MSc Programme Soil and Water

Erosion Hazard Analysis using USLE and SLEMSA of a SOTER pilot area in South America.

by

Not for publication

Pedro Cunha

under the supervision of:

Prof. Dr. S.B. Kroonenberg

Ir. Erik R.Jordens

Drs. V. van Engelen

WAGENINGEN AGRICULTURE UNIVERSITY (WAU), THE NETHERLANDS

September 1993

Wageningen Agricultural University - The Netherlands

Erosion Hazard Analysis using USLE and SLEMSA of a SOTER pilot area in South America.

by

Pedro Cunha

under the supervision of:

Prof. Dr. S.B. Kroonenberg

Ir. Erik R.Jordens

Drs. V. van Engelen

WAGENINGEN AGRICULTURE UNIVERSITY (WAU), THE NETHERLANDS

September 1993

Erosion Hazard Analysis using USLE and SLEMSA of a SOTER pilot area in South America.

by

Pedro Cunha

under the supervision of:

Prof. Dr. S.B. Kroonenberg

Ir. Erik R.Jordens

Drs. V. van Engelen

WAGENINGEN AGRICULTURE UNIVERSITY (WAU), THE NETHERLANDS

September 1993

Thesis submitted to the Wageningen Agriculture University (WAU), Department of Soil and Geology, Wageningen, The Netherlands, as a partial fulfilment of the requirements to achieve a degree of Master of Science (M.Sc.) in Soil Survey and Land Evaluation.

ACKNOWLEDGEMENTS

This study was made possible by the Netherlands Fellowship Programme under a Grant in support of a Master of Science course in Soil and Water.

The supervision and assistance from the Department of Soil and Geology : Prof. Dr. S.B. Kroonenberg, Ir. Erik R. Jordens are heartily acknowledged, together with Drs. V. van Engelen, Ir. M. van den Berg , Prof. Dr. E.M. Bridges who corrected the English and Ir. Piet Tempel who helped me with programming in the International Soil Reference and Information Centre (ISRIC).

I am grateful to the collaborators of the LASOTER project and the access to the database : Prof. Rosa Maria di Giacomo, Prof. Egon Klant, Prof. Dr. F.H. Semmelmann, Dr. Isa Comadre for the data collection and the Wageningen Fonds for the travel support.

II

EROSION HAZARD ANALYSIS USING USLE AND SLEMSA OF A SOTER PILOT AREA IN SOUTH AMERICA.

ABSTRACT

Calculations of the erosion hazard index (EHI) were made using the computer program SOTER Water Erosion Assessment Programm (SWEAP) (van den Berg, 1992). This program has been developed as an application programme of the SOTER database. It contains modules for Universal Soil Loss Equation (USLE) and Soil Loss Estimation Model for Southern Africa (SLEMSA). Both models were adapted to be compatible with the SOTER database. The results of the runs for hypothetical situations of Vegetation/Land use/Management, are written in tabulated form per SOTER unit (mapping unit) to a user defined output file. These results were manipulated by a geographical information system using ILWIS software and displayed as erosion hazard maps.

Then, these were compared with the present status of soil degradation (shown in 5 classes from none to very high), from an pilot area LASOTER with an scale of 1:1 million database created according to the GLASOD methodology (Oldeman, 1991).

PREFACE

The assessment of erosion hazard is a specialized form of land resource evaluation, to identify areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss. The assessment aims at dividing a land area into regions, similar in their degree and kind of erosion hazard, as a basis for planning soil conservation work (Morgan, 1986).
The dissertation is written in 5 chapters with a bibliography and appendixes.

The first chapter begins with a general introduction to the study area and thereafter concentrates on some concepts of erosion models and erosion hazard assessment.

The second chapter deals with the description of the materials and techniques used : models, database structure and the adjustments made to run erosion models, as well the methodology of the "ground truth" soil and terrain database and the methodology from the site specific checking of independent data from rivers discharge and sediment yield of the Ibicui basin .

Chapter 3 gives the results of the regression analysis of the model's rainfall factors and the 12 scenario maps produced as predicted erosion hazard index with a comparison between 2 scenarios and the small scale qualitative map created to describe the actual status of soil degradation, including expertise judgment on this "ground truth".
The results of the Ibicui river basin data are evaluated as a regression analysis of the denudation rates predicted by the erosion models and the measurements one in 7 basins.

In **chapter 4** is presented the discussion of actual erosion with the calculated results and the relations with (expected results and) with others peoples' results using similar approach.

In **chapter 5** the conclusions and the recommendations for further studies are presented.

The dissertation is concluded with the **bibliographical references** and the following **appendices** :
appendix 1 the SOTER methodology and its map legend;

appendix 2 an additional explanation and references of the soil factors as soil depth and sensitivity to capping showing how they were derived from the correlation of other soil parameters;
appendix 3 the basic concepts of vector and raster map;
appendix 4 the GLASOD methodology for small scale map to describing the actual status of soil degradation;
appendix 5 describes the modifications made to the erosion models USLE and SLEMSA within the SWEAP software;
appendix 6 shows examples of the climate and soil SWEAP input files.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1 - Introduction

Erosion hazard analysis is a technique to draw attention to the physical danger of soil erosion over large areas. It considers several factors such as rainfall erosivity, soil erodibility, vegetation and erosion control practices; which are combined to estimate the overall hazard prevailing. (Stocking et al,1988).

Erosion hazard assessment should be a basic part of land evaluation. It can be linked with productivity considerations to select management strategies that maximize long-term crop production. The qualitative assessment of water erosion hazard can be presented on small-scale (1:100,000 to 1:1,000,000) maps by the combination of different parameters (soil erodibility, land use, land management, slope, etc.) as an erosion hazard index (EHI) with classes from none to very high attributed to each terrain unit.

The propose of this study is not to make a quantitative assessment of EHI but to provide a qualitative assessment of EHI. This information can be used later as a cartographic basis for the identification of priority areas at exploratory scale of 1:1 million, but also with more refined information at reconnaissance scale 1:100.000 to 1:25.000, to investigate vulnerable areas for regional planning on soil conservation purposes at reconnaissance level.

The two models that are most commonly used for this purpose are USLE (Universal Soil Loss Equation) and SLEMSA (Soil Loss Equation for Southern Africa).
In this study a comparison will be made between the response of these two models for an pilot area of 460Km x 500Km covering parts of Argentina, Brazil and Uruguay.

1.2. Research Question

Can existing erosion models, USLE and SLEMSA, be linked with soil and terrain database-(SOTER, 1991) to provide reliable erosion hazard maps at a scale 1:1 Million ?

1.3. Objectives

- To compare the results of (adapted versions) USLE and SLEMSA applied to the LASOTER area, with present status of soil degradation caused by water erosion.

- To analyze discrepancies between the model results and "ground truth" in the SOTER units.

- To give suggestions for further refinement of the models.

1.4. General Description of the Study Area

1.4.1. Location

The LASOTER Pilot area is located within coordinates 54^{0}-60^{0} W longitude and 28^{0}-$32^{0}30'$S latitude, covering parts of Argentina, Brazil and Uruguay. 46 % of the area is in Argentina and 27 % in each of Brazil and Uruguay.
The total area of the LASOTER pilot area is 286.000 Km^2.
Provinces within the area:
Argentina: Entre Rios, Corrientes, Santa Fe and Misiones.
Brazil: Rio Grande do Sul
Uruguay: Artigas, Salto, Paysandu, Tacuarembo, Rivera and Cerro largo.

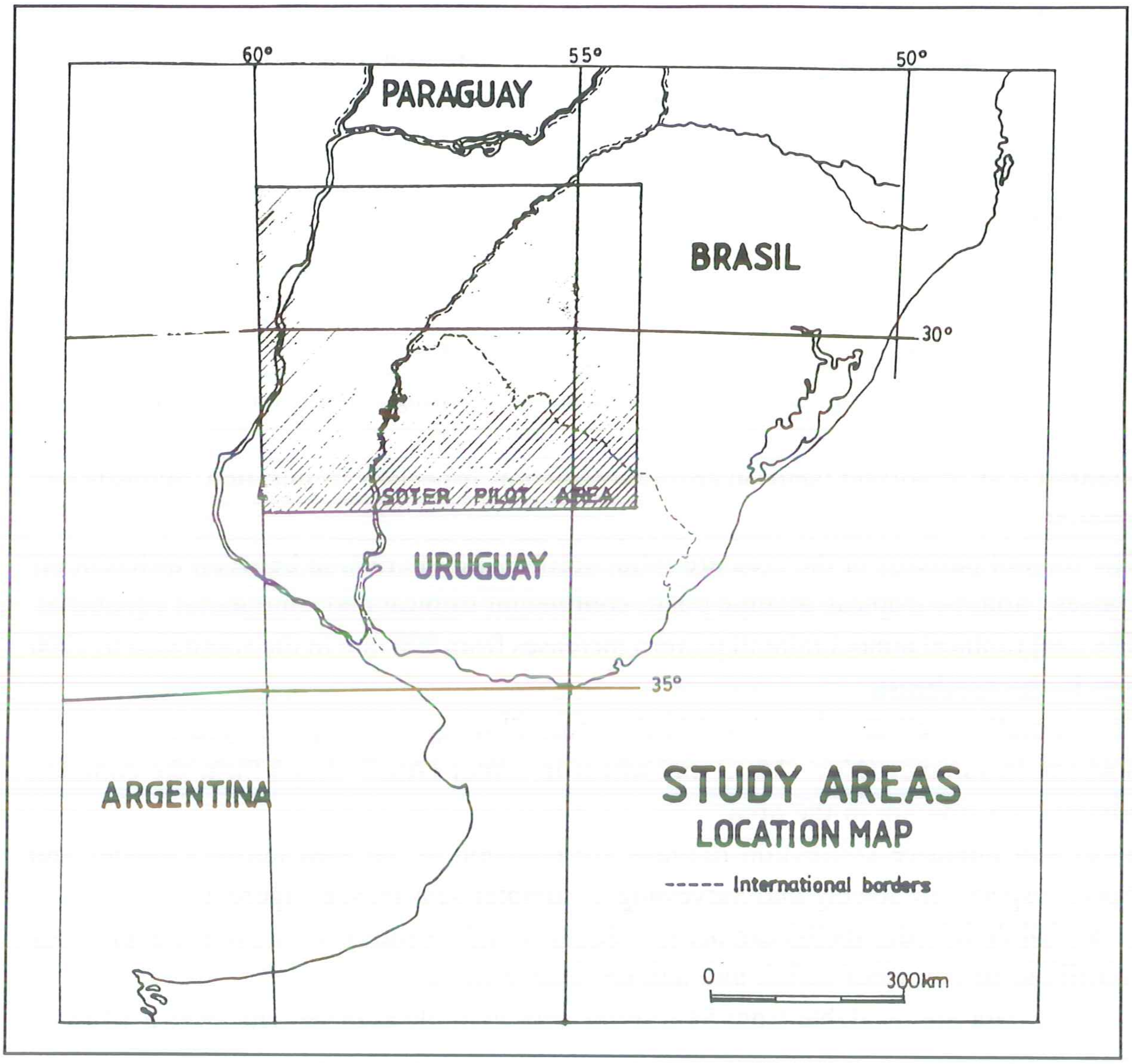

Figure 1.4.1. Study area

1.4.2. Hydrography

The two main river basins in the area are the Parana basin in the west part and the Uruguay basin in the central part of the area.
Quaternary fluvial deposits of Parana and Uruguay rivers are the important geological formations of the alluvial plain landscape of the study area.
The tributaries of the Parana river are : Santa Lucia in the north and Gualeguay in the

south of the basin.
In the Uruguay basin is located one of the biggest sub-basin of the study area the Ibicui basin with an area of 42.498 Km square, see on map annexo **Figure 1.4.2. Hydrography of the area with Ibicui 7 basins** .

1.4.3. Climate

The Climatic zone C according to the Köppen Climate Classification System is prevailing in the entire study area. The Climate Type is Cf : indicating a warm moist temperate climate. The mean temperature of the coldest month ranges between 12 and 16^{0}C.

