series of computations necessary at the field level. At a scale of 1:1M, individual field characteristics cannot usually be considered. Details of crop types, yields, and residue management practices are likely to be sketchy at best. It is therefore proposed that a simple rating of land use, similar to that applied in the water erosion risk assessment, be used to compare map polygons. The suggested V_r factor values are presented in Table 17.4.

Table 17.4 Estimated vegetation factor "V_r" for use with the Wind Erosion Equation

Ground or Plant Cover Class	Vegetation factor "V_r" by season				
	Planting	Growing	Fallow	Wet	Dry
Horticultural (HUMM)	0.90	0.25	0.80	-	-
Orchards (ORCH)	-	0.05	-	0.0	0.10
Annual cropland (ANNU)	0.80	0.10	0.50	-	-
Perennial forage(PERR)	-	0.05	-	0.0	0.10
Perennial grazing(GRAZ)	-	-	-	0.05	0.30
Bushland grazing (BUSH)	-	-	-	0.03	0.10
Plantation (PLAN)	-	0.05	-	0.0	0.10
Prod. woodland (WOOD)	-	0.00	-	0.0	0.0
Bog, Fen (BOG)	-	-	-	0.0	0.0
Arctic tundra (ARCT)	-	-	- (thawed)	0.20 (frozen)	0.05
Outdoor recreation (RECR)	-	0.05	-	0.0	0.10
Unvegetated *	1.0	1.0	1.0	1.0	1.0

* Unvegetated includes sand, salt, rubble, rockland etc.

17.2.2 Estimating annual wind erosion rate from seasonal V_r values

The climate data file should be used to provide estimates of C_w for the seasons used in Table 17.4. This can be in the form of simple percentages or proportions of the annual C_w factor. Using the values of V_r from Table 17.4, a weighted mean annual value of V_r should be computed by multiplying each seasonal V_r by the percentage of the annual C factor that occurs in each season. This mean annual V_r can now be used as a proportionality constant to reduce E to a value that represents an estimate of the present rate of wind erosion.

17.2.3 Estimating classes of present wind erosion rate

The computed value of present rate of wind erosion is just as subject to inaccuracies and potential misinterpretation as is the value of wind erosion risk. It is therefore equally important that values be grouped into classes for comparative purposes. Table 17.5 presents a suggested set of class limits for wind erosion rate. It will be re-evaluated when some experience has been gained with its use.

Table 17.5 Class limits for present wind erosion rates

Wind erosion rate class	Map symbol	Computed value of E r (t.ha .a)
None	0	< 1.0
Slow	1	1.0 - 4.9
Medium	2	5.0 - 24.9
Rapid	3	25.0 - 99.9
Extremenly rapid	4	100.0 +

18. ASSESSMENT OF THE RATE AND RISK OF SALINIZATION

Methodologies for risk assessment for soil salinity have not yet been clearly defined because of the complexity of the hydrologic and chemical conditions that are associated with this soil degradation problem. Under irrigation, however, if poor drainage and high water tables exist in soils with even moderate quantities of salt in the subsoil, or if irrigation water high in salt content is used, then salinization can be expected.

Dryland salinity, on the other hand, is far more difficult to predict because it depends on groundwater movement from adjacent or even distant recharge areas. Slight modification of surface or groundwater hydrology, may be sufficient to have an effect on the water table at some point in the landscape, and dryland salinity could result.

The procedure presented here for assessing the rate and risk of salinization is a preliminary attempt to interpret the data of the SOTER extended legend. Further modification and improvement is expected before a final methodology evolves.

In this manual it is assumed that no attempt will be made to estimate a RATE of salinization unless it has already been identified that salinity exists within the soil map polygon (see Sect. 14.3.2). This, then, presupposes that there are salts already present in the soil, and simplifies the rate assessment procedure.

The risk assessment, on the other hand, does not require that salinity should already be present in the soil. Except for this major difference, the criteria for interpreting the SOTER data are essentially the same for salinization risk assessment as for the present rate estimate.

The method of interpretation of the SOTER database proposed in this manual uses a numeric rating of the principal factors controlling soil salinization, much as was used in the methodology proposed by FAO (1979). The availability of the SOTER database, and the larger scale of mapping being used here, makes it possible to improve the sensitivity of the assessment when compared with the FAO approach. Thus the numerical ratings that are suggested are different, both in value and in variability, from the values proposed by FAO.

The rating scheme proposed herein follows the principle that if a factor is at a level such that it is likely to increase the rate or risk of salinization, it must be assigned a value greater than 1.0 - the actual value used being selected to reflect the relative importance of this factor when compared to others used in the assessment. If the factor level is such that it will probably result in a reduced rate or risk of salinization, then it must be assigned a value less than 1.0 (but greater than 0). Again, the actual value will reflect the relative importance of this factor in controlling salinization. If a factor level is such that it is unlikely to affect the rate or risk of salinization determined by other factors, then it is assigned a value of 1.0. If the factor has not been measured and must therefore be omitted from the analysis, then it can be automatically assumed to be equal to 1.0, and thus has no effect on the numerical rating established by the other factors. If a factor is at a level that PRECLUDES the development of salinity, then it can be assigned a value of 0, which when multiplied by any other factor values will result in the same zero risk of salinization.

The numerical value of the rate (RA_s) or risk (RI_s) of salinization is computed from the following equation:

$RA_s - RI_s = F, X F_2 X F_3 X \text{------}.X F_n$

where: F_n is the factor value of the nth factor considered in the assessment.

The range of possible conditions and RA_s and RI_s values have been plotted on a matrix. The likely RA_s and RI_s values associated with the classes of rate or risk (slight, moderate, etc.) used in the GLASOD assessment have been tentatively identified from this matrix.

18.1 Rate and risk of salinization of irrigated land:

Where irrigation is practiced, internal drainage and water table depth will most likely control waterlogging. Since no information is available in the SOTER database on the quality of irrigation water being used, the source of salts must initially be assumed to be the subsoil materials. If salinity is present in the subsoil, and if there is a degree of waterlogging from overirrigation or poor drainage, then there will be migration and concentration of salts in the surface soil, resulting in salinization.

Each of the factors suggested for use in the rate and risk assessment of salinity under irrigation is described below, starting with the climatic factor, then those that are stored in the SOTER Terrain Attribute database, and then those stored in the SOTER Soil Layer Attribute file. Finally, irrigation water quality is considered as a factor, although this information is not presently included in the SOTER database.

18.1.1 Climatic factor

The Moisture Availability Index (MAI) developed by Hargreaves (1972) has been proposed as an indicator of the probability of leaching or of accumulation of salts. This index is based on potential evapotranspiration estimated from solar radiation as well as temperature, and has been shown to be more reliable for use in tropical climates than indices such as Thornthwaite's P-E, that are based on temperature alone (Cochrane et al. 1985). The MAI is the ratio of "dependable precipitation" divided by potential evapotranspiration. A value of one or more indicates a condition in which there will probably be a net leaching of surface soils, and accumulation of salts is almost impossible. MAI values less than 1.0 indicate moisture deficient conditions, in which the accumulation of salts in surface soils may occur if they are present in subsoils or in irrigation water. Very low values of MAI (e.g. less than 0.34) indicate high rates of evapotranspiration, and a high probability of salinization under irrigation if drainage is poor and a source of salts is present.

MAI values for use in the GLASOD salinization rate and risk assessment will be generated for each soil map polygon from the SOTER Climate data file. The use of these MAI values in the salinization rate and risk assessment is suggested as follows:

MAI greater than 1.0 - factor value = 0
MAI 0.8 - 1.0 - " " = 1
MAI 0.5 - 0.8 - " " = 2
MAI less than 0.5 - " " = 4

Simply stated, this indicates that salinization will not occur if MAI values are greater than 1.0; at MAI values between 0.8 and 1.0 it may occur if other factors are favourable; at MAI values between 0.5 and 0.8 it is twice as likely to occur than at values between 0.8 and 1.0; and at MAI values less than 0.5 it is four times as likely when compared with areas with MAI values of 0.8 to 1.0. The choice of factor values is preliminary, and can be altered as more information becomes available.

One exception to the above set of values is necessary: when the MAI value is 1.0 or greater but salinity is already present in the soil, then it must be assumed that localized climatic variation and/or topography and/or local ground water movement has resulted in an environment in which salt may accumulate. In this situation the factor value for climate should be increased from zero to 1.0 so that the assessment can continue, considering other factors in order to assess salinization rate and risk.

18.1.2 Interpretations from the SOTER Terrain Component Attribute File

18.1.2.1 Depth to groundwater

Without continuously recorded watertable measurements it is difficult to determine depth to groundwater with much certainty. The SOTER Terrain Component database therefore requires an estimate of water table depth or mottling depth. The following factor values are suggested for salinization rate and risk assessment:

SOTER depth to groundwater AG200 - factor value = 0.5
" " " " AG100,TG100,
TL100,MG100,MG50 - " " = 1
" " " " AL100,ML50 - " " = 2

These suggested factors indicate that soils where groundwater is always greater than 200 cm, or mottling is always deeper than 100 cm, have a rate and risk of salinization of only half that expected in soils where watertables are always or often between 100 cm and 200 cm in depth, or mottling is between 50 and 100 cm deep. By contrast, soils in which the watertable is always within the upper 100 cm, or where mottling occurs at less than 50 cm depth, will be expected to have about twice the rate or risk.

The relatively narrow range of suggested factor values is intended to reflect the difficulty often encountered in estimating watertable depths accurately, especially at the small scale used in the SOTER data collection. Where data are detailed and reliable, a wider range of factors, based on local experience, can be used.

18.1.2.2. Quality of groundwater

Salt content of groundwater, measured by electrical conductivity (EC) is an indicator of salinization rate and risk, as this can be the source of salinity under irrigation. Quality of irrigation water is often unknown or the data are unavailable. Very low EC values of groundwater indicate a reduced rate or risk of salinization under irrigated conditions. The EC values are recorded in the SOTER Terrain Component file in five classes. The following are the suggested factor values to be used with these classes:

Quality of groundwater 0001 - factor value = 0.75
" " " 0250, 0750 - " " = 1
" " " 1500 - " " = 1.5
" " " 5000 - " " = 2

These factor values indicate that low salt content of groundwater will reduce the rate and risk of salinization in discharge areas or depressions, compared with higher groundwater EC values. Very high EC of groundwater will contribute to increased rate and risk of salinization, especially in irrigated downslope areas.

18.1.3 Interpretations from the SOTER Soil Layer Attribute File

18.1.3.1 Slope position

The rate and risk of soil salinization is greatly affected by the probability of groundwater reaching a depth at which migration of moisture from the watertable to the surface is possible. Slope position can be used as an indicator of this situation. Upslope positions are less likely to have high watertables, and water tends to drain away from the root zone. By contrast, soil at the base of slopes or in depressions will be more likely to be affected by groundwater discharge.

The "position on slope" recorded in the SOTER soil layer attribute file can be used in the salinization risk assessment. Suggested factors are as follows:

SOTER slope positions SUM, SHO, MID - factor value = 0.25
" " " FOO, ALL (level) - " " = 1
" " " TOE, DEP - " " = 3

Use of these suggested factor values indicates that a position from the top to the middle of a slope will reduce the rate and risk of salinization to about 25% of that of other soils in the region situated on level sites. Soils at the toe of a slope, or in a depression, will be three times more likely to develop salinity compared with level land, and twelve times more likely than soils in upslope positions. These factors can be adjusted as more information becomes available.