Rainfall is an important factor in erosion prediction, especially its duration, intensity and amount.
The rainfall patterns in the area are influenced by the interaction between different air masses : atlantic tropical, atlantic polar, continental tropical and continental equatorial.
The geographical annual rainfall pattern increases from 900 mm in the southwest to 1700 mm in the northeast.
The rainfall is well distributed within the year, allowing two crops per year.
Soybean in summer (Nov.- Mar.) and wheat in winter (April- Aug.) form the common annual crop rotation in the area.
Short and intensive convection rainfalls are common in the area during October and April, respectively sowing and harvesting at summer season, see Figure 1.1..
A rainfall deficit (dry spells) can occur in January and February when hot summer winds contribute to the water-deficit and hamper crop growth.
Climatic data are available from 54 stations with monthly average data over a 10 to 40 years period.
The raw data is available per year in 4 stations from Uruguay.

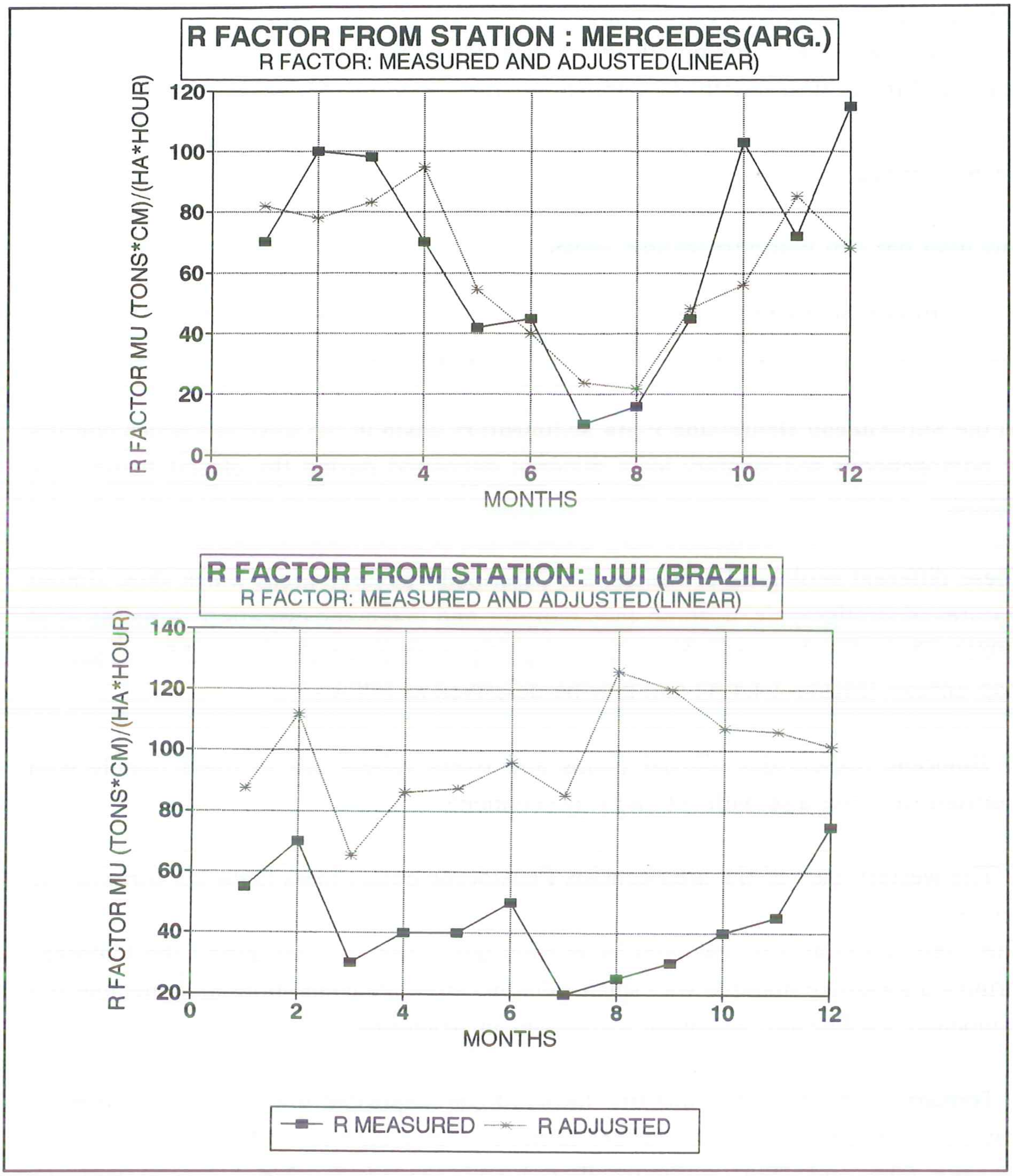

Figure 1.4.3. R factor distribution, station Mercedes (Ar.) and Ijui(Br.).

Temperature: The temperature follows a similar pattern from southwest to northeast, the coldest temperature of the month, July, varies from 12^0 C in the south to 14^0 C in the north and the hottest month, January varies from 23^0 C to 25^0 C (mean values).

1.4.4. Geology

The area has two morphostructural units;

A) the **Brazilian shield** underlies the eastern part with a varying lithology of volcanic rocks as rhyolite, dacite and basalt overlying sedimentary rocks as sandstones;

B) the **Sub-Andean Depression Plata Sedimentary basin** in the west part which consists of homogeneous sedimentary loess material deposited during the glacial Pleistocene period.

These different geological provinces, are described " as large areas which show similar features of stratigraphic, tectonic, metamorphic and magmatic evolution" Almeida et al (1981). Their distribution is shown as a map of parent materials and land forms see on map annexo (Figure 1.4.4.A) and may be described as follows :

1) **Holocene** present-day alluvial plains and rivers valleys are in filled mainly with unsorted sand but also with silt and clay sediments.

2) The western part of the area consists **Pleistocene** eolian loess material, forming the peneplain.
This loess material was reworked by erosion and sedimentation during the **Holocene** forming a loess-like material with small calcium carbonate concretions and, includes the Pampeano, La Paz and Bonpland formations in Argentina.

3) **Tertiary** sandstone with some fine layers of clay deposited in a fluvial environment, now occur on the high plateau surface of the dissected landscape. The thickness varies between 60m and 80m, easily weathered and eroded. In Brazil it is called the Tupancireta formation.

4) A **Cretaceous** basaltic lava flow, occasionally occurs in an interbedded sequence with eolian sandstone.
Intense vulcanism occurred between 130 and 140 millions of year ago when the effusive rocks were deposited, normally an acid effusive material very resistant to weathering like rhyolite ,rhyodacite or dacite occurs covering the overlying sequence of eolian sandstone and basalt.

This formation occurs on high and low plateau, and in the boundary between plateaus and depression areas on the footslopes of the steep areas of acid effusive material. This formation is named Serra Geral in Brazil and Curuzu Cuatia in Argentina and has a thickness varying from 25 to 80m.

5) **Jurassic** eolian reddish mediun fine grained sandstone were deposited in a desertic environment, forming the low plateau with the Cretaceous basaltic formation, this is named Botucatu formation in Brazil.

6) **Triassic** fine to mediun grained light reddish sandstone with some calcium carbonate concretions were deposited in a fluvial/lacustrine environment, forming the depression area of the Negro and ibicui rivers, normally developing soils as Acrisols which have high erodibility on agriculture, and are named the Rosario do Sul formation in Brazil.

7) **Permian** siltstone, and limestones of marine and fluvial environment, forming the low plateau of sedimentary rocks, are located in southeast of the area.

8) Igneous acid and metamorphic rocks as granite and gneiss, of mainly **Precambrian** origin occur in small areas on the low plateau at the east part.

The different geological provinces described above have their different natural geological erosion related to the lithology, surface form, vegetation and soil types.

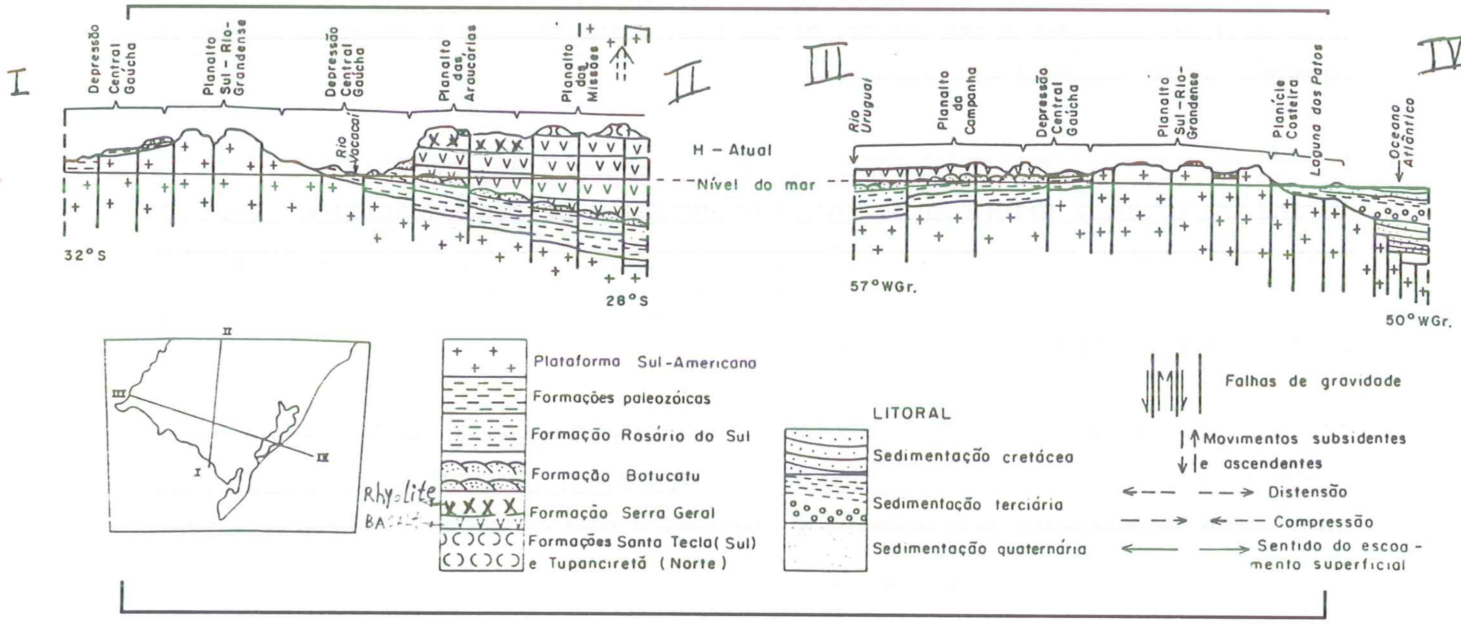

Figure 1.4.4. Section of Geological formations on Brazil

See in (Map annexo).**Figure 1.4.4.A) Map of the parent material and surface form** and **Figure 1.4.4.B) Map of the Land form**.

1.4.5. Topography

The pilot area has an rather uniform landform. This was one of the reasons for selection of the area for the practical field application of the SOTER methodology. The lower part of the area is the poorly drained alluvial plain of the Parana river in the west about 20 m.a.s.l..

The elevation increases gradually from southwest to northeast reaching the highest part in the extensive undulating and rolling peneplain at about 500 m.a.s.l..
The slope gradients are following the same pattern from 0-4% in southwest in the eolian plains, to 16% in the irregular dissected peneplains of the northeast. The Slope length ranges from 300 to 1000 m in the eolian plains to 50 to 300 m in the eastern part of the pilot area where the older, dissected peneplain occurs.

1.4.6. Geomorphology

The LASOTER area can be subdivided in the following geomorphological provinces:

-Peneplain : Water Erosion processes were intense during the Pleistocene when the base level of rivers changed in the estuary of the river Plata, forming a dissected valleys in response to the lower of sea levels.

During the Quaternary a thick loess was deposited and then reworked by the rivers Parana and Uruguay, to form an peneplain, of undulated and gently undulated relief with some river terraces on the margin of Uruguay and Parana rivers. This loess material is forming in an process of desiccation and cracking of clay-rich deposits having strong binding structure by Ca and Mg salts.