18.1.3.2 Electrical Conductivity

The electrical conductivity (EC) of the soil is a direct indication of its salt content. Those soils being assessed for RATE of salinization are those in which salts are already known to exist. If there is no salinity present in the soil profile, the factor value is set at zero, and the rate of salinization is automatically "none". In soils that are not saline, a RISK of salinization may still be present, and can be assessed from other factors such as quality of groundwater or irrigation water (if known).

The depth of any existing soil salinity is important in the assessment of further salinization in irrigated soils. The assignment of factor values to electrical conductivity classes according to the layer in which the highest EC occurs is therefore proposed as a method of accounting for the greater importance of shallow salinity as compared with salinity deeper in the subsoil. Two depth zones have been used, 0-50 cm and 51-100 cm. The suggested factor values for RATE of salinization under irrigation are as follows:

Highest SOTER EC class in:

Upper soil layers (0-50 cm) 01 - factor value = 0
" " " (") 02 - " " = 1.5
" " " (") 04,08 - " " = 3
" " " (") 16 - " " = 4
" " " (") 26 + - " " = 5

Lower soil layers (51-100 cm) 01,02 - " " = 0
" " " (") 04,08 - " " = 1.5
" " " (") 16 - " " = 2
" " " (") 26 + - " " = 3

When soil EC classes are known in each layer, the HIGHEST class present in the upper 50 cm AND the highest class present in the layers below 50 cm should be used as shown above to select factor values. The HIGHEST of the two factor values should then be used in the computation of RA_s for rate of salinization.

For assessment of RISK of salinization, existing soil salinity is not a prerequisite. The procedure indicated above should be used, but with different factor values for the non-saline classes as follows:

Highest SOTER EC class in:

Upper soil layers (0-50 cm) 01 - factor value = 1

Lower soil layers (51-100 cm) 01 - " " = 1
" " " (") 02 - " " = 1.5

These suggested factor values indicate that soils that are already saline will become more saline when other conditions are favorable, at a rate dependent to a large degree on the amount of salinity already present in the soil. This will also apply to the RISK of further salinization. However, while there is no RATE of salinization if the soil EC is very low the RISK of salinization can still be computed from other factors. A factor value of 1.- has therefore been used for risk assessment in soils with no present salinity.

18.1.3.3 Saturated Hydraulic Conductivity

The FAO proposed salinity risk assessment (1979) ascribes a large degree of rate dependency on soil texture. The explanation seems to lie in the use of texture as a surrogate for saturated hydraulic conductivity, drainage and electrical conductivity. In the GLASOD assessment these factors can be separated, so the apparent discrepancy between the FAO soil texture effects and the soil saturated hydraulic conductivity used here can be explained. Soil texture is not used directly in this assessment unless there is no information on saturated hydraulic conductivity, which is an optional attribute in the SOTER layer file. Soil texture is discussed below in section 18.1.3.4.

The saturated hydraulic conductivity (Ksat) classes used in the SOTER layer file can be used in the irrigation salinity rate and risk assessment as follows, where the layer chosen is that within the upper 100 cm depth that has the lowest Ksat class:

Ksat class (lowest in top 100 cm) 15.0 - factor value = 0.5
" " (" " " " ") 0.6 - " " = 1
" " (" " " " ") 0.1 - " " = 1.5

These factor values indicate that soils through which water moves rapidly will be less likely to accumulate salts than those where water movement is very slow, and leaching by irrigation water will be more easily accomplished.

18.1.3.4 Texture

Texture can be used as a general substitute for more detailed information on soil hydraulic properties. It was used in the proposed FAO methodology (1979) without specifying its role in the salinization process. It is suggested here that it be used as a substitute for saturated hydraulic conductivity only when the latter is not available. If saturated hydraulic conductivity data are available in the soil layer file, then the texture factor should be ignored. Suggested values for the classes of the Soil Layer file are as follows, with the texture used being the finest in the top 100 cm:

Texture (finest in top 100 cm) all sands - factor value = 0.5
" (" " " " ") all loams,
silt - " " = 1
" (" " " " ") all clays - " " = 1.5

This assessment is at a very generalized level, but the relationships between texture and hydraulic conductivity are affected by many other factors, such as structure. Any attempt to improve the sensitivity of this characteristic is probably not justified by the available data.

18.1.4 Irrigation Water Quality (if available)

When irrigation water quality information is available, salinity rate and risk interpretations can be made from electrical conductivity (EC) data in much the same way as have been indicated for groundwater salinity. Since this information will not be stored in the SOTER database, it is necessary to define some classes of irrigation water EC. The following classes are adapted from data reported by Israelsen and Hanson (1962), where EC is reported in decisiemens per metre (dS/m) :

EC of irrigation water < 0.1 - very low salt, mountain streams
" " " " 0.1-1.0 - good, suitable for most soils
" " " " 1.0-3.0 - poor, likely to injure some crops
" " " " > 3.0 - very poor, damages most crops and causes salinity unless special measures are taken.

As a factor in rate and risk of soil salinization, quality of irrigation water can be used in the assessment using the following factor values:

EC < 0.1 - factor value 0.5
EC 0.1-1.0 - " " 1
EC 1.0-3.0 - " " 2
EC > 3.0 - " " 5

These factor values have a greater range than those of groundwater, which reflects their greater importance as a determinant of salinization under irrigated conditions. The irrigation water quality factor should be used in addition to the factors already described, so that excellent irrigation water quality will reduce the rate and risk already determined, and poor irrigation water quality will increase the rate and risk. Where irrigation water quality is at a level that is unlikely to affect salinization rate or risk one way or the other (i.e. between 0.1 and 1.0 dS/m), the factor value will be 1.0, and the previous assessment remains unchanged.

18.1.5 Other factors affecting salinization under irrigation

The method of rate and risk assessment presented here has been developed to permit the addition of other factors if these are locally important. The class that will likely have little or no effect on rate or risk of salinization should be assigned a factor value of 1.0. Reductions and increases of rate or risk associated with all other classes can then be given values less than or greater than 1.0, respectively, in a way that reflects the importance of the factor relative to the others suggested above.

18.1.6 Interpretation of the Assessment

Matrices were developed of the RA_s and RI_s values computed from the factor values suggested above. Values of RA_s for the irrigation salinization assessment ranged from zero to 216 when irrigation water quality was not considered. If the most saline class of irrigation water was to be used, the maximum RA_s value would be 1080. This is the most exteme condition that could ever be encountered, and since the intention behind the "extremely rapid" rate class is to identify conditions under which no doubt can exist concerning the irreversible and catastrophic nature of the problem, it is suggested that the "extremely rapid" rate be limited to this one condition. A lower limit of RA_s of 1000 is therefore suggested for the "extremely rapid" rate of salinization under irrigation. This means that no rate can be considered "extremely rapid" unless irrigation water quality is known, the irrigation water quality is in the poorest class, and all of the other factors are at the levels that are most conducive to salinization.

At the other extreme, values of RA_s of 1.0 or less clearly identify situations where salinization is probably either stable or regressing. Thus this range can be selected to represent the "none" rate of salinization.

From the distribution of the remaining RA_s values in the matrix, it has been possible to define preliminary ranges of values to represent other degrees of RATE that approximate those described in the GLASOD soil degradation status assessment (see section 15.1). This was done by selecting values for the class limits so as to divide the area between the "none" rate and the "extremely rapid" rate into "slow", "medium" and "rapid", with "slow" lying approximately along the diagonal of the matrix.

It should also be noted that many of the situations that appear on the matrix are very unlikely to be seen in the field, and some may never be encountered because they are precluded by environmental factors.

The RISK assessment is closely related to the rate, but is extended to soils that are not already salinized. Values of RI_s ranged from zero to 360, or to 1800 if the most saline irrigation water is used. Using the same class limits as were suggested for the RATE provided a very similar distribution of zones on the matrix, with slightly more conditions indicating a "high" risk compared with the "rapid" rate. This appears quite acceptable, as "risk" is a more subjective concept.

The suggested ranges for values of RA_s and RI_s for each RATE and RISK class, respectively, are as follows:

Rate (RA_s)	Risk (RI_s)	Value range
None	None	0 - 1.0
Slow	Low	1.01 - 20.0
Medium	Moderate	20.01 - 100.0
Rapid	High	100.01 - 1000.0
Extremely rapid	Extreme	> 1000.0

Opportunities exist for adjusting the ranges of values chosen to represent each class of rate or risk. These adjustments will evolve as experience is gained with the application of the assessment methodology to actual databases collected in different pilot areas.

Table 18.1 presents a summary of the RA_s value matrix in the form of interpretations based on the ranges of values shown above.

18.1.7 Some examples

Example 18.1: Assume: Existing salinity is slight (EC = 3 dS/m,
SOTER class 02, in upper 50 cm; EC = 6 dS/m,
SOTER class 04, in 50-100 cm layers).

RATE of salinization is appropriate, because soil already shows slight salinity.

Soil is in a semi-arid zone; from SOTER climate file,
MAI = 0.65 - factor value = 2
From SOTER Terrain Component Attribute file,
Groundwater is shallow; depth = AL100 - " " = 2
Groundwater is non-saline; EC = 0001 - " " = 0.75
From SOTER Soil Layer Attribute file,
Slope position is toeslope; = TOE - " " = 3
SOTER EC in upper 50 cm = 02 - factor value = 1.5
SOTER EC in 50-100 cm = 04 - " " = 1.5
Lowest saturated hydraulic conductivity in any layer in the first 100 cm = 0.6
(or finest texture = loamy) - " " = 1

Without knowing the quality of irrigation water, the factor values compute to the product $RA_S = 2 \times 2 \times 0.75 \times 3 \times 1.5 \times 1 = 13.5$, which represents a SLOW rate of salinization.

If irrigation water quality is known, and if it assumed that its EC = 2 dS/m, then the irrigation water quality factor value = 3. The new $RA_S = 13.5 \times 3 = 40.5$, which is now a MEDIUM rate of salinization.

The RISK of salinization of this soil will be computed as above, since the soil is already slightly saline. The risk of further salinization is assessed as low when no information is available on irrigation water quality. With an irrigation water EC of 2 dS/m, the RISK becomes moderate.

Example 18.2 Assume: No existing salinity (EC = 1 dS/m,
SOTER class 01, in upper 50 cm; EC = 3 dS/m,
SOTER class 02, in 50-100 cm layers).

RATE of salinization is not needed, because soil is non saline.

Soil is in a sub-humid zone; from SOTER climate file,
MAI = 0.9 - factor value = 1
From SOTER Terrain Component Attribute file,
Groundwater is deep; depth = AG 100 - " " = 0.5
Groundwater salinity class = 1500 - " " = 1.5
From SOTER Soil Layer Attribute file,
Slope position is level; = ALL - " " = 1
SOTER EC in upper 50 cm is 01 - factor value = 0
SOTER EC in 50 - 100 cm is 02 - factor value = 0
Highest EC factor at any depth - factor value = 0
Lowest saturated hydraulic conductivity
in any layer in the first 100 cm = 15.0
(or finest texture = FS or "sandy") - " " = 0.5

The factor values compute to the product $RA_S = 1 \times 0.5 \times 1.5 \times 1 \times 0 \times 0.5 = 0$ which confirms that salinization is not proceeding under irrigation.

The RISK of salinization of this soil can be computed as above, except that a different factor value will be used for soil EC. With the SOTER EC class = 01 in the top 50 cm, with a factor value of 1, and class 02 between 50 and 100 cm, with a factor value of 1.5, the highest factor value for soil EC = 1.5, and the $RI_S = 1 \times 0.5 \times 1.5 \times 1 \times 1.5 \times 0.5 = 0.56$, which indicates no risk of salinization.

If irrigation water quality is known to have an EC of 2 dS/m, the factor value is 2, and the new $RI_S = 0.56 \times 2 = 1.13$, and risk is now considered to be LOW.