The peneplain landform is subdivided into : 1) the **low, flat, poorly drained plain** in the northwest part of the area where is located the depression of the Ibera river and 2) the **undulating, well-drained peneplain** in the southwest part of the area, where is located the undulated Meridionales peneplain.

Flood sediments tend to diminish the local relief, by filling in lakes and marshes, during this process poorly drained conditions prevail as in the present landscape of the Parana river valley.

In general, areas subjected to the prevailing influence of floods in the Parana river basin show characteristics of plains that have a imperfect poor drainage (Iriondo, 1984). According to the SOTER methodology the predominant landforms in this province are : plain and valley. The latter occur locally along the main river valleys.
The predominant and **dissected** landforms in the **Brazilian shield** are subdivided into:

The **gently undulating high plateaus :**

1A) "**Missoes Plateau**" this province is located in the highest part of the area, determined by the homogeneity of the relief, with gently slopes on the sandstone which are underlying by the basalt. There has been no significant folding since Precambrian time in this province. These homogeneous relief characteristics are combined with deep soils such as Ferralsols and Luvisols which make an important contribution for agriculture in this province.

1B) Steep "**Araucaria Plateau**" were the effusive hard acid rocks cover the effusive basic rocks, with Major soils grouping Cambisols and Lithosols, slope range from 30 to 50 %. On that province the relief is the most limited factor for agriculture. Shifting cultivation is the actual landuse and the original vegetation was sub-tropical forest with **Araucaria angustifolia**, the escarpment relief with some foothills of 620 m depth and is highly structure oriented, there is high precipitation caused by the orographic effect.

The Undulating Low Plateaus :

2A) "Campanha Plateau" on effusive basic rocks and Jurassic eolian sandstone, with common remnants Mesa and cuestas landscapes on the boundary with the depression area, the common soils on the more dissected area with structure orientated relief with basalt lithology occur the Major group of Lithosols, Luvisols and Acrisols (plinthic); on the sandstone lithology occur the Ferralsols and Acrisols. The erosions process and mass movements are common occurring rill and gully less often, there is an large area on the Jurassic sandstone with a desertification process taken place.

2B) "Sul Rio Grandense Plateau" with more complex acid plutonic lithology as granite, forming and dissected landscape with convex slopes and deep valleys, the soils are of the Major grouping Acrisols and Lithosols. The most important land and surface forms according to the SOTER methodology are: plain, upland, tableland and valley with the following surface forms : level, undulating, rolling on these geomorphological provinces.

3) The depression area of the Negro and Ibicui rivers : Triassic, Jurassic and Quaternary formations comprising fluvial and eolian sandstones, are present.

The local relief is undulating with erosional processes likely to occur in deep soils with high erodibility such as Acrisols, Phaeozems and Planosol on the alluvial terraces.

These erosion processes and landscapes are related to the rivers which have an dendritic drainage pattern. On the right bank of the Ibicui river the relief is of steep hills where mass movement are common.

The general relief is described as : elongated hills, flat summits, cuestas and Mesa remnants showing the original level covered by the basalt.
The most common land and surface forms are : upland, tableland and hill, with Undulating, Rolling, and Steep surface forms.
A cuesta landscape occur at the border of the plateau with the dissected valley.

4) **River Terraces** : Uruguay river with two levels, the first older and higher characterised on meandering shape with scars of abandoned meanders result of a combination of gradual (lateral and down-valley) migration of meander loops and evulsive channel shifts causing abrupt cut-offs of loop segments. The second, lower terrace is characterised by sand and clay material.

The Parana river terraces are lower an flooded, with large flood plain of broad alluvial valley with large and abandoned meanders.
The Parana moved to its present alluvial plain some time around the beginning of the Holocene. It might not have been a migration of the channel due to wandering but to an avulsion process, that is, a sudden change of the whole channel which occurs when its gradient is exaggeratedly diminished by sedimentation. The so called "coastal levee" in the province of Santa Fe, the flood plain is about 600 Km long by 15 to 20 Km wide (Iriondo & Cerutti, 1981), see on (Map annexo) **Figure 1.4.6.A) Local surface form** and **Figure 1.4.6.B) Map of parent material and geomorphological provinces.**

1.4.7. Soils

The major soil groups (FAO) of the LASOTER pilot area in each geomorphological provinces cited above are ; Vertisols, Phaeozems and Luvisols, in the eolian peneplain, in descending order of occurrence.

In the **undulating, well-drained peneplain** Vertisols are dominant, developed in the lacustrine redeposited loess material; Phaeozems occur associated with Vertisols also developed in eolian loess material; Phaeozems are found on the higher slopes. Vertisols occur on the backslope where the loess material has been eroded.
The Vertisols show all typical characteristics like intersecting slickenside, cracks and

gilgai. Their topsoil is normally very dark and shows mollic characteristics.

In the **low flat poorly drained plain** (depression of the Ibera) Luvisols occur in fine texture calcareous parent material with a high content of organic matter. Arenosols on coarse material usually associated to the valley landscape and bad drained shown " stagnic properties", Degradation processes like; crusting, and compaction by overgrazing occurs in these soils.

In the River Terraces the occur the major soil grouping Arenosols on coarse material usually associated to the valley landscape and bad drained shown " stagnic properties" not well developed soils, and usually shown water and wind erosion.

In the **gently undulating high plateaus**:
The landscape is more complex as soil pattern is more complicated and heterogeneous because of differences in lithology.

On the "**Missoes Plateau**" occur deep soils such as Ferralsols and Luvisols in basaltic parent material and gentle slopes.
Most soils have illuvial clay horizons and so those soils that do not have mollic and/or vertic characteristics are classified as Luvisols.
Luvisols occur on slopes from 8 to 15% and with an "argilic horizon (Bt)" and a prismatic structure; (these characteristics increases hazard of erosion of these soils compared with the Ferralsols).
Ferralsols occur with a soil depth of more than 3 meters and slopes from 4 to 9%, low fertility status, moderately susceptible to erosion and with a low water holding capacity.
The most developed soil on basalt is classified as "Latossolo vermelho escuro" according to the Brazilian system (Carvalho, 1978) and Haplorthox according to (Carvalho, 1975).

On the " **Araucarias Plateau**" the hard acid effusive rock rhyolite cover the basalt, steep slopes areas occur.
The Major group Lithosols and Cambisols with horizons A,(B) and C , the characteristic of this soil is the B horizon not developed, has some restrictions to agriculture as , slope and soil depth, low fertility status, and very susceptible to erosion.

The low Plateaus composed of "**Campanha Plateau**" in Brazil and "Cuesta Basaltica" in Uruguay with the Major group Lithosols, Luvisols and Acrisols common on the basalt lithology. **The Lithosols** are characterised by shallow pedon, A horizon thickness of 30 cm, clay texture, on steep slopes, with high organic matter content, direct over the basalt parent material.
On the sandstone lithology developing the Major groups Ferralsols and Acrisols.

The soil unit **Plinthic Acrisol** occur on the west part of this Plateau on the margin of the Ibicui and Uruguay rivers, on gently undulating relief, with an "plinthic horizon" with thickness of more than 15 cm, on basalt parent material, has as landuse : pasture, wetland rice, maize and sorghum.

On the **"Sul Rio Grandense Plateau"** occur the Major group Acrisols and Phaeozem, the **Phaeozems** have an mollic A horizon with dark colour, and "argilic Bt horizon" and usually shown "gleyic and stagnic properties", occurring on different reliefs and parent materials with an soil depth ranging from 50 to 100 cm on the study area.

In the **depression of Negro and Ibicui rivers** with a rolling relief on sandstone parent material, the following soils occur;.
Acrisols on gently undulating relief on Tertiary sandstone deposits, on slopes between 4 to 8%, common have an abrupt horizon boundary between A/B with an "argilic horizon (Bt)" concentration of clay on B horizon (clay of high activity as 2:1 structure), and usually show "gleyic and stagnic properties".
The most limited factors for agriculture on this soils are, bad drainage and its physical properties as well the low fertility status. That soil has an high susceptible to erosion, proved by the occurrence of gully erosion.
Planosol occur on recent alluvial deposits, slopes from 1 to 3% with poor drainage, sand to medium topsoil texture, abrupt horizon boundary between A/B, "argilic horizon (Bt)" and usually show "gleyic and stagnic properties" and low fertility status.

Vertisols occur usually on Permian siltstone, level to gently undulating relief and present all typical characteristics like intersecting slickenside, cracks, prismatic structure and gilgai relief. The topsoil is normally very dark and presents mollic characteristics. Has an sequence of horizons as A, Bt and C. The limitations for agriculture on this soils are due to bad drainage and the physical properties. Even though the relief from level to gently undulating this soil can be susceptible to erosion because of the week structure of the A horizon associated to the low infiltration rates of the Bt horizon when cultivated. **Gleysol** also occur on **level** landscape on slopes up to 2%. These soils have an "gley" horizon within 60 cm from the surface, are fine textured, contain a high organic mater content and are poorly drained.

1.4.8. Landuse

The traditional land use in the LASOTER area since the sixteenth century has been extensive grazing which has not changed the soil qualities to any extent. During the second half of the nineteenth century a great number of immigrants from European origin settle the area, mainly from Germany and Italy.

Inevitably land use became more intensive and European style crop production systems were introduced. This occurred mainly in the eastern part of the LASOTER area, specially in Rio Grande do Sul. In a very short time the first human-induced soil degradation phenomena became evident. These soil loss were caused by water erosion and exhaustion (loss of topsoil), as sited by Kuiper, M. (1988).
The present most extensive land use in the study area is grazing of natural grasslands that still occupies approximately 60 % of the total area. Grazing is often combined with other land use in the western part of the area, where livestock production combined with agriculture based on forages and annual crops like linseed, sorghum, soybean and cereals. The main crops are : corn, wheat and soybean.

In the LASOTER area there are extensive grazing which have, 1 animal per 30 or more ha, and areas kept under natural vegetation for different proposes e.g. for natural reservation.
The natural denudation rates were accelerated with the increase of the human influence. As a result of an intensive plan of deforestation which was implemented in Rio Grande do Sul, Brazil, only 3% of the original forest vegetation is left and in the province of Entre Rios, Argentina, forest is left only along creeks and waterways (Peters 1990).

On the **eolian plain** (geomorphological province, **undulating well-drained peneplain**) the fine textured soils, mostly Luvisols and Fluvisols situated on the margins of the Uruguay and Parana rivers are used for annual crops like tobacco, corn, cassava. Locally reforestation and citrus plantations are implemented.
On the Mollisols and Luvisols more intensive pasture with 1 animal per less than 5 ha is the practice.
In the south western part of the eolian plain, Mollisols are used for annual cropping as (corn, cassava, cotton, rice, wheat, soybean, yerba mate, linseed).

In the **low, flat, poorly drained plain** (depression of the Ibera) in the northern part of this geomorphological province on Vertisols, Luvisols and Fluvisol the landuse is to graze natural pasture rather than arable agriculture (linseed, sunflower, sorghum) and on the Vertisols with poor drainage conditions rice is grown.

In the **gently undulating high plateaus,** geomorphological provinces, the land use in the Uruguayan part from the west to the east is : annual agriculture, mixed agriculture and pasture, natural pasture; The annual agriculture crops are sunflower, sugar beat, sugar cane, sorghum, linseed and barley. The average farm size is about 400 ha. The mixed agriculture and pasture land use takes place on farms with an average size of about 500 ha to 1000 ha.

In the Brazilian part from the north to south land use consists of annual agriculture, mixed agriculture and pasture, natural pasture.
The annual agriculture crops are more cereals and concentrated on the north on "Missoes Plateau", the north part of the "Campanha Plateau" and the alluvial valleys on the depression of Ibucui and Negro rivers.
The common crop rotation is of soybean or corn in summer from (November to February) and barley, wheat or oats in winter from (April to August). Wetland rice and beans usually are grown on farms with average size less than 50 ha.
Pastoral agriculture is practised on natural grassland and usually is rather extensive.
The "Araucarias Plateau" has shifting cultivation and pasture.
In the **depression area of Negro and Ibicui rivers**, the land use are : natural pasture, and mixed agriculture with annual crops such as corn, beans and rice, see on (Map annexo) **Figure 1.4.8. Land use according the SOTER database.**

1.5. General Approach to Soil and Terrain survey (SOTER)

The methodology used in the LASOTER pilot area is outlined in chapter 3 of the second version of SOTER Procedures Manual (Shields & Coote,1989). Since then the SOTER methodology has been updated and the fourth version published.
The source maps were organized and selected the existing information and adapted to the criteria of the SOTER Procedures Manual.