18.2 Rate and risk of salinization of non-irrigated land (dryland salinity):

In non-irrigated land the relative importance of groundwater quality is greater than in irrigated land, as this represents the principal source of salts. Slope position and depth to groundwater are also of relatively greater importance, as upslope dryland salinization is practically impossible and depth to watertable in downslope positions will determine the rate and risk of seepage water reaching the soil surface. On the other hand, soil saturated hydraulic conductivity has less effect on dryland than on irrigated land salinization, because overirrigation to leach salts from the profile is not an option. The principles of the assessment procedure remain the same as in irrigated land, but now land use will impact on water consumption and salinity in adjacent areas is also likely to affect the risk of dryland salinity.

18.2.1. Climatic factor

The effect of climate, by way of affecting evapotranspiration and soil moisture deficits, is similar to that seen in the irrigated land salinization assessment. Factor values for extremely dry climates have been reduced, however, for the dryland salinity assessment. This reflects the lower probability of seepage water being available for salinization in these climates, in contrast to the situation under irrigation where the source of seepage water is provided by the irrigation itself. The suggested factor values are as follows:

MAI greater than 1.0 - factor value = 0
MAI 0.8 - 1.0 - " " = 1
MAI 0.5 - 0.8 - " " = 2
MAI less than 0.5 - " " = 3

As was seen above for irrigation salinization, an exception to the above values is necessary. This occurs when a soil is already saline, yet it is in a zone where the MAI is greater than 1.0. This may be the result of local topography or groundwater conditions, or may reflect local climate variability that is not indicated by the available climatic data. Where this situation is encountered, the factor value for the MAI should be set at 1.0 instead of zero.

18.2.2 Interpretations from the SOTER Terrain Component Attribute File

18.2.2.1 Depth to Groundwater

The effect of groundwater depth is of greater importance in dryland salinization compared with irrigated land, as groundwater is now the only source of saline water from which salts can be concentrated in the soil by evapotranspiration. The factor values suggested below reflect this enhanced role of groundwater depth:

SOTER depth to groundwater AG200 - factor value = 0.1
" " " " AG100,MG100,TG100 - " " = 1
" " " " TL100,MG50 - " " = 2
" " " " AL100,ML50 - " " = 3

18.2.2.2 Quality of groundwater

In dryland salinization, salts reaching the soil surface can be transported to the site by groundwater. The factor values suggested below reflect the relative importance of groundwater quality data:

Quality of groundwater 0001 - factor value = 0.25
" " " 0250 - " " = 1
" " " 0750 - " " = 1.5
" " " 1500 - " " = 2
" " " 5000 - " " = 5

18.2.2.3 Land Use/Vegetation

In dryland agriculture there is an increased rate and risk of salinization where plant moisture consumption is less than that under natural vegetation. This tends to be the case with annual crops, so that the numerical rate computation should include a vegetation factor, -suggested factor values are as follows:

SOTER land use/vegetation class AN,HO - factor value = 1.5
" " " / " " GR,FO,
and all native vegetation classes - " " = 0.5
All other land uses - " " = 1.0

Irrigated land use classes will not apply in this assessment, so the factor value should be zero.

For RISK assessment it should be assumed that a change in land use is possible to one with a higher factor value. The factor value of 1.5 should therefore be used for land use.

18.2.3 Interpretations from the SOTER Soil Layer Attribute File

18.2.3.1 Slope position

Slope position is of paramount importance in determining the rate and risk of dryland salinity. Dryland salinity is practically impossible in summit or slope crest positions. If other conditions are conducive to salinization, then toe slopes and depressions are favored locations for dryland salinity to appear. The preliminary factor values chosen below reflect these influences:

SOTER slope positions SUM - factor value = 0
" " " SHO - " " = 0.1
" " " MID - " " = 0.25
" " " FOO,ALL - " " = 1
" " " TOE,DEP - " " = 5

18.2.3.2 Electrical Conductivity

The role of soil EC is similar in dryland salinization to that in irrigated land. The assignment of factor values to electrical conductivity classes has been done according to the layer in which the highest EC occurs to account for the greater importance of shallow salinity as compared with salinity deeper in the subsoil. Two depth zones have been used, 0-50 cm and 51-100 cm. The suggested factor values for RATE of dryland salinization are as follows:

Highest SOTER EC class in:

Upper soil layers (0-50 cm) 01 - factor value = 0
" " " (") 02 - " " = 2
" " " (") 04,08 - " " = 4
" " " (") 16 - " " = 5
" " " (") 26 + - " " = 6

Lower soil layers (51-100 cm) 01 - " " = 0
" " " (") 02 - " " = 1.5
" " " (") 04,08 - " " = 2
" " " (") 16 - " " = 3
" " " (") 26 + - " " = 4.5

When soil EC classes are known in each layer, the HIGHEST class present in the upper 50 cm AND the highest class present in the layers below 50 cm should be used as shown above to select factor values. The HIGHEST of the two factor values should then be used in the computation of RA_s for rate of dryland salinization.

For assessment of RISK of dryland salinization, existing soil salinity is not a prerequisite. The procedure indicated above should be used, but with different factor values as follows:

Highest SOTER EC class in:

Upper soil layers (0-50 cm) 01 - factor value = 1

Lower soil layers (51-100 cm) 01 - " " = 1

These suggested factor values indicate that soils that are not already saline may become saline if other conditions are favorable.

18.2.3.3 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity has little effect on dryland salinization and has therefore been omitted from this assessment.

18.2.3.4 Texture

Texture was used in the irrigation salinization assessment only as a surrogate for hydraulic conductivity, as other texture related factors are specified separately. Since hydraulic conductivity is ignored in the dryland salinization assessment, it follows that texture should also be disregarded.

18.2.4 Adjacent polygons

Where a polygon occupies a lower slope position AND salinity is present in adjacent upslope polygons, the rate and risk of salinization is increased because of salt migration in shallow groundwater. It is therefore suggested that a factor be added to the assessment to account for this as follows:

Slope position TOE, DEP and adjacent polygon with some present salinity (slight, moderate) - factor value = 1.5
Slope position TOE, DEP and adjacent polygon with severe salinity (severe, extreme) - factor value = 2
All others - factor value = 1

18.2.5 Other factors affecting dryland salinization

See Section 18.1.5, above.

18.2.6 Interpretation of the Assessment

The method followed in developing the interpretation of this assessment has been essentially the same as that described in Section 18.1.5 above. The ranges of values of RA_S and RI_S for salinization of irrigated land appear to be suitable also for dryland salinization. Further experience with the use of the assessment methodology will allow for refinement of the class ranges.

The suggested ranges for values of RAs and RIs for each RATE and RISK class, respectively, are as follows:

Rate (RAs)	Risk (RIs)	Value range
None	None	0 - 1.0
Slow	Low	1.01 - 20.0
Medium	Moderate	20.01 - 100.0
Rapid	High	100.01 - 1000.0
Extremely rapid	Extreme	> 1000.0

18.2.7 Some examples

Example 18.3*: Assume: Existing salinity is moderate (EC = 8 dS/m, SOTER class 08, in upper 50 cm; no data for lower soil layers)

RATE of salinization is appropriate, because soil already shows moderate salinity.
Soil is in a sub-humid zone: From SOTER climate file,
MAI = 0.75 - factor value = 2
From SOTER Terrain Component Attribute file,
Groundwater usually 1-2m ; depth = AG100 - " " = 1
Groundwater salinity class = 5000 - " " = 5
Land use/vegetation type = AN - " " = 1.5
From SOTER Soil Layer Attribute file,
Slope position is level; = ALL - " " = 1
SOTER EC in upper 50 cm is 08 - factor value = 4
SOTER EC in 50 -100 cm unknown " " = 1
Highest EC factor value at any depth - factor value = 4

The factor values compute to the product:

$RA_s = 2 \times 1 \times 5 \times 1.5 \times 1 \times 4 = 60$

which indicates a medium RATE of salinization.

The RISK of salinization can be computed as above:

$RI_s = 2 \times 1 \times 5 \times 1.5 \times 1 \times 4 = 60$

which indicates a moderate RISK of dryland salinization.

Example 18.4*: Assume: Existing salinity is slight (EC = 4.9 dS/m, SOTER class 04, in upper 50 cm; unknown EC below 50 cm)

RATE of salinization is appropriate, as soil is already slightly saline.

Soil is in a sub-humid zone; from SOTER climate file,
MAI = 0.75 - factor value = 2
From SOTER Terrain Component Attribute file,
Groundwater usually <1m; depth = AL100 - " " = 3
Groundwater salinity class = 0001 - " " = 0.25
Land use/vegetation native grassland - " " = 0.5
From SOTER Soil Layer Attribute file,
Slope position is depressional = DEP - " " = 5
SOTER EC in upper 50 cm = 04 - factor value = 4
SOTER EC in 50-100 cm unknown- " " = 1
Highest EC factor value at any depth - factor value = 4

The factor values compute to the product:

$RA_s = 2 \times 3 \times 0.25 \times 0.5 \times 5 \times 4 = 15.0$

which indicates a slow RATE of salinization.
The RISK of salinization can be calculated as above, except that the factor value for land use will be increased to that of annual cropland, 1.5. The new product RI_s will be:

$RI_s = 2 \times 3 \times 1.5 \times 0.5 \times 5 \times 4 = 45$

which indicates that the risk of dryland salinization in this soil is moderate.

* Note: Examples 18.3 and 18.4 are actual soils in Manitoba, Canada, data provided by courtesy of R. Eilers, Canada-Manitoba Soil Survey, Winnipeg, Manitoba.

19. RATE AND RISK OF CHEMICAL DETERIORATION DUE TO NUTRIENT LOSS

The interpretations which follow arise out of an attempt by the author and Dr. T. Cochrane (GLASOD Committee member from Bolivia) to categorize the various factors that most influence the probability of soil leaching and nutrient/chemical decline, primarily for tropical soils, and list them in a table along with their expected impact. Most of the chemical and physical processes involved have never been quantified, so the relative importance of each factor can only be estimated from limited field experience.

The provisional soil degradation assessment methodology published by FAO in 1979 identified moisture surplus, soil texture, clay type and slope as the principal determinants of soil chemical degradation. Human factors affecting land clearing and management were also recognized, but the scale of the assessment (1:5 million) did not allow for these factors to be considered. The present assessment builds on the earlier interpretations of FAO, and utilizes the SOTER database as a means of identifying significant conditions associated with the problem of decline of soil nutrient and chemical status.

The rate and risk of chemical deterioration due to nutrient loss is highly dependent on the leaching potential of the soil, and on the soil's ability to retain nutrients in a leaching environment. Intensive tillage can result in loss of organic matter and excessive nitrogen fertilizer use can lead to a decline in pH, a reducion in cation exchange capacity, and accelerated leaching of bases. Loss of organic matter will also result in deterioration of soil structure, which indirectly reduces the effectiveness of the nutrient status of the soil.

The probability of excessive soil leaching is greatly influenced by the frequency of moisture surpluses, an indication of which can be obtained from Hargreave's Moisture Availability Index (MAI). The preferential use of this index over that of Thornthwaite was discussed in Section 18 where climatic effects on salinization were considered. For salinization an annual soil moisture balance is appropriate because leaching during wet periods will often remove salt accumulated during dry seasons. However, when seasonal surpluses of soil moisture can be responsible for leaching nutrients beyond the root zone, drier periods of the year will do little to restore these nutrients to a depth where they are likely to be recycled. Thus the soil water surplus of the wet season is more appropriate for assessment of nutrient/chemical decline by leaching than is the annual water surplus.