The general approach to soil survey is different in each of the three countries, therefore correlation procedures were important to unify the criteria on map units (polygons), terrain components, soil components, attributes and classes.
In spite of the differences and difficulties it became evident after a very short time that SOTER generates a uniform approach, creating a 1:1M database plus polygon maps.(W.L.Peters, 1990)

1.6. Literature Review and Concepts

1.6.1 Models

Kinds of models for practical prediction of erosion hazards at regional scale. Models can be theoretically divided into 2 broad groups:

1. Parametric (empiric).
2. Deterministic (physical)

Parametric:	Deterministic:
Simple structure	Complicated structure
Model reflects correlations, not real processes.	Model describes physical processes and their interactions
Application limited to experimental range (interpolation)	Application allowed for any situation, as long as governing processes are accounted for.
Applicable scale depends on spatial variability of (average or constant) land characteristics	Applicable scale depends on dynamics of the processes.
Easy to use even with simple pocket calculator	Computer required
Model can be used as a tool for prediction.	Model can be used for prediction and to improve understanding.

Parametric models: are based on hypothetical simple correlations. Parameters are generally determined through regression.
They are valid within the range of experiments only. (examples : USLE and SLEMSA models).

Deterministic models : are based on mathematical equations which describe the natural processes, derived from physical laws.
Transferable to any situation. (examples : ANSWERS by Beasley, 1980; and CREAM by Knisel, 1980)

Parametric models:

Example 1.: **USLE**: A=R*K*LS*C*M*P.

Objective: Quantification of soil losses by sheet erosion in ton/ha.yr of experimental plots

Data requirements:

- R: Usually derived from detailed rainstorm data (EI30), "timestep" ±10min.
- K: Average (20yr?) standard erodibility, but expressed in terms of EI30
- LS: Can only be determined for constant slopes, no differentiation between concave and convex.
- C: Average annual reduction factor. Difficult to make correction for seasonal variation.
- P: Management factor can not be extrapolated to large areas simple, can not be used for "short" term (≤1yr) assessment, interactions are too simple.

K, C, and P factors are difficult to transfer to other regions, Heavy data needs which are not justified by quality or practical applicability of results.

Example 2. Improved **SLEMSA**: Z=K*C*X

Objective: Semi quantitative indication of problem areas.

Data requirements:

- K: (Yearly) precipitation totals + transfer function for expression in rainfall energy and soil erodibility (expert judgement rating 1-10).
- C: Seasonal rainfall energy interception to be inferred from crop characteristics (LAI) and yields.
- X: Topographic ratio, comparable with LS of USLE.

Management changes are accounted by adjustments of X, C or K.

Quality of results probably comparable with USLE.

Moderately heavy data requirements, compatible with (semi-quantitative) quality of results.

Additional advantage : highly flexible.

Calibration and validation

After all parameters values have been obtained, the system should be thoroughly tested. In addition to testing the model, it must be validated with data not used in its development. This will not only provide a check on the sensitivity analysis but also help to the stability of the system.

1.6.2. Erosion Hazard Assessment

Generalized assessments of erosion risk are made often at the exploratory scale and at this scale the surveys are based on analyzing climatic data or make use of measures of the intensity of erosion. Using erosivity indices Stocking and Elwell (1976) show the mean annual erosivity in Zimbabwe.

The temporal variation in erosion risk is revealed by the mean monthly erosivity values in combination with the plant cover development pattern during the seasons, giving protection against erosion and lowering the risk.

The **actual erosion** is the soil erosion during a given period (expressed in tons/ha * year) in the actual state of the land with respect to erosivity, soil, relief and vegetation, and with the existing management and conservation practices (e.g. contouring, terraces). As vegetation, management and practices may change in time and from farmer to farmer, it is useful to define the potential erosion as the soil erosion to be expected under the most unfavourable circumstances (as bare soil, without conservation practices). So, **potential erosion** is a function of merely physical factors (rain, soil, relief) and independent of soil cover, land use and land management.

Erosion hazard is a measure of the change that soil erosion will take place. When soil erosion has already begun, erosion hazard is the degree of the future erosion which can be expected. The erosion hazard is difficult to modify in so far as it is related to the factors of climate, relief, and soil. This relatively permanent hazard can be called land **erosion susceptibility or land erodibility** (Eppink, 1992).

Rainfall aggressiveness is the ratio $(p_i)^2/P$, where p_i is the highest mean monthly precipitation and P is the mean annual precipitation, which has been shown to be significantly correlated with sediment yields in rivers (Fournier, 1960). Using data from seventy-eight drainage basins, Fournier derived the following empirical relationship between mean annual sediment yield (Qs; g m^{-2}), mean altitude (H;m) and mean slope of the basin (S):

$$\log Qs = 2.65 \log((p_i)^2/P) + 0.46(\log H)(\tan S) -1.56$$

this equation has been used by Low (1967) to investigate regional variation in erosion risk in Peru, estimating erosion rates from 1000 to 7000 (tons/Km^2/year) and common value 1500 (tons/Km^2/year) which is double that found by Fournier for South America, the lower rates estimates are for the lower region with rain forest.

Where sufficient data are available on sediment yields in rivers they can be used as an alternative to measures of erosion intensity although, they may be unreliable as statements of rate of erosion on hillslopes.

Maps of regional variations in erosion have been prepared from sediment yield information for Yugoslavia (Jvanovic, 1958), Romania (Diaconu, 1969), and South Africa (Rooseboom, 1981).
An indication of actual rates of erosion was obtained by using the equations relating mean annual sediment yield to $(p_i)^2/P$ derived by (Fournier, 1960);
the following equations are appropriate to Peninsular Malaysia.
$Qs = 27.12p^2/P - 475.40$ for lowlands
$Qs = 52.49p^2/P - 513.20$ for highlands

where Qs is in (tons/Km^2/year); these equation predicted for the lowland areas rates between 880 and 2230 (tons/Km^2/year) with $(p_i)^2/P$ values between 50 and 100 respectively; and in the highlands rates of 2110 (tons/Km^2/year) with $(p_i)^2/P$ values of 50.
Comparing these predictions with measured rates in the lowlands with rates from 495 to 800 (tons/Km^2/year), and in the highlands rates from 670 to 1090 (ton/Km^2/year) where the $(p_i)^2/P$ values is less than 50, it can be seen that they are of the right order of magnitude for areas affected by man-induced erosion. They are too high, however, for rain-forested areas (Morgan, 1976)
A factorial scoring system for rating erosion risk has been devised by Stocking and Elwell (1973) in Zimbabwe.

Taking a 1:1.000.000 base map, the country is divided on a grid system into units 184 Km^2. Each unit is rated on a scale from 1 to 5 in respect of erosivity, erodibility, slope, ground cover and human occupation, the latter taking account of the density and the type of settlement. The scoring is arranged so that 1 is associated with a low risk of erosion and 5 with a high risk.

Several problems are associated with this technique; the classification may be sensitive to different scoring systems; each factor is treated independently whereas, there is in reality an interaction between them. Slope steepness may be much more important in areas of high than in areas of low erosivity. Taking into account spatial variation at a world scale, the relation between soil loss and climate shown that erosion reaches a maximum in areas with an effective mean annual precipitation of 300 mm.

At precipitation totals below 300 mm, erosion decreases as precipitation decreases. At precipitation totals above 300 mm the protection effect of vegetation counteracts the erosive effect of greater rainfall, so that soil loss decreases as precipitation increases (Langbein and Schumm, 1958).

This rating approach is also used in SLEMSA with the soil erodibility in the factor F_{base} and $F_{modifiers}$, this can be taken from local erosion data, as (Lantieri, 1990) in the Parana Brazilian state : where was presented in **ascending order of soil erodibility** :

Soil (units) Brazilian Classification / FAO Classification (group)

-Latossolo Vermelho Escuro, tex. (clay to clay loam) /Ferralsols
-Latossolo Roxo and Latossolo Bruno, tex. (clay) /Ferralsols and Nitosols
-Latossolo Vermelho Amarelo, tex. (clay) /Ferralsols
-Terra Roxa, tex. (clay) /Acrisols
-Cambissolo tex. (clay) /Cambisols
-Latossolo Vermelho Escuro tex. (sand to sand loam) /Ferralsols
-Podzolico text. (sand to sand loam) /Acrisols
-Litolico (high erodibility) /Lithosols

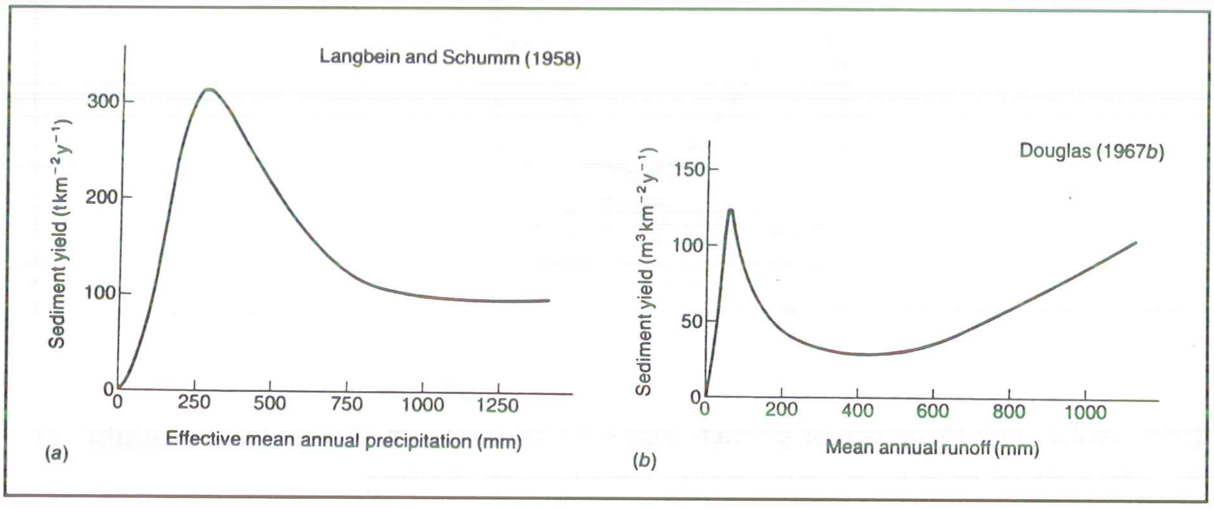

Figure 1.6.2.1. Proposed relationship between sediment yield and a) effective mean annual precipitation; b) mean annual runnof (after Gregory and Walling, 1973).

Soil erodibility and **rainfall erosivity** are two important physical factors that affect the magnitude of soil erosion. **Erodibility** as a soil characteristic, is a measure of the soil's susceptibility to detachment and transport by the agents of erosion. **Erosivity** is an expression of the ability of erosive agents as rainfall and wind to cause soil detachment and its transport.

Soil erodibility is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil particle to detachment and subsequent transport. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic mater content, nature of clay minerals, and chemical constituents.

Soil parameters that affect soil structure, slaking and water transmission characteristics also affect soil erodibility. These soil characteristics are dynamic properties. They can change over time and under different land uses, soil surface management, and cropping/farming systems. Soil texture is an important factor that influences erodibility because it affects both detachment and transport processes. The most susceptible textural range for detachment and transport is fine sand and silt. Thus soils derived from eolian parent material, loess, are very susceptible to erosion.

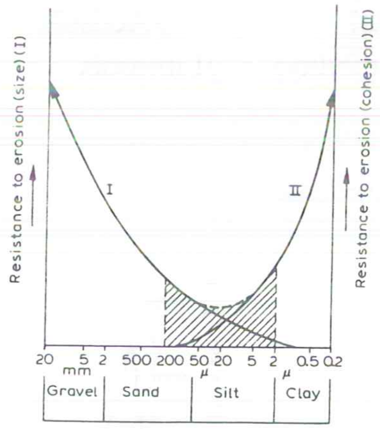

Figure 1.6.2.2. The influence of particle size (I) and cohesion (II) on the erodibility of soils. The zone of minimum resistance is indicated by shading.

Both USLE and SLEMSA models do not represent many interactions between erosion factors as erodibility, erosivity, slope, crop and soil management. That can be a sources of inaccuracy on erosion predicted models. The study of sediment yield became complex when human modification of the land use takes place, e.g. experiments at the Cerrado Research Station (CPAC, 1981). Showed that erodibility on a soil with slope of 5 %, no-tillage system, on soyaben, varied from the average erodibility factor K calculated by the Universal Soil Loss Equation K-value of 0.09 in the first year, to K= 0.39 in the second year to K= 0.50 in the third year, through compaction of the soil by management practices. The erodibility of the soil had changed in three years to give five times the rate of soil loss.

The USLE was designed to predict annual soil loss from sheet and rill erosion on a field scale, and does not take into account deposition; moreover it may be inaccurate for extreme slopes and textures, and in regions where the erosive forces are primarily from overland flow (Robinson, 1979).

The SLEMSA model basically works like USLE, only the management factor is left out of the model and can be adjusted according to available information from previous years management that might be applied as F_m modifier factor.
Many assumptions can be made in the model based on available information.
The factor rating is from 1 to 10.

The measurement of the rate of erosion can be accomplished using several approaches within a watershed. The **sediment yield** which is the total sediment outflow from a catchment measurable at a point of reference and a specified period of time on the mouth of a river basin, is not the same as the rate of erosion within the basin, because storage of eroded materials as colluvial and alluvial deposits can be much greater than the actual sediment yield measured at the mouth of the river basin. The relative magnitude of these potential sources depends on factors that include slope steepness and length, slope shape, soil type, land use, and rainfall characteristics.

Denudation Rates of river basin is the estimation of the land surface lowering measured as an threshold value of Ton/Km^2/year, expression of the general magnitude of erosion rate, used for relative comparison analyses, for example Erosion Hazard mapping.
The fraction of the gross erosion that is transported from a given basin as sediment yield is the **sediment delivery ratio** (Roehl, 1962)

Sediment Delivery Ratio(%) = (Y/T)*100

Where :
Y = sediment yield at measuring point
T = total material eroded from watershed and drainage ways upstream from the measuring point. The available information on sediment loads in rivers relates only to the material carried in suspension because of the technical difficulties in measuring bed load. They can be used to provide a reasonably reliable assessment of the global pattern of water erosion (Walling and Webb, 1983). The relative importance of the factors controlling spatial variations in erosion is dependent upon scale. The relation between delivery ratio and drainage area of the basin, for determined climate has been calculated for the Blackland Praire in Texas (Maner, 1962), as the following equation;

$$\log SDR = 1.8768 - 0.14191 \log (10 * A)$$

where :

A = basin area in Km^2

SDR = sediment delivery ratio in %

Sediment yield in a basin is computed by multiplying the water discharge by a discharge-weighted sediment concentration determined from suspended-sediment samples. The measurement equipment and procedures are different for small and larger catchment areas.

Sediment rating curves(Campbell and Bauder, 1940) : The sediment rating curve expressing the relationship between water discharge and sediment discharge rate can be constructed by sampling stream flow. Sediment yield frequency distributions and sediment rating curves (Williams, 1974).

This relationship is influenced by the anthropogenic factors as land use changes, making more complicated and less reliable.

In the LASOTER area, the Ibicui river basin has data on suspended sediment samples from 7 rivers, for better calibration of the models in the area.

Examples of similar studies with both models :

1) In the Zambezi river basin, the impact of land use change on erosion hazard was estimated using the model SLEMSA. An Approach based on a Geographical Information System was used to produce the soil erosion hazard maps for different land use scenarios : cropping, grazing and deforestation. (Leenaerts,H., 1990).

2) Water erosion risk in Canada is being estimated using USLE. The computed values of soil erosion were classified qualitatively to compare polygons by erosion risk class.(Shelton et. al., 1991).

3) In Kenya, soil loss due to water erosion and its related impact on productivity of land, was assessed. The methodology for the estimation of topsoil loss was based on USLE. Topsoil loss was subsequently converted into productivity loss, with or without specific soil conservation measures.(Kassam et.al., 1991).

Chapter 2 - Material and Methods

For the calculations of the erosion hazard index (EHI) the computer program SOTER Water Erosion Assessment Programm (SWEAP) was used (van den Berg,1992). This program was developed as application programme of the SOTER database. It contains modules for USLE and SLEMSA. Both models were adapted to be compatible with the SOTER database. The results of the runs for hypothetical situations of 6 types of Vegetation/Land use/Management, are written in tabulated form per SOTER unit (mapping unit) to a user defined output file.

These results were manipulated by the Geographical Information system using ILWIS software. They have been classified from quantitative values in (tons/ha/year) to 5 qualitative classes from none to very high, these classes are based in research done by (Lantieri, 1990) close to the study area in similar soil units relating soil losses (tons/ha/year) to qualitative erosion rates, and displayed as erosion hazard maps. Then these were compared with the present status of soil degradation shown in 5 classes from None to Severe from an pilot area LASOTER organized by the GLASOD methodology (Oldeman, 1991).

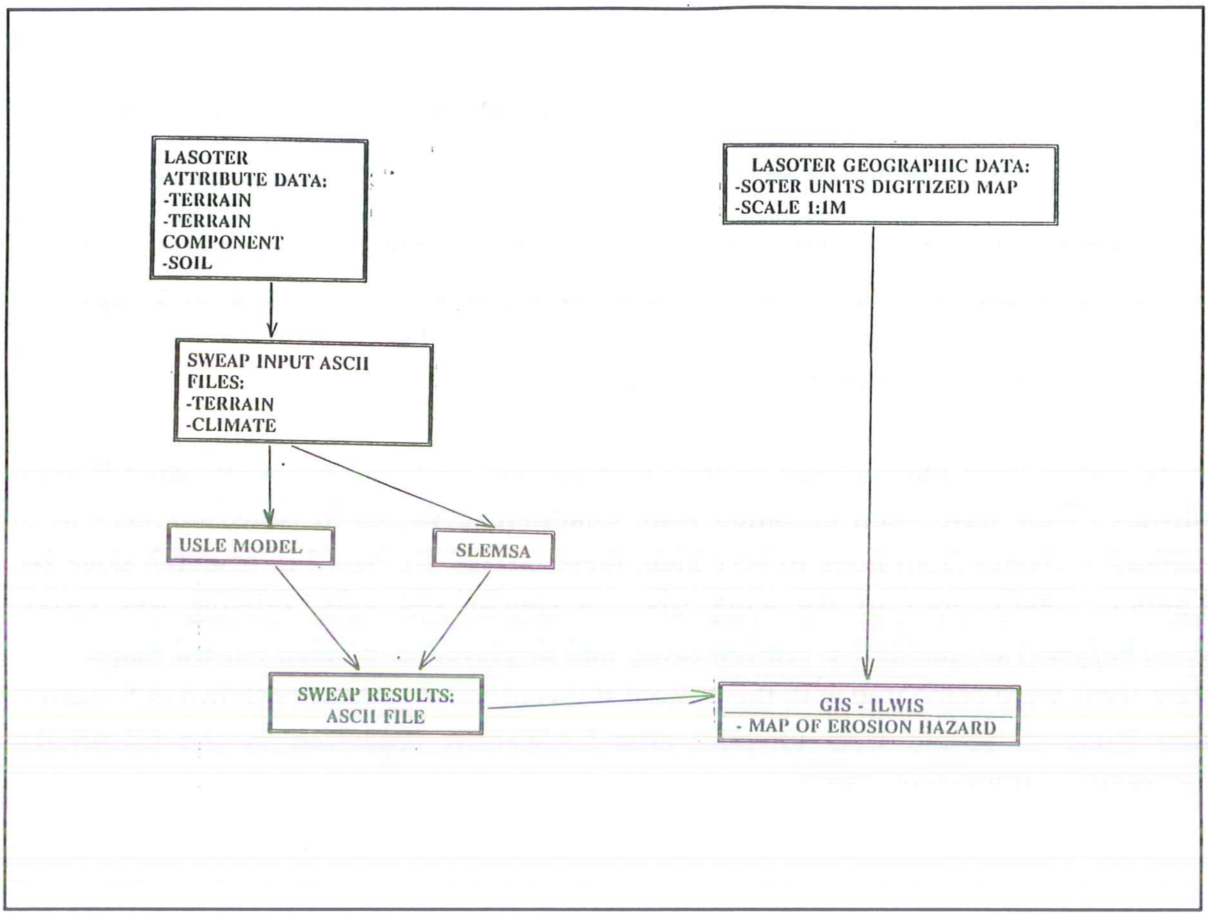

Figure 2. Diagram of the study.

2.1. The SWEAP Structure

SWEAP consists of two parts: (1) The menu and (2) the model. These parts must be linked with the SOTER facilities: (a) the data base and (b) the GIS. For a general description of the SOTER methodology see Van Engelen and Pulles (1991).

SWEAP's menu part is an interface between the user and the model. It enables the user to "tell" the model the boundary conditions that must be taken into account:

- From which INPUT file data will be retrieved
- To which OUTPUT file results are to be sent
- Which erosion hazard assessment model is to be used (USLE or SLEMSA).

- For which (hypothetical) situation of Vegetation/Land use/Management (=scenario) the calculations are to be made.

2.1.1. Soil Loss Model USLE

The model that is most commonly used to produce erosion hazard maps is the Universal Soil Loss Equation USLE, (Wischmeier and Smith, 1978).

$$A = R * K * L * S * C * P$$

where

A, the computed soil loss per unit area, here expressed in tons.ha^{-1}.$year^{-1}$.

R, the rainfall and runoff factor, expected in rainfall erosion (metric) units (meter-tons per ha x cm per hour x year)

K, the soil erodibility factor, i.e. the (long term average) soil loss rate per erosion index unit as measured on a unit plot, which is defined as a 22m length of uniform 9% slope, continuously in clean-tilled fallow. K is expressed in tons.ha^{-1}.$year^{-1}$.(rainfall erosion index $unit)^{-1}$

LS, the slope length and steepness factor, which is the ratio of soil loss from an field with specified slope length and slope gradient to that from the unit plot.

C, the cover and management factor; is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow. Then 0 for a completely protected soil, and 1 for a clean-tilled fallow.

P, the support practice factor, is the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight row farming up and down the slope.

Several of the components of USLE change on a seasonal basis, notably R and C. These are generally accounted for by first calculating annual weighted averages and subsequently multiplying the averages (e.g. Wischmeier and Smith, 1978; Kassam et al., 1991). A better result can be obtained however by first multiplying the factors for smaller periods, hence calculating short time A values, and then integrating the results in order to obtain a yearly figure. This involves more calculations. For the purposes of SWEAP a monthly time step *i* seems appropriate (van den Berg, 1992).

Hence the USLE was rewritten as:

$$A = \Sigma_{i=1,12} R_i*K*LS*C_i*P$$

The USLE model was developed in the United States based on empirical equations or tabulated relations for each of its parameters. As empirical relationships are valid only within the range of experimental conditions, there is no justification for expecting the same relationship to hold beyond the measured range (Hudson,1980).

2.1.2. Soil Loss Model SLEMSA

A model, that was especially designed for use at regional scale in Southern Africa, is SLEMSA (Elwell and Stocking,1982). In SLEMSA, four factors are used to summarize erosion hazard: (1) rainfall; (2) soil; (3) vegetation and (4) relief. These factors are described by five control variables: seasonal rainfall energy, E(in J/m2/year); soil erodibility, F (as an index); seasonal energy intercepted by the crop, i (in %); slope steepness, S (in %); and slope length, L (in m).