The probability of soil nutrient loss by leaching is also greatly affected by land use. Rates can be expected to be high where existing land use is annual cropping or intensive pasture grazing and soils already have a high potential for this problem. On the other hand, if even very susceptible soils are permanently vegetated with forest or natural savanna, then the present RATE of chemical/nutrient decline is likely to be very low. The RISK, however, may remain very high because of the possibility of a change in land use. Thus it is necessary to consider risk in the context of possible changes to the existing land use, as well as with the land use continuing unchanged.

Soil factors relevant to the risk of soil leaching include texture, clay mineralogy, drainage, cation exchange capacity, pH, base saturation and Al saturation. Each of these is used in the assessment that follows when data are available. Slope and slope position have not been included because infiltration rates of many well and excessively drained tropical soils are rapid enough that even upslope soils may become highly leached.

The assessment methodology proposed here follows the same approach as that presented in Chapter 18 for the assessment of salinization. It is also similar to that used by FAO (1979). Each of the characteristics considered in the assessment is given a factor value of 1.0 when it is at a level that is unlikely to have any effect on soil leaching. When the factor is likely to increase the problem it is given a value greater than 1.0; and when it may reduce the severity of soil chemical/nutrient decline it is assigned a value less than 1.0, but greater than zero. If a factor is at a level where soil leaching and nutrient decline is precluded, it is assigned a value of zero, and the problem can be ignored regardless of the levels of the other relevant soil attributes or other characteristics. For a more detailed description of the proposed approach, see the introductory section of Chapter 18.

19.1 Rate of chemical deterioration due to nutrient loss

The determination of RATE of chemical/nutrient decline, like the rate of salinization, need only be made if the soil has already been identified as having a degree of present degradation due to loss of nutrients. If no present degradation exits, there may still be a significant RISK of degradation by this process, especially if land use and vegetation is changed. This will be discussed in section 19.2.

19.1.1 Climatic factor

The Moisture Availability Index developed by Hargreaves (1972) has been described in section 18.1.1. It will be computed for soil map polygons from the SOTER Climate Data File. Where possible, wet season values will be available. An annual estimate will always be provided.

The following factor values are suggested for MAI values, which should be either the annual mean or the highest seasonal estimate available - the wet season MAI taking precedence if it is available:

Wet season MAI greater than 2.0
or annual MAI greater than 1.5 - factor value = 3
Wet season MAI 1.51 - 2.0
or annual MAI 1.26 - 1.50 - " " = 2
Wet season MAI 1.01 - 1.5
or annual MAI 0.75 - 1.25 - " " = 1.0
Wet season MAI less than 1.0
or annual MAI less than 0.75 - " " = 0

These values indicate that leaching will not occur if MAI values are always less than 1.0. If only annual means are available, however, leaching could still be significant during the wet season, even though the mean annual MAI is less than 1.0. Because of this uncertainty, the annual MAI value below which no leaching problem is considered possible has been reduced to 0.8. At high annual or wet season MAI values the probability of leaching losses of nutrients increases markedly.

19.1.2 Interpretations from the SOTER Terrain Component Attribute File

19.1.2.1 Land Use

Soil nutrient loss seldom occurs under natural vegetation. Neither is it common when land is reforested. These land uses provide the opportunity for the recovery of leached nutrients lower in the soil profile, and their return to the surface through biomass recycling. On the other hand, annual cropping, wide-spaced plantations and similar land use will permit nutrients to leach beyond the root zone, and permanent soil depletion results. The following factor values are suggested for rate of soil nutrient loss by leaching as a function of land use as recorded in the SOTER Terrain Component Attribute file:

SOTER land use/vegetation class AN,HO - factor value = 2
" " " / " " SH - " " = 1.5
" " " / " " MI,HW,BU,PA,OR,
IC,IH,IO,PL - " " = 1.25
" " " / " " DT,QU,RO,RE - " " = 1.0
" " " / " " GR,HP - " " = 0.5
" " " / " " FO,BO,SW,CA,FT,
FG,FC - " " = 0

The factor values above can be used for RATE of soil chemical/nutrient decline by considering the existing land use. The possibility of a change in land use is discussed in the section below on RISK.

19.1.2.2. Parent Material Origin/Rock

Soil parent materials high in bases will usually mitigate against severe soil degradation by leaching and nutrient decline. On the other hand, parent materials low in bases will provide few weatherable minerals containing basic plant nutrients, and often also lead to soils with low cation exchange capacities.

The following factor values are suggested for use with the parent material origin/rock classes of the SOTER Terrain Component Attribute file:

SOTER parent material/rock class RA, TA, PA - factor value = 3
" " " / " " SN, RE - " " = 2
" " " / " " RB, TB,PB - " " = 0.75
" " " / " " MR,LI - " " = 0.5
" " " / " " All others - " " = 1.0

19.1.3. Interpretations from the SOTER Soil Layer Attribute file

19.1.3.1 Saturated Hydraulic Conductivity

The use of Ksat provides a means of estimating the rate at which water will percolate through the soil, facilitating the leaching process. The assessment should be based on the LOWEST hydraulic conductivity in the soil profile, since interruption of the leaching process in any layer will effectively reduce leaching considerably. The following factor values are suggested:

SOTER Ksat class (lowest in any layer) 15.0 - factor value = 2
" " " (" " " ") 0.6 - " " = 1
" " " (" " " ") 0.1 - " " = 0.5

Although these factors may, in some instances, reflect the same conditions that can be accounted for by the soil texture class, there are significant exceptions. Strongly structured clay soils with high permeabilities are often encountered in residual soils of tropical regions, and these can have high leaching potential. The use of a saturated hydraulic conductivity factor in such situations will help to correct for any incorrect interpretations that would arise from use of texture alone.

19.1.3.2 Soil Texture (If hydraulic conductivity not available)

Soil texture was used in the proposed FAO (1979) assessment as an indicator of several soil characteristics that are important in soil leaching i.e. hydraulic conductivity, cation exchange capacity, base saturation, etc. In this assessment these attributes are considered independently wherever data are available. However, since saturated hydraulic conductivity is only an optional SOTER soil layer file attribute, soil texture has been included here to provide a surrogate characteristic for use when Ksat data are not available. The factor values suggested below are the same as those used in the proposed FAO methodology (1979):

SOTER texture classes: All SANDS - factor value = 2
" " " All LOAMS, SILT - " " = 1
" " " All CLAYS - " " = 0.5

The SOTER layer file provides many different classes of texture, but the groupings above can be used as a guide. The layer with the LOWEST factor value anywhere in the soil profile should be used in this assessment.

19.1.3.3 Clay Mineralogy

Clay mineralogy is an important determinant of soil nutrient status, exchange capacities, and content of weatherable minerals. Clay mineralogy information is available in the SOTER data file by layer, but is only an optional characteristic. It is suggested that the mineralogy factor be determined from the layer having the mineralogy that is least susceptible to nutrient leaching, since this layer will tend to control the rate of nutrient loss from the soil profile. The mineralogy with the lowest factor value will be that which is least susceptible to leaching losses. Suggested factor values are presented below:

SOTER clay mineralogy class OXID - factor value = 5
" " " " KAOL - " " = 4
" " " " MIXE,MONT,ILLI,
VERM,ALLO - " " = 1

" " " " CHLO,GYPS,CARB - " " = 0.5

The factor values suggested above reflect the very poor nutrient and cation exchange status of oxidic and kaolinitic clays, compared with the relatively unweathered chlorite clays and the calcium saturated gypsic and carbonatious materials.

19.1.3.4 Calcium carbonate equivalent

Another indicator of the presence of bases to buffer the deterioration of soil quality by excessive leaching of nutrients is the calcium carbonate equivalent. Where soils have a high calcium carbonate equivalent content, there is practically no likelihood of chemical deterioration as a result of leaching in the short term. Like clay mineralogy, this attribute is optional in the soil layer file. The following factor values are suggested:

SOTER calcium carbonate equiv. P15,P40, S40 - factor value = 0.25
" " " " P01,P06,S15 S06 - " " = 1
" " " " P00,S00,S01 - " " = 3

Note that the calcium carbonate equivalent is a quantitative measurement, compared with the clay mineralogy which is only qualitative. This allows the use of a lower factor value in cases where high CaCO3 equivalent is present compared, for example, with that used for carbonitic mineralogy.

19.1.3.5 Diagnostic horizon/feature

Since clay mineralogy and calcium carbonate equivalent are only optional attributes of the SOTER Soil Layer file, it is proposed that the diagnostic horizon, which is mandatory, should be used as a substitute when either of these attributes is not available. The following factor values can be used with the diagnostic horizon information:

SOTER diagnostic horizon OXIC - factor value = 3
" " " NATR,CALC,GYPS - " " = 0.25
" " " GLEY - " " = 0
" " " All others - " " = 1

As noted above for calcium carbonate equivalent, the diagnostic horizons are more quantitative than the clay mineralogy classes. It is therefore possible to use a lower factor value where gypsic diagnostic horizons are present than where the mineralogy is only known to be gypsic. In this assessment it is assumed that a gleyed soil has no potential for nutrient losses by leaching, since drainage is clearly impeded.

19.1.3.5 Cation Exchange Capacity (CEC-total)

Soils high in CEC will lose nutrients by leaching at a slower rate than those in which CEC is low. The content of exchangeable bases will also be higher, even when base saturation is low. The following factor values are suggested for CEC. They should be applied to the highest CEC at any depth below the topsoil or plow-layer. Once leached beyond the topsoil, basic cations may be retained by a layer of higher CEC in the subsoil.

SOTER Total CEC class 01 - factor value = 4
" " " " 03 - " " = 2
" " " " 06 - " " = 1.5
" " " " 13 - " " = 1
" " " " 30 - " " = 0.5
" " " " 36 - " " = 0

These factor values indicate that a soil with a very high CEC can retain enough bases, even at low base saturation, that soil depletion can be essentially ignored. At very low CEC, losses of bases will be rapid if conditions conducive to leaching are present.

19.1.3.6 Aluminum Saturation

This attribute indicates the percentage of the cation exchange capacity of the soil that is occupied by aluminum. The balance of the CEC is occupied by H and basic cations. Soils with high Al saturation are usually acid, but Al saturation can be a superior parameter for indicating base leaching potential than pH. If the aluminum saturation is high, a soil poorly provided with weatherable basic minerals is indicated, with an elevated content of iron and aluminum oxides and soluble aluminum. The exchangeable aluminum competes with basic cations for retention by the soil's exchange capacity, with the result that leaching of these bases is accelerated.

The following factor values are suggested for use with the SOTER Al saturation classes, and can be applied to the layer with the the lowest Al saturation in the soil regardless of depth within the upper 1 m:

SOTER Al Saturation class 01 - factor value = 0.5
" " " " 10 - " " = 1
" " " " 50 - " " = 2
" " " " 75 - " " = 4

19.2 Risk of chemical deterioration due to nutrient loss

The assessment of the RISK of soil degradation by nutrient leaching is essentially the same as that indicated above for the rate, with the exception that a possible future risk can be assessed if the present land use is one that is less detrimental to this form of soil degradation than annual cropland. Annual cropland generally places the ultimate degree of stress on land, excepting the total destruction that occurs if the land is mined or urbanized. Land that is presently under its natural vegetation is considered here not to be at risk of degradation by nutrient loss.

It is proposed that a "present risk" of soil nutrient loss should be determined using the factor value of the present land use in the computation of RI_n, the product of the factor values for risk assessment. A "future risk" of soil nutrient loss should then be assessed using the factor value for annual cropland, to determine the impact of removing the present vegetation to change the land use into a more intensive form of agriculture.