These control variables have been arranged into the equation:

$$Z = K * C * X$$

where :

Z, is the predicted mean annual soil loss ($t.ha^{-1.y-1}$);

K, means annual soil loss ($t.ha^{-1}.y^{-1}$) from a standard field plot 30 m x 10m at a 4.5% slope for soil of known erodibility F under a weed free bare fallow surface;

C, is the ratio of soil lost from a cropped plot to that lost from bare fallow land;

X, the ratio of soil lost from a plot of length L under slope percent S, to that lost from the standard plot.

Stocking et al.(1988) suggest to express the results in dimensionless Erosion Hazard Units (EHU) on a scale of 1-1000. This model has not been extensively validated yet (not even for Southern Africa).

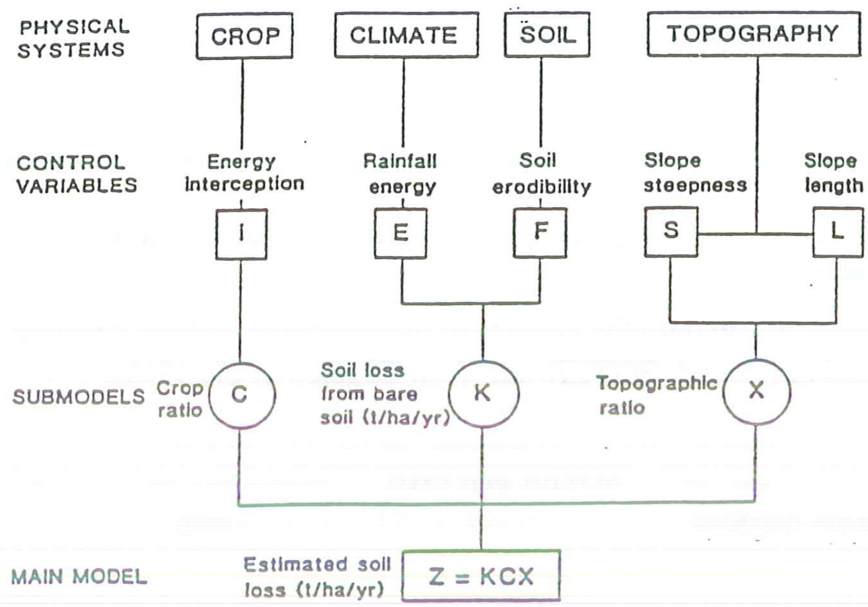

Figure 2.1. The framework of SLEMSA, from Stocking et al., 1988.

2.2. SOTER-World SOils and TERrain digital database for small scale.

The SOTER methodology (Shields & Coote, 1989) has the objective of producing a World Soils and Terrain digital database containing digitized map unit boundaries and their attribute database, supported by a file of chosen point data.
The SOTER database has an average scale of 1:1 million.The SOTER database structure is composed of two different data type:

1) **Geographic data**, file containing information on the location of each SOTER unit.

2) **Attribute data**, containing information about Terrain, Terrain Components and Soils stored in three interactive files:

-The polygon file
-The terrain component file
-The soil layer file

The geometric part is stored and handled in ARC-INFO and ILWIS geographic information system GIS software, while the attribute part is stored in a separate set of attribute files, manipulated by a Relational Database Management System (RDBMS) i.e. the DBASE software.

A unique label attached to both the geometric and attribute database connects these two types of information for each SOTER unit (van Engelen et al., 1993).

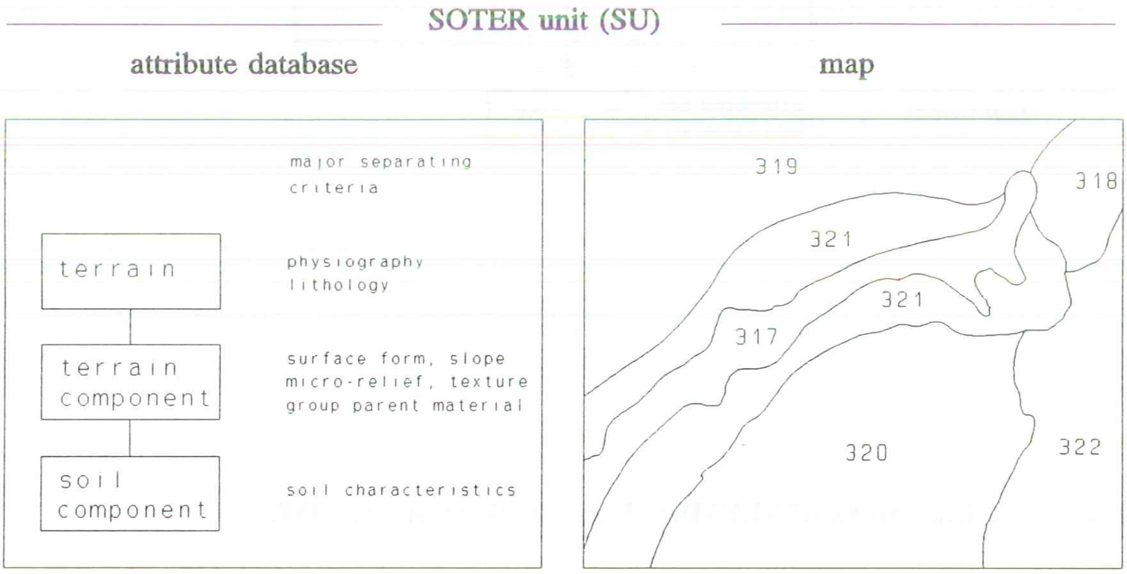

Figure 2.2.1. Relations between a SOTER unit and their composing parts and major separating criteria.

The attribute data consists of Soil and Climate data organized in DBASE files, the soil data is structured in seven files as LAYER.DBF, PROFILE.DBF, SOILPROF.DBF, SOILCOMP.DBF, TERRDATA.DBF, TERRCOMP.DBF and TERRAIN.DBF, according to the procedures described in the SOTER manual, with codified and standardized soil and terrain attributes.

These files are linked by one or more key fields creating an large file which is transferred to the geographical database (digitized LASOTER map) and displayed as an

map.
For reasons of database efficiency the SOTER database structure describes : Each SOTER unit in terms of a maximum of 3 terrain components. For convenience of computerization, a terrain component is defined as a segment of the overall landscape of a SOTER unit with comparable topographic (surface form and slope gradient) and soil patterns. For each terrain component, at least one soil is characterized; **a maximum of 3 soils may be characterized for each SOTER unit**.
Furthermore, terrain components and soils are indicated by the area which applies to the proportion of the SOTER unit.

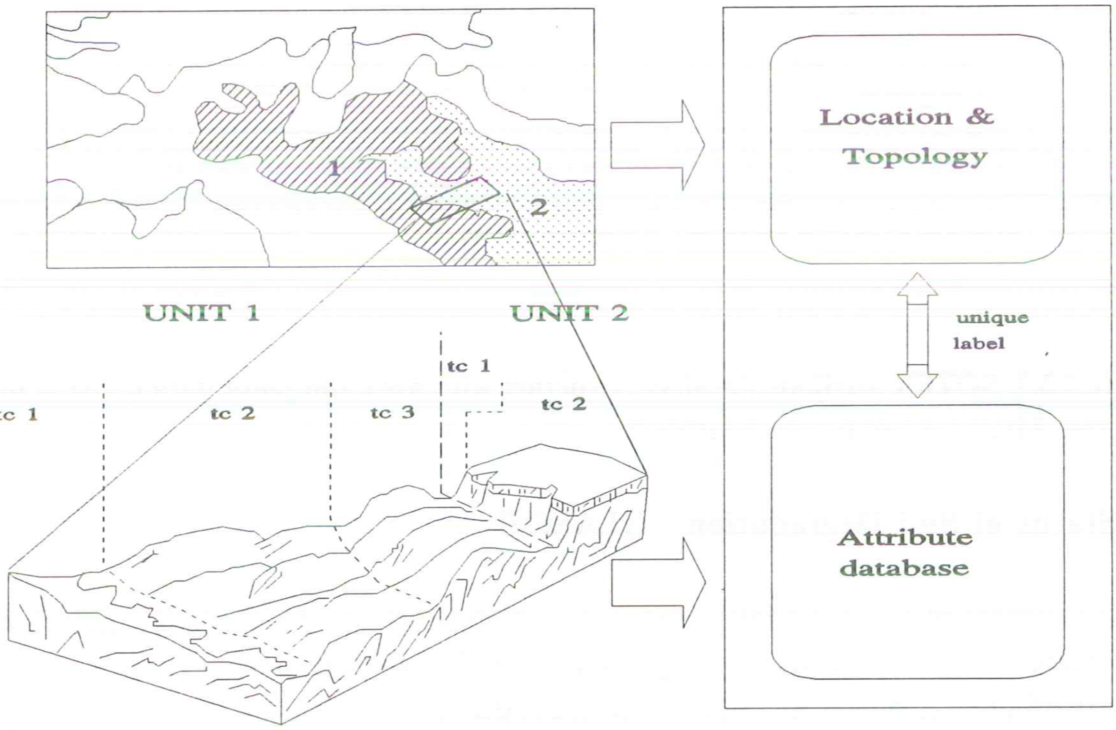

Figure 2.2.2. Soter units, their terrain components (tc), attributes, and location.

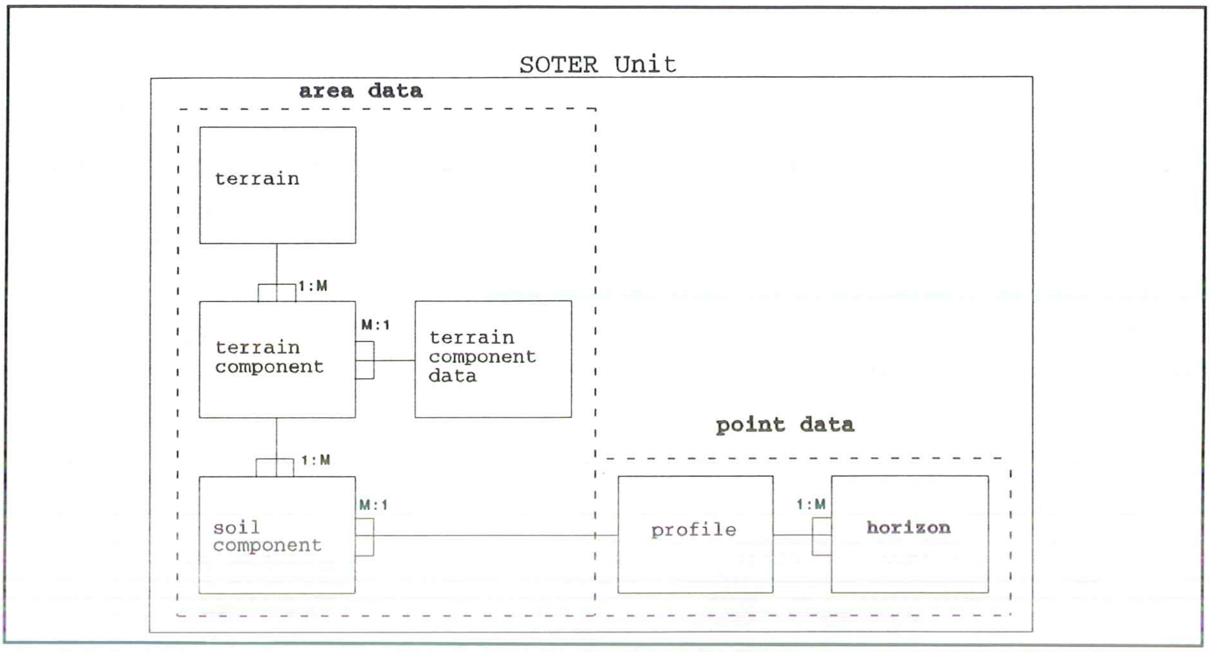

Figure 2.2.3. SOTER attribute database structure with area and point data (1:M = one to many, M:1 = many to one relations).

2.3. Status of Soil Degradation - GLASOD

The assessment of soil degradation induced by human activity the GLASOD guidelines (Oldeman, 1988) was the methodology used in the LASOTER area.
The GLASOD legend is explained in the appendix 4.
The most important natural factors in the LASOTER area, not considering land use and vegetation, intervening in soil degradation are the following :
- climate (rainfall intensity, duration and total)
- terrain (relief and slopes)
- soils (erodibility or erosion susceptibility, and infiltration)

as (Peters, 1990).
Erosion may be caused by one or both (with different intensity) of the following types :

Wd: water erosion, terrain deformation (rill and gully erosion).
Wt: water erosion, loss of topsoil (sheet and rill erosion).

The GLASOD map mentioned as "ground truth" in this study, is an qualitative map of the status of the soil degradation type Wt, which use the information of the first terrain

component of each SOTER unit, methodology described in (Oldeman, 1988).
where is described;
- **type of erosion**: Water, Wind, chemical or physical;

The soil degradation status is defined according the combination of degree and relative extent determining the severity;

- **degree** in four classes : from light to extreme;

- relative **extent** of the degradation type : given in four classes from 5 to over 50% of the unit affected;

- the **severity** : then 20 combinations are possible, grouped into 4 classes :
low, medium, high and very high.

The human-induced degradation types encountered in the LASOTER area were caused by factors such as pasture overgrazing, deforestation and intensive annual cropping. There are some comments after the GLASOD methodology was applied in the study area, as :
- The constraints were the shortage of information and the lack of apparent relation between land use, terrain component and human-induced degradation, that makes correlation at map unit level difficult because in each map unit several terrain components and several different kinds of land use may occur (Peters, 1990).

In many cases consultation of local experts was necessary and field checks had to be done.

- The concept of **soil layers** (SOTER, 1989) is : 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 50 to 150 cm. Usually the concept of **soil horizon** (genetic) do not fit in this 4 layers.

Therefore to avoid such problems the new 5 version (SOTER 1993), is working with soil horizon data, limited to 5 horizons to be described, and is a mandatory attribute, as well diagnostic horizon as (FAO/Unesco Soil Map of the World, 1988).

The map of the LASOTER area using the GLASOD methodology for the main type of erosion, see in Figure 2.3.1.(Map annexo) the following figures :
Figure 2.3.1 : Status on the main type of soil degradation

Figure 2.3.2 : Status on water type Wd (rill and gully erosion)
Figure 2.3.3. : Status on water type Wt (sheet and rill erosion)
Used as "ground truth" information, to compare with the predicted EHI values.

2.4. Soil Attribute Data

2.4.1. SOTER Data

SWEAP input is in the form of ASCII files extracted from the SOTER database version 4 (van Engelen & Pulles, 1991).
The program uses the following SOTER data:

Terrain component data:
1,2[1] SUID: Soter Unit ID (1[2]), integer number
1,2 SLOP: Dominant slope gradient (18), %
1,2 SLEN: Slope length (19), m
1,2 ROCK: Surface rockiness (24), % coverage
1,2 STON: Surface stoniness (25), % coverage
1 PDEP: Depth to parent rock (26), m

Soil data:
1,2 PROP: Proportion that the soil occupies within the SOTER Unit (36), %
1,2 RDEP: Rootable depth (38), cm

Profile data:
1,2 IDRN: Internal drainage (47), Alphanumeric class
1 SDEV: Soil development (49), Alphanumeric class
1 SCAP: Sensitivity to capping (52), Alphanumeric class
1 MSUB: Material below the pedon (53), Alphanumeric class

Layer data (only for first layer):
1 LDEP: Depth of lower boundary of layer (56), cm
1 BOUN: Abruptness of boundary (57), Alphanumeric class
2 STFO: Form of structure (60), Alphanumeric class
2 STSI: Size of structure elements (61), Alphanumeric class

[1]Variables marked with "1" are used for SLEMSA; variables marked with "2" for USLE.

[2]Numbers between brackets refer to the corresponding numbers given in the SOTER manual (Van Engelen and Pulles, 1991); p12 + Chapter 5.

2 STGR: Grade of structure (62), Alphanumeric class
2 CARB: Organic carbon content in the fine earth fraction (63), wt.%
1 ECE: Electrical conductivity of saturation extract (80), mS/cm
1,2 CFVO: Volume of coarse fragments (83), %
2 VFSA: Very fine sand, 0.05-0.1mm (90), wt.%
2 SILT: Silt, 0.002-0.05mm (91), wt.%
2 CLAY: Clay, <0.002mm (92), wt.%
1 TXTC: Texture class of the fine earth, (94), Alphanumeric class
1 1 DIAP: Diagnostic properties (100), FAO, Alphanumeric class (3 values)

Land use and vegetation data:
1,2 LUSE: Land use (II.6.1.3) Alphanumeric class
1,2 VEGE: Natural vegetation (II.6.2.3) Alphanumeric class

The program also requires that climate stations are linked to SOTER units, and not, as requested by the SOTER manual, just by the geographical coordinates. In the provisional soil ASCII file this is done by adding the following data:

CLIMFIL: Name of file with climate data
ICLIM: Code (max 5 characters) of the reference climate station.

Each line of the file CLIMFIL contains the following data:

- Station code (c.f. Van Engelen and Pulles, 1991: Annexo 4)
- Latitude of the climate station in degrees (negative values for southern hemisphere);
- Altitude above or below (negative) sea level (m).
- Name of the climate variable (c.f. Van Engelen and Pulles, 1991: Chapter 8).
- Twelve monthly average values of the climate variable.

SWEAP uses the following climate variables (monthly averages):

Variables used to calculate rainfall erosivity:
RAIN: Precipitation, $mm.month^{-1}$
RDAY[3]: Number of days with at least 1mm of precipitation ($day.month^{-1}$)

[3]Optional for certain methods to calculate erosivity (section 5.1.1 in SWEAP)

RMAX[4]: Maximum 24-hour rainfall in indicated month, (mm)

Variables used to calculate growing period:
TMIN: Minimum temperature during a 24h period, (°C)
TMAX: Maximum temperature during a 24h period (°C)
RADI or SUNH: Total radiation ($MJ.m^{-2}.day^{-1}$) or
Hours of bright sunshine per day
VAPP or HUMI: Vapour pressure (mbar) or
Average rel. humidity during 24h period (%)
WIND: Mean wind velocity at 2m during 24h. period, $m.s^{-1}$
PETP[5]: Penman, or PETT[5]: Thornthwaite potential evapotranspiration ($mm.month^{-1}$)

An example of a climate file is given in Appendix II, by the file TESTCL.DAT.

2.4.2. Updating of LASOTER Data

The database of the LASOTER area was created using the SOTER structure 2 version (Shields & Coote, 1989), therefore it was necessary to revise the data to version 4 (van Engelen & Pulles, 1991) for the purpose of use SWEAP.

Was necessary to create some new SOTER data parameters by correlation with the old ones, because in the version 4 has some soil parameters as **SCAP (Sensitivity to soil capping) used by SLEMSA** which do not exist in version 2 of the SOTER manual. The updating and correlation of these database was done within DBASE software, for the following parameters:

PDEP (depth to parent rock) used by SLEMSA : was correlated with the parameter LDEP(cm) lower depth of the lowest layer of the profile.

SCAP (Sensitivity to capping) used by SLEMSA: was correlated with the parameters CLAY%, SILT% and (CARB * 1.8)= O.M. degradation risk as a function of organic matter content (M.O.) and % clay plus silt was created Pieri (1989).

MSUB (Material below pedon) used by SLEMSA: this parameter was created from the parent material rock attribute parameter and given just three classes N (unconsolidated rock), R (unweathered hard rock), U (unknown),and P (petroplinthite) extracted from

---

[4]Optional

[5]Optional

the description of the SOTER units in the Brazilian technical report (EMBRAPA, 1988).

2.4.3. The SWEAP Terrain Input File

The attribute files were joined after the update procedure to SOTER (1991). The large attribute file with 1170 records has 487 SOTER units, 778 Terrain Components and 1170 Soil units, was copied as an ASCII file.
The SOTER units are distributed among the three countries as follows : from; 1 to 155 in Brazil, 1001 to 1264 in Argentina and 2001 to 2083 in Uruguay.
The order of parameters names in the SOTER ASCII file is the same as the one given in the item 2.4.1., and lines are in ascendent ordered by SOTER unit number, the proportion of occurrence of the soils in the SOTER unit are largest first.

2.5. Climatic Attribute Data

2.5.1. The Climate Input File

The two original climatic files were joined by the station number code, in total the area has 59 climate stations distributed as follows : 30 in Argentina, 13 in Brazil, 13 in Uruguay and 3 in Paraguay.
The data consist of monthly averages ranging from 10 to 40 years.
The data set is not complete enough to calculate the R-factor using the four options given in the SWEAP programme, just for 11 stations in Brazil the two parameters RDAY and RMAX are given.
In about 17 stations TMAX and TMIN were defaulted from the near station, to make the set of data complete necessary to run SWEAP.
The raw yearly data without average are given for 18 stations, an example of this file is given in the appendix 9.

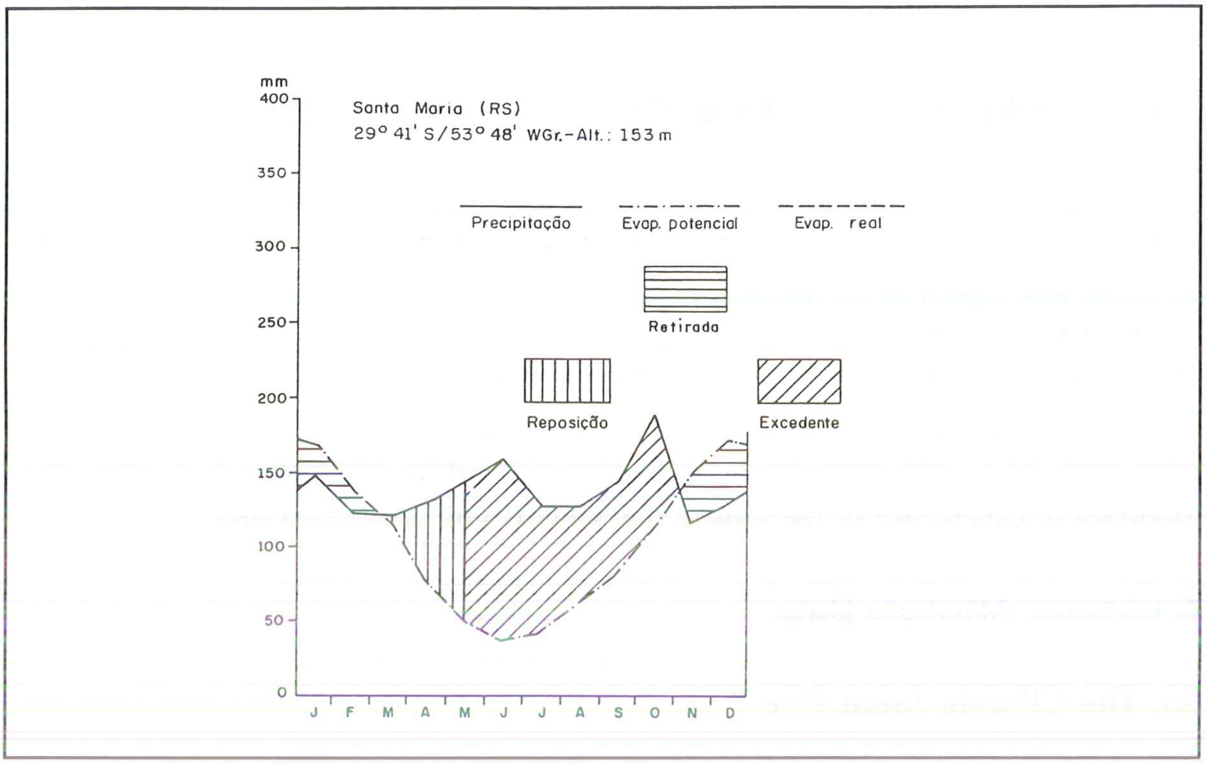

Figure 2.5.1. Water balance at the Brazilian station Santa Maria.

2.5.2. Thiessen Polygons Approach

The link between each SOTER unit attribute data and the meteorological stations, was done by using ILWIS and Thiessen polygons methodology.