19.3. Interpretations of the Assessment

As was done with the salinization assessment, a matrix was prepared that allowed all of the factors discussed above to be combined into a display of RA_n values. From examination of these values a set of class ranges has been selected for rates of chemical/nutrient loss in classes of none, slow, medium, rapid and extreme. These are only tentative, and experience gained in applying the assessment to soils in the pilot project areas will be used to redefine these classes where necessary, or to re-evaluate the factor values suggested in the sections above.

The tentative class ranges of RA_n values for rate of chemical/ nutrient decline are as follows:

None - RA_n= 1.0 or less
Slow - RA_n= 1.01 - 50
Medium - RA_n= 50.01 - 500
Rapid - RA_n= 500.01 - 5000
Extremely rapid - RA_ngreater than 5000

The matrix developed for the various combinations of RA_nvalues is very complex, and difficult to present in a two-dimentional table. The following examples, however, will serve to demonstrate the principles of the assessment.

19.4 Some examples

Example 19.1: Assume: Oxisol, humid tropics, used for native forest, with the following characteristics:

From SOTER Climate file,
Annual MAI = 1.4 - factor value = 2
Wet season MAI = 2.2 - " " = 3
Highest MAI factor value = 3
From SOTER Terrain Component Attribute file,
Present land use native forest- " " = 0
Parent material/rock residuum - " " = 2
From SOTER Soil Layer attribute file,
Lowest Ksat, top 100cm = 15
(or finest texture is clayey) - factor value = 2
Least restrictive clay mineralogy
in top 100 cm is OXID - factor value = 5
Highest CaCO3 equiv. = P00,S00- " " = 3
(or least restrictive
diagnostic horizon is OXIC - factor value = 3)
Highest CEC, top 100 cm = 2 - " " = 4

Lowest Al sat, top 100 cm = 75 - " " = 4

From the above factor values, the RAn can be computed as:

RA_n= 3 x 0 x 2 x 2 x 5 x 3 x 4 x 4 = 0

The interpretation is that there is no present deterioration by nutrient loss, because the soil is under its natural vegetation, and no "present risk" as long as the land use does not change.

For "future" RISK assessment, the land use/vegetation class should be set at the level associated with the highest future risk (i.e. annual crops or horticulture), so the RISK assessment value, RI_n, is computed as follows:

RIn = 3 x 2 x 2 x 2 x 5 x 3 x 4 x 4 = 5760

The interpretation is that the RISK of soil deterioration by nutrient loss is extreme (only one condition worse than this, if parent rock were acid).

Example 19.2: Assume: Ultisol in S.E. USA (e.g. Cecil sandy loam), used for annual crops.

From SOTER Climate file,
annual MAI = 0.9 - factor value = 1
wet season MAI = 1.2 - " " = 1
Highest MAI factor value = 1
From SOTER Terrain Component Attribute file,
Present land use = AN - " " = 2
Parent material/rock = RE - " " = 2
From SOTER Soil Layer Attribute file,
Lowest Ksat, top 100 cm = unknown
Finest texture class is loamy - factor value = 1
Least restrictive clay mineralogy
in top 100 cm is KAOL - " " = 4
Highest CaCO3 = P01,S06 - " " = 1
Highest CEC in 100 cm = 03 - " " = 1.5
Lowest Al sat, top 100 cm = 10 - " " = 1

From the above factors values, the RAn can be computed as:

RAn = 1 x 2 x 2 x 1 x 1x 4 x 1.5 x 1 = 24

The interpretation is that the RATE of deterioration by nutrient loss is slow.

In this case the land use/vegetation type is already at the level associated with the highest future risk, so the present and future RISK assessment value, RI_n is also 24, and is interpreted as low.

Example 19.3: Assume: Regina Clay Plains, Canadian Prairies

From SOTER Climate file,
Annual MAI = 0.7 - factor value = 0
Wet season MAI = 1.1 - factor value = 1
Highest factor value = 1
From SOTER Terrain Component Attribute file,
Present land use = AN - factor value = 2
Parent material/rock = LA - " " = 1
From SOTER Soil Layer Attribute file,
Lowest K sat, top 100 cm = 0.1- " " = 0.5
(or finest texture is clayey - " " = 0.5)
Least restrictive clay mineralogy
in top 100 cm is MIXE - " " = 1
Highest CaCO3 = P15,S40 - " " = 0.25
Highest CEC, top 100cm = 30 - " " = 0.5
Lowest Al sat, top 100 cm = 01 - " " = 0.5

From the above factor values, the RAn can be computed as:

RAn = 1 x 2 x 1 x 0.5 x 1 x 0.5 x 0.5 = 0.25

The interpretation is that the is no deterioration due to nutrient loss in this soil.

In this case the land use/vegetation type is already at the level associated with the highest future risk, so the RISK assessment value, RI_n, is also 0.25, and there is therefore no present or future risk of soil deterioration by nutrient leaching loss from this soil.

20. RATE AND RISK OF SODICATION

Sodication (alkalinization) is usually a very slow process. The principle that there cannot be a RATE of sodication unless there is already a degree of soil degradation by sodium salts can be applied in the same way as is done for salinization. RISK of sodication is not precluded by a lack of present sodic conditions, but the likelihood is relatively remote unless irrigation water high in sodium is used.

Sodication can occur under a wide range of climatic conditions, although it is most likely in regions with net soil moisture deficits. However, the presence of a source of sodium, or an imbalance of sodium compared with other cations, is a requisite condition.

The approach used here to identify various degrees of rate and risk of sodication is similar to that used for salinization and chemical/nutrient loss. The introduction to Section 18 (p. 18.1 - 18.2) should be consulted for an explanation of the method of application.

When sodic conditions are already present in the soil, the rate and risk of further sodication can be fairly independent of climatic conditions. Two processes are possible: 1 - salinization in the presence of salts high in sodium, leading to a saline-sodic soil; and 2 - leaching of salts from a saline soil so that the exchangeable sodium percentage (ESP) increases, and the soil becomes sodic.

20.1 Rate and risk of sodication of saline irrigated land.

20.1.1 Rate and risk of sodication when irrigation water quality is not known

Sodication of saline irrigated land may occur as a result of high sodium contents or percentages in the soils, as a result of improved drainage or increased leaching rates in saline-sodic soils, or as a result of irrigating with water having a high sodium content. For the RATE assessment, it is necessary that the soil not only have existing sodic conditions, but it must also be saline (saline-sodic soils).

The assessment procedure used in Section 18 can be applied in exactly the same way, but the additional effect of the exchangeable sodium percentage (ESP) must also be considered. This is a mandatory attribute of the SOTER soil layer file.

The suggested factor values are as follows:

SOTER ESP class 01 in top 50 cm - factor value = 0
" " " 09 " " " " - " " = 0.5
" " " 16 " " " " - " " = 1
" " " 26 " " " " - " " = 1.25
" " " 40 " " " " - " " = 1.5
" " " 01 " 50-100 cm - " " = 0
" " " 09 " " " " " - " " = 0.25
" " " 16 " " " " " - " " = 0.5
" " " 26 " " " " " - " " = 0.75
" " " 40 " " " " " - " " = 1

Where different factor values are obtained from soil layers in the upper 50 cm and those in the 50-100 cm depths, the higher of the two factor values should be used.

With the factor values suggested above it is apparent that a soil with an ESP of 16% in the top 50 cm, or 40 or more in the 50-100 cm depths, is expected to become saline/sodic at the same rate that it becomes saline. On the other hand, if the ESP of the upper layers is very high, the sodication rate may be faster than the salinization rate. If the ESP is low, i.e. below 9% throughout the profile, there should be no sodication as salinization progresses.

Soils that contain gypsum are unlikely to become sodic. The following factor values are suggested to account for this:

SOTER gypsum class 01 in top 50 cm - factor value = 1.0
" " " 03 " " " " - " " = 0.5
" " " 06+ " " " " - " " = 0
" " " 01 " 50-100 " - " " = 1.0
" " " 03 " " " " " - " " = 0.75
" " " 06 " " " " " - " " = 0.5
" " " 10+ " " " " " - " " = 0.25

The lowest gypsum factor in either of the soil depth zones should be chosen. Gypsum at depths greater than 50 cm may not be able to mitigate against sodication at the surface, so that the factor value is not zero unless gypsum is also present in the surface layers.

The ESP and gypsum factor values should be multiplied by the factor products RA_s and RI_s, obtained in the salinization rate and risk assessment, to obtain new products RA_a and RI_a, which are the factor products for rate and risk of sodication, respectively.

An exception has to be made, however, for soils that are saline but RA_s or RI_s values are low, indicating low or no salinization rate or risk, respectively. Under these circumstances it is not correct to assume that because the salinization rate or risk is low there cannot be sodication. To allow for this, it is suggested that the minimum RA_s and RI_s values that should be used in the sodication assessment is 20.0. In this way, if ESP and gypsum conditions are conducive to sodication, then soils that are considered to have salinization rates or risks that are low or zero can still be assessed at low, or even medium, sodication rate or risk, since RA_a and RI_a values can now range from 0 to 30 in these soils.

After making the adjustment for low salinization rate and risk discussed above, the same class limits can be used for RA_a and RI_a as were used in Section 18.2.6 for RA_s and RI_s. The rate of sodication under saline irrigated conditions can then be estimated as none, slow, medium, rapid and extremely rapid; the risk can be assessed as none, low, moderate, high and extreme.

20.1.2 Rate and risk of sodication in saline irrigated soils when sodium content of irrigation water is known

When data are available on irrigation water quality such that the sodium percentage is known or can be calculated (not part of SOTER data file), it is possible to further refine the sodication rate and risk assessment.

Irrigation water can be roughly divided into 3 classes based on the percentage of the dissolved cations that are sodium. If sodium is less than 40% of the dissolved cation content, then sodication from this source alone is unlikely. If it is greater than 75%, then sodication is probable.

As a simple adjustment to the assessment obtained in Section 20.1, it is suggested that the sodication rate and risk should be raised by one class if the irrigation water sodium percentage is 75 or more, and lowered by one class if it is less than 40%. Where irrigation water has between 40 and 75% sodium, the assessments will remain unchanged.

20.1.3 Rate and risk of sodication in irrigated saline-sodic soils when drainage is improved

An improvement in drainage, and consequent increase in leaching rates, may result in new or enhanced sodication if gypsum ammendments are not used. Any assessment of these situations using the SOTER database is practically impossible. However, the seriousness of such a condition is great enough to justify a separate intervention, on the part of those applying the GLASOD assessment, to draw attention to the rapid rate, or high risk, of sodication that may result if it occurs. Since these assessments cannot be done following a prescribed procedure, it is left to those responsible for the application of the GLASOD to assign a "rapid" rate, or "high" risk, of sodication to irrigated saline-sodic soils that are known to be in the process of being drained, but where gypsum ammendments are not being used.

20.2 Rate and risk of sodication in irrigated non-saline soils

Sodication is possible in soils that, because they have low EC values (see Section 14.3.3), are considered non-saline. For a RATE assessment to be made, however, it is necessary that the soil is already considered sodic (see Section 14.4.1.3).

Further sodication can be caused by fluctuating high watertables, by an improvement in drainage conditions that results in a markedly lower watertable, or by the use of poor quality irrigation water. The only factor among these that is recorded in the SOTER database is depth to groundwater.

It is suggested that if a sodic soil has a SOTER depth to groundwater that is always less than 100 cm (AL100), then the rate of sodication should be considered as "slow". For all other depths to groundwater, the rate and risk of sodication should be considered "medium" and "moderate", respectively.

When irrigation water quality is known, sodium percentages less than 40% should reduce the rate and risk by one class, and greater than 75% should increase the rate by one class, as was suggested for irrigated saline-sodic soils.

Known changes to drainage should be handled as suggested above (Section 20.1.3). If irrigated sodic soils are drained and no provision is made for gypsum treatments, then the rate and risk of sodication should be flagged as "rapid" and "high", respectively.

The RISK of sodication in irrigated soils that are not presently sodic is dependent primarily on the quality of irrigation water. The SOTER database does not distinguish between soils with ESP values less than 9%, and so low risks of sodication cannot be readily determined. It must be assumed, then, that where soils are non-sodic and irrigation water quality is not known, that there is a "low" risk of sodication. When irrigation water is known to contain sodium percentages of 40-75%, the sodication risk in non-sodic soils can also be assumed to be "low" (but not zero), and if it is 75% or more, the risk can be described as "moderate". Only where irrigation water is known to have less than 40% sodium can the risk be considered as "none". Since large areas of the world are irrigated successfully with no risk of sodication, it may be possible in many situations to assume that the irrigation water has less than 40% sodium, and then the risk can be assessed as "none".

20.3 Sodication of dryland (non-irrigated) soils.

Sodic soils are often encountered in non-irrigated soils in the presence of salinity, i.e. saline-sodic soils. They can also be found without associated salinity - sodic or "alkali" soils. In either case the sodic nature is expressed through ESP values exceeding 9%, and pH values exceeding 8.4.

The rate and risk of saline-sodic soils developing under non-irrigated conditions can be estimated in the same way as presented in Section 18.2. for dryland salinity, and Section 20.1 above for sodication of irrigated soils. The factor values used in Section 20.1 for SOTER ESP classes and gypsum classes can be multiplied by the RA_s and RI_s values computed for dryland salinity. In other words, the rate and risk of salinization can be estimated as before, and then the results adjusted according to the presence of sodium (ESP) which may lead to sodication, or of gypsum that will mitigate against sodication.

As with irrigated saline-sodic soils, any drainage improvements without gypsum ammendments should be flagged as possible sites with "medium" or "moderate" sodication rates and risks, respectively.

In the absence of salinity and irrigation water the processes involved in sodication are essentially natural, very slow, and more difficult to assess. It is probably beyond the scope of the GLASOD study to attempt an assessment of the rate and risk of sodication in dryland soils. In the absence of irrigation or drainage works, the effect of human intervention is very small, and natural processes are not part of the GLASOD mandate.

20.4 References

Broughton, R.S. (Ed.) 1984. Subsurface drainage design analysis, Mardan Salinity Control and Reclamation Project. Pakistan Water and Power Development Authority, Harza/Nespak, Canadian International Development Agency, Lahore, Pakistan, 224 pp.

Cairnes, R.R. and Bowser, W.E. 1977. Solonetzic soils and their management. Agriculture Canada, Pub. 1391, 37 pp.

Food and Agriculture Organization for the United Nations. 1979. A provisional methodology for soil degradation assessment. FAO, Rome, 84 pp.

Holm, H.M. and Henry, J.L. 1982. Understanding salt-affected soils. Saskatchewan Agriculture, Regina, Sask., 14pp.

Israelsen, O.W. and Hanson, V.E. 1962. Irrigation Principles and Practices. 3rd Ed., John Wiley and Sons.

Russell, E.W. 1961. Soil Conditions and Plant Growth. 9th Ed., Longmans, Green and Co., London.

21. CLIMATE DATA ANALYSIS FOR DEGRADATION ASSESSMENT

The SOTER data files that make up the extended legend for the soil maps include two CLIMATE DATA FILES. The contents of these files are derived from climate stations in the region covered by the map sheet. Data for individual soil map polygons will be interpolated from the network of climate stations surrounding each polygon. Estimates of 21 climatic elements will be available through this procedure for each soil map polygon. The following sections describe the computations and interpretations using these data that are necessary for the soil degradation rate and risk assessments of chapters 16 - 20 to be made.

21.1 Climate data analysis for assessment of rate and risk of water erosion

21.1.1 Rainfall/runoff erosivity estimate (R_t):

The rainfall/runoff erosivity estimate is critical to the entire USLE analysis. It is therefore important that the best estimates possible should be used, and that an effort be made to correlate values of R_t with other regions, countries and continents. R_t is the sum of the seasonal R values, usually an R value for seasons with rainfall and no snow, and on R_s value for seasons with snow or a mixture of rain and snow: $R_t = R + R_s$. In regions with no distinct winter period, R_t= annual R.

The most reliable method of computation of R is that developed by Wischmeier and Smith (1978). However, it is very time-consuming, and has data requirements that are not always possible to meet. This may be especially true in developing countries that do not have an intensive rainfall intensity monitoring network in place.

The approach which will be presented in this manual provides the user with a set of alternative methods for calculation of R, starting with the prefered method and continuing in descending order of reliability. It is recommended that the user apply the best method for which data are available. It is also recommended that data for at least one climate station in each map sheet area be analysed using the prefered method of Wischmeier and Smith, so as to provide a means of calibrating estimates obtained by other methods to an international standard reference. This will provide for global compatibility among the maps. If more than one site in each map sheet area can be analysed using this most detailed method, improved consistency of the overall water erosion assessment will result.

It is essential that a pattern of variability of R_t within the map area is established. Once the area is linked to other regions of the globe through the R_t it is possible to estimate local (within-map) variation through a simpler methodology that will depend mainly on the availability of climate data within the map area. The choice of method is limited by the data set that is being compiled for the SOTER climate files, as well as by the completeness of that data set. The order of the methods presented below reflects the degree of detail of the required input data:

1 - The detailed method of Wischmeier and Smith (1978)
2 - The method of Bols (1978)
3 - The method of Arnoldus (1977)
4 - The method of Ateshian (1974) with intensity estimated by the method of Hargreaves (1981)

Although the order presented above reflects the detail of data needed for the method to be used, it does not necessarily reflect the reliability of the results (see Section 21.1.1.2.4).

21.1.1.1 Computation of R by the detailed method of Wischmeier and Smith

This procedure requires the assembly of detailed rainfall records for a minimum of 10 years (if data available). Each rainfall event must be broken down into periods of approximately equal intensity. A rainfall energy value is then selected from a table (see Table 21.1) and multiplied by the rainfall of the period; these products are accumulated for the entire rainfall event. The event total is then multiplied by the maximum 30-minute intensity of the event to obtain an estimate of the erosivity of the event (EI). The EIs of each rainfall event throughout the 10 year period are accumulated, then divided by 10 (or by the total number of years if other than 10 are used) and an average annual EI total is obtained. These values, after they have been modified to meet local requirements, are referred to as 'R' and serve as a basis for global comparison. The principal local modification needed will be to take snow-melt into account in those areas where a significant amount (>5%) of the annual precipitation is in the form of snow.

Values of EI for each month (or season if distinct seasonal vegetation patterns are known) should be accumulated separately, then divided by 10 (or by the total number of years if other than 10 are used) to obtain an average EI value for each month (or season). These values should be expressed as a frequency distribution with the mean for the month (or season) divided by the annual mean so that the proportion of the total that occurs in each month (or season) is given. These proportions will be important for the estimation of vegetation cover effects on erosion risk (see section 16.2.2).

21.1.1.1.1 Separation of periods of equal intensity:

The raingauge chart should be divided into segments (or periods) of approximately equal intensity, and the time recorded at the beginning and end of each segment. The length of time (duration) of each segment (in hours), and the precipitation amount (in mm), should be recorded and the intensity in mm/hr determined.

21.1.1.1.2. Determination of storm energy:

Table 21.1 should be used to estimate the energy of each intensity (as kilo joules/ha.mm of rain). This energy values should be multiplied by the mm of rainfall in each segment. The total of these products is the total energy of the storm.

Table 21.1 Kinetic energy of rainfall per mm of rain for intensities up to 76 mm/h (kJ/ha.mm rain)

Intensity (mm/h) tens	units 0	1	2	3	4	5	6	7	8	9
0	0	119	145	160	172	180	187	193	198	202
1	206	210	213	216	219	221	223	226	228	230
2	232	234	236	237	239	241	242	244	245	246
3	248	249	250	251	253	254	255	256	257	258
4	259	260	261	262	263	263	264	265	266	267
5	268	268	269	270	270	271	272	272	272	273
6	274	274	275	275	276	277	277	278	278	279
7	280	280	281	282	282	283				

21.1.1.1.3 Determination of storm EI:

Review the records of intensity for each segment of the storm raingauge chart and select that 30-minute period with the highest overall intensity. The total energy of the storm should then be multiplied by this maximum 30-min intensity (mm/hr) to obtain the total storm EI.

21.1.1.1.4 Determination of monthly (or seasonal) EI and R:

The values of EI should be accumulated in intervals of 1 month (or other seasonal periods as defined in section 16.2.1.). Average annual and average monthly (or seasonal) EI values should be determined for the period of record (minimum of 10 years). The average annual EI value is now the value of R.

21.1.1.2 Computation of R values by alternative methods

With the following methods of estimating R, every effort must be made to compare these estimates with the values obtained by the detailed method (Section 21.1.1.1). If the detailed R calculation can be made at one or more climate stations within a map sheet, then any alternative method given below, which is chosen because of lack of data at other climate stations, should also be carried out at the detailed station. This will provide a means of calibrating the alternative estimates. The difference between the detailed method and the alternative estimate (+ or -) should be added to all of the alternative estimates using the same method on the same map sheet. This will help provide consistency between map sheets, and contribute towards a comparable global assessment.

If it is possible to complete a detailed R computation as outlined above for several stations on the map sheet, with corresponding values estimated by the alternative methods, then a regression relationship may be obtained. This will provide a better estimate of the true R value at any site for which only an alternative estimate is possible, than that obtained by adding (or subtracting) an equal amount to (or from) the alternative estimate.

21.1.1.2.1 Alternative 1: Estimation of R using the method of Bols (1978)

R can be estimated (R_b) from the method developed for use in Indonesia by Bols (1978). Bols' equation is as follows:

$$R_b = R_j\sum_{j=1}^{12} = 6.119(P_j)^{1.21} (D_j)^{-0.47} (P_{max})^{0.53} \qquad (21.1)$$

where: R_j = mean R factor for month j(metric units)
P_j = mean precipitation for month j (in cm)
D_j = average number of rain days in month j
P_{max} = mean maximum precipitation in 24 hrs in month j(mm)

P_j, D_j, and P_{max} will all be available in the SOTER Climate Files.

This method has provided a good correlation with Wischmeier and Smith's method. Bols (1978) obtained a value of r^2 of 0.995 using 47 climate stations with 38 years of data each, and comparing 564 mean monthly computed EI values with the corresponding R_j values computed with eq. 21.1.

21.1.1.2.2 Alternative 2: Method of Arnoldus (Arnoldus 1977; FAO 1979)

This estimate of R is derived from an index calculated from the sum of the squares of the monthly precipitation amounts divided by the total annual precipitation (Arnoldus 1977):

$$R_a = \sum_{i=1}^{n} P_i^2/P \qquad (21.2)$$

where R_a = R factor index(dimensionless)
P_i = precipitation for month i(mm)
P = total precipitation for year(mm)
n = number of months

The relationships between R_a and R should be established locally if possible. R_a and R values for the detailed site(s) for the map area, and for detailed sites in adjacent map areas, should be used to prepare a "rating curve" for R_a vs R. A minimum of two detailed sites (i.e. those having rainfall intensity data) are required, but a greater number is desirable. From these "rating curves", R values can be estimated for each site on the map area for which mean monthly precipitation data are available.

If even this proves impossible, a relationship could be substituted for R_a and R from 178 USA and West Africa sites (Arnoldus 1977) as follows:

$$\log R = 1.9 \log R_a - 1.5 \qquad (21.3)$$

21.1.1.2.3 Alternative 3: Method of Hargreaves (1981) applied to Ateshian's Equation (partly suggested by Cochrane, pers.comm.).

A third alternative method to compute R is proposed that utilizes two equations of Hargreaves(1981) to estimate rainfall intensity for any return period using data usually available in most countries. The rainfall intensity estimates may then be applied to other prediction equations, such as that of Atesian (1974) and Wischmeier and Smith(1978) presented in equation 21.4:

$$R_h = 0.417\, P_{2,6}^{2.17} \qquad (21.4)$$

where $P_{2,6}$ is the expected 2-yr, 6-hr rainfall (mm), and R_h is in metric units. Hargreaves first equation can be written:

$$P_{T,t} = kT^{1/6} . t^{1/4} \qquad (21.5)$$

where: $P_{T,t}$ = rainfall (mm) for return period T and duration t
T = return period (in years)
t = duration of rainfall (in hrs)
k = a constant estimated from the 10 yr, 24 hr. rainfall ($P_{10,24}$)

To estimate k for a given location, a second equation is used to estimate $P_{10,24}$ as follows:

$$P_{10,24} = 22 + 0.3\ (a + b\bar{P}) \qquad (21.6)$$

where

$\bar{P}$ = mean monthly rainfall amount (30 yr. mean if possible) in mm (from mean annual rainfall divided by 12), and a and b are constants for given locations (see Table 21.2).

When $P_{10,24}$ from equation 21.6 is substituted in equation 21.5:

$$k = \frac{22 + 0.3\ (a + b\bar{P})}{3.25} \qquad (21.7)$$

Table 21.2 Values of the coefficients a and b for use in equations 21.6 - 21.9 (from Hargreaves, 1981).

Country	Coefficients	
	a	b
Albania	121	1.70
Argentina	109	1.52
Austria	26	2.01
Bangladesh	241	1.29
Brazil	146	1.27
Belgium	24	2.63
Bulgaria	7	2.22
Canada	18	1.97
Chad	46	1.49
Congo Republic	82	1.45
Czechoslovakia	19	1.93
Dahomey	95	1.31
Denmark	31	1.78
Dominican Republic	74	2.16
Ecuador	-14	2.17
France	16	2.38
Germany	16	2.12
Ghana	21	1.96
Greece	19	2.25
Hungary	48	1.71
Iceland	16	2.21
India	155	1.73
Ireland	-6	1.97
Italy	43	2.11
Ivory Coast	94	1.69
Japan	97	1.69
Korea	-35	3.04
Malagasy	95	2.19
Mali	78	1.50
Mauritius	5	2.22
Mexico	112	1.87
Mozambique	16	2.75
Netherlands	-2	2.31
New Zealand	91	1.59
Niger	-70	2.39
Nigeria	112	1.28
Norway	-11	2.51
Pakistan	71	2.08
Philippines	40	2.11
Portugal	18	2.70
Romania	43	1.70
Senegal	-2	1.61
Sierra Leone	-21	1.75
South Africa	109	1.50
Spain	5	2.96
Sri Lanka	158	1.79
Sudan	131	1.11
Sweden	13	2.13
Switzerland	74	1.75
Taiwan	-43	3.21
Tanzania	91	1.57
Thailand	159	1.17
Togo	113	1.32
Turkey	27	2.25
Uganda	136	1.13
United Kingdom	-23	2.47
United States	76	1.75
Upper Volta	28	1.71
Uruguay	-178	5.13
Yugoslovia	13	2.12
Zambia	129	1.26

So for $P_{2,6}$ in equation 21.4, an estimate based on mean monthly rainfall ($\overline{P}$) can be made from equation 21.5 and 21.7 as follows:

$$P_{2,6} = k \cdot 2^{1/6} \, 6^{1/4} = \frac{22 + 0.3(a + b\overline{P})}{3.25} \times 1.7567$$

$$= 11.9 + 0.162(a + b\,\overline{P}) \qquad (21.8)$$

Equation 21.4 can now be written:

$$R_h = 0.417\,(\,11.9 + 0.162(a + b\overline{P}))^{2.17} \qquad (21.9)$$

21.1.1.2.4 Comparison of the alternative methods of computing R

The three alternative methods of estimating R have been tested against R values computed by the Wischmeier and Smith (1978) method. Alternative 1 (Bols) was compared with R values at 32 climate stations (16 stations in Canada, 8 in the U.S., 5 in Argentina, 2 in Mexico and 1 in Uruguay). The results showed that the best fit of Bols R (R_b) to Wischmeier's R was a power function as follows:

$$R = 0.024\,R_b^{1.45} \quad r^2 = 0.64^{**} \qquad (21.10)$$

The best-fit linear relationship was almost as good a fit:

$$R = 1.28R_b - 1042 \quad r^2 = 0.63^{**} \qquad (21.11)$$

Alternatives 2 (Arnoldus) and 3 (Hargreaves/Ateshian) were tested with data from the same 32 stations used for the Bols method, plus one additional station in Argentina and 4 in Uruguay, for a total of 37 stations. The results were better for the Hargreaves/Ateshian method (R_n) than for the Arnoldus method (R_a), but neither gave results as good as the Bols method (Alternative 1). The best fit relationship for the Hargreaves/Ateshian method was a linear relationship between R_h and R was as follows:

$$R = 2.63R_a - 1545 \quad r^2 = 0.54^{*} \qquad (21.12)$$

For the Arnoldus method (Alternative 2), the best fit between R_a and Wischmeier's R was a power function:

$$R = 9.4 \times 10^{-7}\,R_a^3 \quad r^2 = 0.36^{*} \qquad (21.13)$$

and the best linear relationship was:

$$R = 5.88\,R_a - 5053 \quad r^2 = 0.33^{*} \qquad (21.14)$$

These results show that the Bols method provided the best estimate of R, but that even this method needed to be corrected through use of a "rating curve" such that shown in equations 21.10 and 21.11. However, the data are not always available for this method to be used. In this case, it would appear that the Hargreaves/Ateshian method, which uses only annual precipitation, plus a set of coefficients that have been published by Hargreaves for most countries, was more reliable than the method of Arnoldus. However, in all cases, a set of R values computed by the detailed method of Wischmeier and Smith(1978) was needed to obtain a "rating curve". Without this "rating curve", estimates may be more than 100% in error, and a meaningful global comparison of water erosion would not be possible.

21.1.1.3 Estimation of the R equivalent of winter precipitation and snowmelt

For climates with a winter precipitation pattern that combines snow with rain on alternating frozen and thawed soils, the method of McCool et al (1982) developed in the northwest USA provides an estimate of the additional R factor (R_s) needed for the "winter" period (December to March in the Pacific Northwest of the U.S.). They determined that R_s should be estimated as:

$$R_s = 0.1\ P_{(D-M)} \qquad (21.15)$$

where: $P_{(D-M)}$ = precipitation during December through March in mm

This adjustment can be made for climates with similar freeze-thaw/snow-rain cycles in winter, using the precipitation total for those months having these conditions.

Another adjustment can be used to take account of snow-melt in regions characterized by more or less continuously frozen soil during winter, and with a distinct thaw in spring. This has also been derived from the work of McCool (1982), modified by experience in the Prairie region of Canada (Tajek et al. 1987). It is based upon the water-equivalent quantity of snow on the ground at the time that the principal thaw (or thaws) occurs. Where data are available, this can best be estimated from the long-term normal "snow-on-ground" value on a date representative of the usual start of spring runoff. An average snow density at this time of year can be used to convert snow depth to water equivalent. The formula for estimating the R_s value to include the snow-melt runoff effect is as follows:

$$R_s = S \cdot D \qquad (21.16)$$

where: S = snow depth (cm) at initiation of snow-melt period, and
D = mean density of snow (cm water/cm snow)

Data on S and D are not available in the SOTER Climate Files, and must be obtained independently.

21.1.1.4 Preparation of a map of R_t:

As many R_t values as possible should be obtained for the map area. Four sites is an absolute minimum, but more than eight is highly desirable. A transparent overlay should be prepared and registered with the 1:1M soil map. Isolines should be drawn within the network of the measured values, interpolating between sites using linear interpolation techniques. Local knowledge of regional landforms and precipitation patterns should also be used to best advantage to interpolate between the measured values. For example, if it is known that precipitation increases with increasing elevation on the windward side of a range of hills (even if measured data are not available) then isolines linking points of equal R_t values (or estimates) should be skewed to reflect the probable greater values in these higher altitude regions. Care must also be taken at the border of the map area to ensure that isolines agree with those for adjacent map areas. Examples of such maps can be found in Wischmeier and Smith (1978) for the USA, and in FAO (1979) for North Africa.

An alternative method of preparation of a map of R_t is to use the mapping capabilities of the geographic information system (GIS) used to handle the climatic data file. Values of R_t may be computed directly from the data in the file, and the spacial distribution of these values can be plotted at any suitable scale. Isolines can be drawn on a map by hand, or plotted by the GIS, depending on the system capability.

21.1.1.5 Estimation of R_t values for soil polygons:

Using the overlay R_t isolines, each soil polygon on the 1:1M soil map can be assigned an R_t value estimated from the nearest isolines. Local knowledge should be used to advantage at this stage so that known differences in the climatic conditions between soil polygons can be reflected in the choice of a "representative" R_t value for each polygon.

Alternatively, if map polygons are coded to fit the spacial capabilities of the climatic data handling system, R_t values can be assigned directly to polygons without the necessity of estimating them from an overlay of isolines.

21.2 Climate data analysis for rate and risk assessment of wind erosion

The method proposed in this manual for wind erosion assessment is based on the U.S. Wind Erosion Equation. Although another method is available for wind erosion assessment that is based on soil moisture and maximum 1-hr wind speeds (Coote et al. 1988), this method has not yet been tested outside of the Canadian prairies, and it would be premature to include it in this procedures manual.

21.2.1 The climate factor:

The US Wind Erosion Equation is based upon an index of mean annual soil moisture conditions such that the Garden City, Kansas, experimental site has a value of 100 (%) calculated using US ("English") units. The index (C_w-factor) is found as follows:

$$C_w = 386 \frac{{V_z}^3}{\left(\sum_{i=1}^{12} 10(P-E)_i \right)^2} \qquad (21.17)$$

where V_z = average annual wind speed in m/s at 10 m height,
i represents months,
and P-E = Thornthwaite's precipitation-evaporation index and is calculated as follows:

$$10(P\text{-}E)_i = 115\ ((P_i/25.4)/(1.8T_i + 22))^{1.11} \qquad (21.18)$$

where P_i = mean precipitation for month i, and must be greater than 12.7 mm (or 12.7 mm must be used)
and T_i mean temperature for month i, and must be greater than -1.7 degrees C (or -1.7 must be used)

The numbers are such that when metric units are used the value of C_w is still 100% at Garden City, Kansas, and the values at other sites are the same as calculated using Chepil et al's (1962) original method (Lyles 1980).

Although it is generally recognized that the Thornthwaite method of estimating potential evapotranspiration may not be valid in many tropical zones, the P-E index used here uses an estimate of actual evapotranspiration and is central to the application of the U.S. Wind Erosion Equation. If other methods are substituted for Thornthwaite's P-E, the comparability between regions will be diminished. It is therefore proposed that equation 21.17 be used in all regions, regardless of uncertainties about the reliability of P-E for other purposes.

21.2.2 Correction of wind speeds

Wind speeds must be standardized to a common height above the ground, 10 m in the case of the C_w calculation. Anemometers are often installed at different heights, and a logarithmic function can be easily used to correct data to a standard 10 m height providing that the height of the anemometer is known. The following equation can be used to determine the correction factor (J) to standardize all wind data to 10 m height:

$$J = 1/(0.233 + 0.656 \log(H + 4.75)) \qquad (21.19)$$

Where H = height of anemometer at which wind speed was measured (m).

The corrected wind speed (V_z) is found as follows:

$$V_z = V_h \times J \qquad (21.20)$$

Where V_h is the wind speed at height H.

21.2.3 Modified Wind Erosion Equation based on month or season with greatest wind erosion risk:

This option uses the same method as already described above, with the exception that in the calculation of C_w, the mean annual wind speed is replaced by the mean wind speed for the month or season with the greatest likelihood of wind erosion. This may be the month or period with the lowest value of P-E or it may be the month or period with the greatest mean wind velocity. Local experience should be used to determine the most appropriate month or period. All other factors will remain the same. It may, however, be necessary to use a different set of class limits for the wind erosion risk classes if this seasonal or monthly wind speed is used.

Another method of choosing the most susceptible month is to compare monthly moisture availability indices (MAI's) as described in the next section (21.3). The month or season with the lowest MAI would be that period for which the mean wind speed is calculated and used in eq. 21.17.

21.3. Climate analysis for assessment of salinization, chemical/nutrient loss, and sodication

Each of these three soil degradation assessments requires information on the Moisture Availability Index (MAI), defined by Cochrane et al. (1985) as dependable precipitation divided by potential evapotranspiration. Dependable precipitation is defined as that which can be expected at the 75% confidence level, or 3 years in 4 (Cochrane et al. 1985). Dependable precipitation (P_d) can be estimated by a simple linear equation:

$$P_d = A + B\bar{P} \qquad (21.21)$$

where $\bar{P}$ = mean monthly precipitation

and A and B are coefficients that vary from region to region, some of which are listed in Table 21.3 (Hancock et al. 1979 as reported by Cochrane et al. 1985)

Potential evapotranspiration should be estimated using the method of Hargreaves, and is a computed component of the SOTER climate files (PETH).

Table 21.3 Regression coefficients for determining dependable precipitation, by location[1]

Region/Country	Area	A value	B value
Central America		-23.0	0.84
South America			
Brazil	1	-20.0	0.85
	11	- 9.0	0.57
	111	-23.0	0.79
	1V	-11.0	0.67
	V	-11.0	
Bolivia		-10.0	0.69
Colombia		-25.0	0.84
Ecuador		- 5.0	0.64
French Guiana		-25.0	0.84
Guyana		-14.0	0.77
Paraguay		-10.0	0.69
Peru	1	- 1.0	0.18
	11	- 5.0	0.70
Surinam		-14.0	0.77
Uruguay		-10.0	0.69
Venezuela		-14.0	0.77
Caribbean Islands		-23.0	0.84

[1] From Cochrane et al. (1985)

The Moisture Avaliability Index (MAI) is then:

$$MAI = P_d / PETH \qquad (21.22)$$

Where P_d is found from eq. 21.21, and PETH is the potential evapotranspiration using the Hargreaves method.

Hargreaves suggested 5 classes of soil moisture availability based on value on the MAI as follows:

0.00 - 0.33	very deficient
0.34 - 0.67	moderately deficient
0.68 - 1.00	somewhat deficient
1.01 - 1.33	adequate
1.34 +	excessive

GLOSSARY

Correlog refers to a log of Correlation activities pertinent to SOTER Projects

Parent material - refers to the unconsolidated mass from which the soil has developed.

Parent rock - refers to the rock from which the parent material was formed by weathering.

Igneous rock - rock solidified from magma may be extrusive on the earth's surface (volcanic) or intrusive into the rocks forming the crust of the earth.

Sedimentary rock - rock formed from material derived from pre-existing rocks by processes of denudation, together with material of organic origin.

Grits - sedimentary rock consisting of coarse sandstone with angular grains.

Arkose - sedimentary rock consisting of sandstones with more than 25% feldspar grains, relatively rich sandstones.

Graywackes - sedimentary rock consisting of fine to coarse, angular to sub-angular particles, which are mainly rock fragments.

Conglomerate - sedimentary rock consisting of gravels.

Schist - a strongly foliated crystalline rock formed by dynamic metamorphism which can be readily split into thin flakes or slabs due to well developed parellelism of more than 50% of the minerals present, particularly those of lamellar or elongate prismatic habit (i.e. mica, hornblende)

Pyroclastic rocks - consist of materials which on having been thrown out of the volcano as liquid globules, has solidified in the air and is subsequently deposited as solid particles such as bombs, pumice (vesicular material derived from acidic lava) or scoriae (vesicular material derived from basic lavas).

Pyroclastic rocks also consist of material which has been thrown out of the volcano a solid fragment by the explosive activity including unconsolidated ashes (which consolidate to tuffs less than 2 cm diameter), breccia (agglomerated ashes greater than 2 cm diameter)

Landsat Spectral Bands and their Principal Applications are shown below:

Satellite/Sensor	Band	Wavelength (Microns)	Applications
LANDSAT: MULTISPECTRAL SCANNER (MSS) Resolution: 80 cm	1	0.5-0.6	Coastal water (turbidity) mapping etc.
- do -	2	0.6-0.7	Useful to distinguish topographical and cultural features; to classify different types of vegetation; mapping of non-vegetated areas, gullies, dry channels, sandy areas, etc.
- do -	3	0.7-0.8	Rock-soil boundary differentiation; landuse changes detection; estimation of green biomass.
- do -	4	0.8-1.1	Demarcation of land/water boundaries; soil-crop moisture studies; surface water bodies mapping; mapping of geological features.
LANDSAT THEMATIC MAPPER (TM) Resolution: 30 m	1	0.45-0.52	Coastal water (turbidity) mapping; soil mapping; deciduous/coniferous flora discrimination; mapping of cultural features.
- do -	2	0.52-0.60	Measurement of visible green reflectance peaks of vegetation for vigour assessment.
- do -	3	0.63-0.69	Mapping of vegetation types and subtypes; discrimination of vegetated and non-vegetated areas.
- do -	4	0.76-0.90	Determining biomass content and for delineating water bodies.
- do -	5	1.55-1.75	Vegetation/soil moisture content and snow/cloud differentiation.
- do -	6	10.40-12.50	Vegetation stress analysis, soil moisture studies and thermal mapping.
- do -	7	2.08-2.35	Discrimination of rock types (mineral and petroleum geology) and hydrothermally altered zones.

REFERENCES

Agriculture Canada, Research Branch, Publication 1459, 1976. Glossary of terms in soil science.

Agriculture Canada, Research Branch, Publication 1646, 1978. The Canadian System of Soil Classification

Agriculture Canada, Research Branch, 1983. J.H. Day, editor. The Canada Soil Information System (CanSIS), Manual for describing soils in the field, 1982 Revised.

Arnoldus, H.M.J. 1977. Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. (In) Assessing Soil Degradation. FAO Soils Bulletin 34, Rome, Italy.

Ateshian, J.K.H. 1974. Estimation of rainfall erosion index. J. Irrig. and Drainage Div., Am. Soc. Civ. Engrs. 100 (IR3):293-307. Proc. Paper no. 10817.

Bols, P.L. 1978. The iso-erodent map of Java and Madura, SRI, Bogor, Indonesia.

Bondy, E., Lyles, and Hayes, W.A. 1980. Computing soil erosion by periods using wind-energy distribution. J. Soil and Water Cons. 35(4): 173-176.

Chepil, W.S., Siddoway, F.H., and Armbrust, D.V. 1962. Climatic factor for estimating wind erodibility of farm fields. J. Soil and Water Cons. 17(4):162-165.

Cochrane, T.T., Sànchez, L.G., deAzevedo, L.G., Porras, J.A., and Garves, C.L. 1985. Land in Tropical America. ISBN 84-89206-37-6. Centro Internacional de Agriculture Tropical. Apartado 6713, Cali Colombia.

Coote, D. R., Malcolm-McGovern, C.A., Wall, G.J., Dickinson, W.T. and Rudra, R.P. 1988. Seasonal variation of erodibility indices based on shear strength and aggregate stability in some Ontario soils. Can. J. Soil Sci. (in press).

Coote, D.R., Padbury, G.A., and Pettapiece, W.W. 1988. Wind erosion risk Alberta. Land Resource Research Centre Map (in press).

Environment Canada, Inland Waters/Lands Directorate, 1987. The Canadian Wetland Classification System.

Environment Canada, Lands Directorate, 1982. Ecodistrict Description and Fact Sheet. Personal Communication, Clay Rubic.

Expert Committee on Soil Survey, 1985. Soil Survey Handbook, Vol. 1. Land Resource Research Centre, Research Branch, Agriculture Canada.

Food and Agriculture Organization of the United Nations - Rome, 1985. Soil map of the World, 1:5,000,000, Revised Legend.

Geoanalysis Ltd., 1981. Landform Descriptive Classes for the Higher Levels of Ecological Land Classification. Contract No. KL229-0-4581, Environment Canada, Lands Directorate, Ottawa.

Hargreaves, G.H. 1981. Simplified method for rainfall intensities. J. Irrig. Drain. Div. Proc., Am. Soc. Civ. Eng. 107(IR3): 281-288.

Kenya Soil Survey, 1978. Guidelines for subdivision of geology/Definitions of land forms in relation to soil mapping and map legend construction. Internal Communications No. 13, Nairobi.

Kocaoglu, S.S., 1975. Reconnaissance Soil Survey of the Sand River Area. University of Alberta Bulletin N.SS 15, Edmonton, Alberta, Canada 83 pp.

Lyles, L. 1983. Erosive wind energy distributions and climatic factors for the West. J. Soil and Water Cons. 38(2):106-109.

McCool, D.K., Wischmeier, W.H. and Johnson, L.C. 1982. Adapting the Universal Soil Loss Equation to the Pacific Northwest. Trans. Am. Soc. Agr. Engr. 25(4):928-934.

McFee, W.W. 1980. Sensitivity of soil regions to long term acid precipitation. U.S. EPA Rep. No. 600/3-80-013.

National Bureau of Soil Survey and Land Use Planning, 1987. Field Manual for Soil Mapping of India and of different states, Nagpur - 440010, 29 pp.

National Soils Handbook, 1986 Amendment. Glossary of landform and Geologic Terms. USDA.

Reconnaissance Soil Survey of the Brazeau Dam Area, 1981. Alberta Soil Survey Report No. S-81-40, Alberta Institute of Pedology, Edmonton, Alberta, Canada, 68 pp.

Soil Conservation Service, 1975. Soil Taxonomy. USDA.

Tarnocai, C., 1977. Manual interpretation of Landsat data for land classification, Northern Keewatin, N.W.T., Canada Soil Survey, Winnipeg, 15 pp.

Thornthwaite, C.W. 1931 The climates of North America according to a new classification. Geog. Rev. 21:633-655.

Wall, G.J., Dickinson, W.T., Rudra, R.P. and Coote, D.R. 1988. Seasonal soil erodibility variation in southwestern Ontario. Can. J. Soil Sci. (in press).

Wang, C. and Coote, D.R. 1981. Sensitivity classification of agricultural land to long-term acid precipitation in Eastern Canada. Res. Br. Agriculture Canada, Ottawa, Ont. LRRI-98.

Wischmeier, W. H., Johnson, C.B. and Cross, B.V. 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil and Water Cons. 26:189-193.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses. A guide to conservation planning. US Dept. Agric. Handbk. No. 537.

Woodruff, N.P. and Siddoway, F.H. 1965. A wind erosion equation. Proc. Soil Sci. Soc. Am. 29(5):602-608.