The construction of the Thiessen polygons is based on the assumption that the observation made at one particular point can be attributed to all points that are closer to the considered point of measurement than to any other point of measurement where similar observations are or have been made simultaneously.

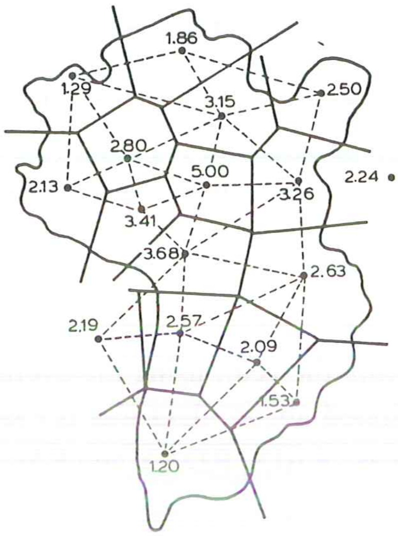

Figure 2.5.2. Example of Thiessen polygons network for average precipitation.

2.6. Geographical Data, LASOTER Units Map

The geographical data consists of the LASOTER polygon map, a vector and a raster map used in ILWIS and ARC-INFO GIS software.
The raster base LASOTER map is used as a frame for the display of the attribute data, showing the geographical distribution of it.

The software ILWIS uses the attribute data in tabulated format with the label of each SOTER unit, it is the joint "key" between attribute and geographic data.

The SWEAP results are given for a maximum of 3 soils, in values of (erosion hazard index-EHI) per SOTER unit.
The maps of the 12 scenarios were created with information of EHI from the first soil, the biggest, of the SOTER unit, representing more than 40 % of the area of the SOTER unit.

2.7. Model Parameters, (SLEMSA and USLE factors)

Available Information from local experiments, to derive model parameters :

The factor L (length of the slope) was limited in the LASOTER database as maximum of 400 feet or 120 m as described by (Wischmeier, 1978).

The R and E factor (rainfall erosivity) were analyzed by using LOTUS software for the 4 methods proposed in (SWEAP, 1992) for calculate R Factor : Bols, Fournier, Ateshian and Roose; and 6 for E Factor : Stocking, Kassam, Lal and Marx.

Monthly average data:

To define the variation of R factor within the year, using the average precipitation data and the four different methods mentioned above; data was prepared from 9 Brazilian stations, which have the complete data as : RAIN, RDAY and RMAX (described in item 2.4.1.).

To define the accuracy of the 4 different methods a comparison was made between the R factor values from literature, measured according to Wischmeier et.al.(1978), and the one calculated from the average monthly precipitation with the four methods; based on values for the specific sites within the study area.

A correlation analysis was made with the two most realistic methods : Fournier and Roose.
The best fit found in the correlation analysis was used to improve the method.

Precipitation data on a yearly basis for 25 years period:

The raw data on a yearly basis was analyzed to investigate the effect of precipitation variation within the period of 25 years, and consequently the R factor calculated with Fournier and Roose methods.

Therefore the climate station El Molino-UR9 from Uruguay was used for this objective.

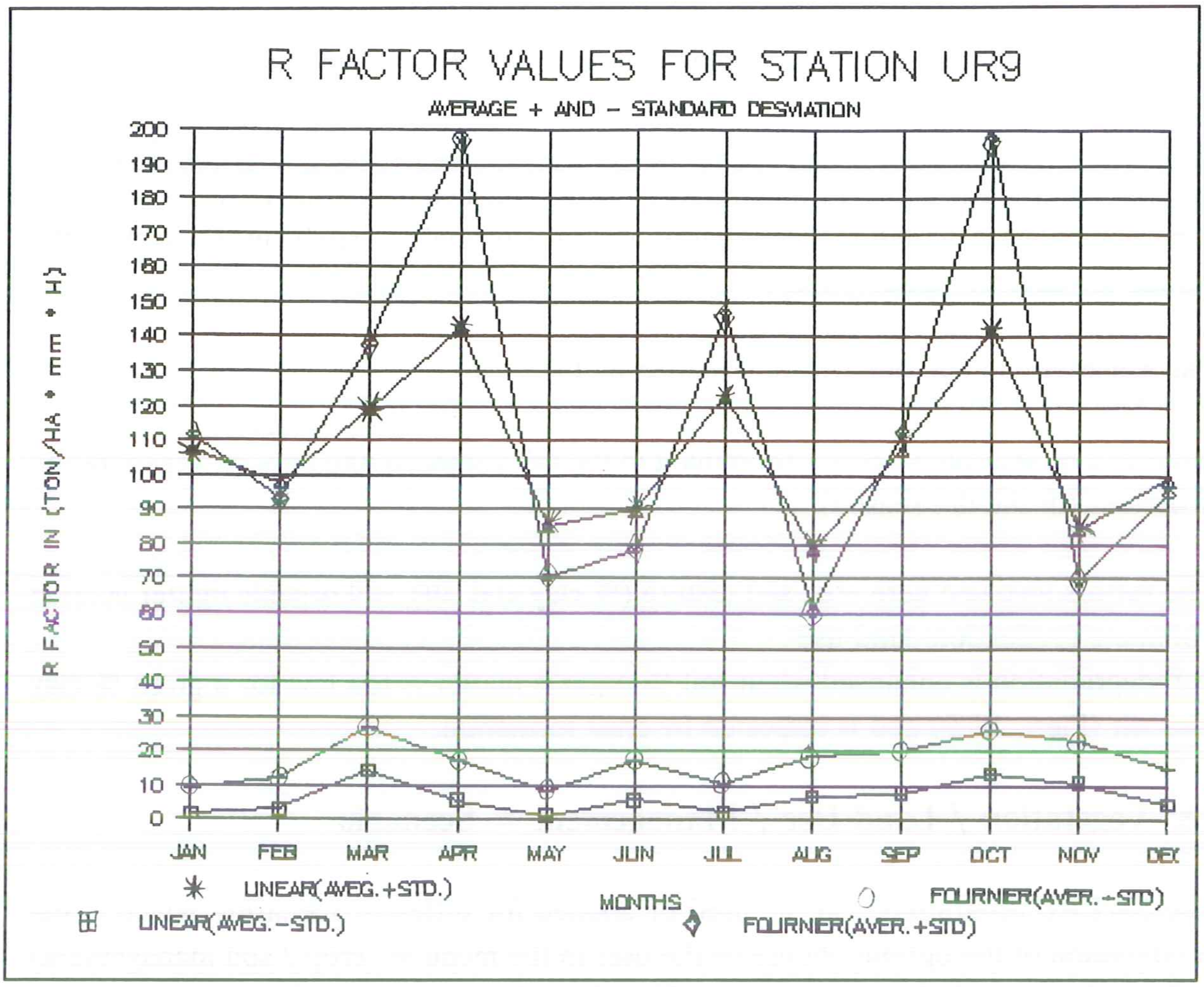

Figure 2.7.1. R factor calculated for climate station El Molino(Ur.),using linear and Fournier methods .

SLEMSA F modifier factor

The SLEMSA model has and F factor which is a soil erodibility rating from 1 (extremely erodible) to 10 (extremely resistant).
These **basic** values of the F factor are depending on the texture class and type of soil development (Kassam et al., 1991) and (Stocking et al., 1988).

The basic F factor can be **modified** according to the following factors : soil management, internal drainage, salinity, presence of a lithic contact, the presence of abrupt horizon boundaries or the sensitivity to capping (see appendix 7).

SLEMSA is very sensitive to F modifiers, especially at high erodibility levels. Therefore it is crucial that the basic adjustment factors be established experimentally. If there is no experimental basis to define these factors, a sensitivity analysis can be useful to show the results for different assumptions.

The sensitivity to capping was determined by Piere as :
the physical condition of the top soil which is the resultant of two types of processes: physical degradation processes (dominant in the rainy season) and physical regeneration processes (in the dry season).

The factors involved here are : soil texture (% clay and silt), soil organic matter content , biomass production, land use .
Soil degradation is enhanced when soil % organic matter is too low for a given % clay plus silt (Pieri, 1989) and is indicated by crust formation.

2.8. Vegetation / Land Use / Management = Scenario

The SWEAP programme can be used or applied for different scenarios, which is the combination of the options choose by the user in the **menu** as (crop / soil management) and the lay-out of the **consweap.cnf** file where is determined the R and E factor regression coefficients (see SWEAP, 1992).

Characteristics of consweap.cnf file used in this study;

- result layout number 1, soil within each SOTER unit sorted by area, biggest first; see SWEAP, (1992) in section 4;
- the equation used to calculate the R factor for USLE was adjusted with the results of an regression analysis, was created an new option with power equation, modifying the original SWEAP programme.

SWEAP was modified as : were was the linear equation E/R type 4 (Table 6 in SWEAP, 1992) became;
$R = 0. + 0.028(P)^{1.64}$, with the power type possibility and 3 regression coefficients;

- results in tons/ha, so not classified

then the others options were keep constant as in the (SWEAP, 1992).

Land preparation practices in the study area

An excess of soil preparation and the lack of soil cover or vegetal residues in periods of intense rains are the main cause of erosion and also soil degradation : loss of organic matter and nutrients, modification of the soil's physical characteristics, making the crop more sensitive to drought, provoking productivity losses.

Traditional soil preparation:

This is the most common form of soil preparation in the are, there is normally one heavy disk harrowing combined with three or four lighter harrowing before each planting. Vegetal residue are not left on the soil surface and usually this technique create a "plough pan" by the weight of the disks always in the same depth.

Conventional soil preparation:

This type of land management uses disk ploughing and two light harrow disks. Previously conventional land management was practice more than today; but the heavy disk harrow has replaced the disk plough because it is quicker and cheaper.

Minimal tillage:

Generally one chisel ploughing takes the place of one disk ploughing or disk harrowing in the primary preparation of the soil. Vegetal residues are left on the surface. The cost of this form of preparation are lower than those of conventional land management and almost the same as traditional land management.

No tillage:

In the no-tillage system, soil is not prepared but planting is done directly on the previous crop stubble. This technique limits erosion due to greater soil protection by crop residues and no exposition of soil particles to rainfall impact, wind and sun erosivity.
The advantages of that system for tropical soils are ; higher water availability in the soil, decrease temperature, preservation of soil structure and increase of biological activity, on the other hand it has some disadvantages as ; high level of technology, soils must have good drainage and a medium to high fertility level and the equipment is more expensive.

However, the no-tillage system is the most protective soil preparation technique.

Land cultivation practices:

Contour cropping :

Contour cropping reduces soil losses due to erosion. studies have shown that such losses can be reduced from 700 to 100 (ton/ha/year) if traditional land management is practice in contour lines and terracing.

Terracing:

The size of the terraces varies from 2-3m width , to 2-6m and 6-12m.
Erosion studies at Agricultural Institute of Parana (IAPAR) Brazil, based on 6 % slope have show that when tillage is performed up and down the slope, erosion can be as high as 700 (ton/ha/year).

When tillage operation are performing on the contour, losses can still be up to 400 (ton/ha/year) while when the combination of terracing and minimum tillage is applied erosion losses can be reduced to less than 100 (ton/ha/year) (Bertoni et al., 1975; Modardo, 1978).

Green manuring:

The green manuring is the main point to convert for non-tillage system, used to substitute winter fallow, and providing soil cover and organic matter, reducing soil losses, improving crop rotation, increasing recycling of nutrients, and also for controlling weeds and some nematodes.

Others practices :

Soil conservation is also improved by avoiding fires after the harvesting and by ploughing in just before planting.
Crop rotation is very important to preserve the soil resources, like alternation of the summer crop between soybean, corn and crops suitable for the non-tillage systems with high dry matter production, which will be soil cover and slowly recycled in the soil.

The Scenarios for the area and according to the proposal of the study are;
The following 6 scenarios are choose from the SWEAP menu;

1) **Actual land use (from SOTER database).**

2) Animal husbandry , extensive grazing from the next menu and finally **ranching.**

3) **Annual crop rotation with 2 crops, soybean in summer, sow in November and harvest in February, and wheat in winter, sow in April and harvest in August.
The option contouring and no-tillage.**

4) **Annual crop rotation as in the scenario number 3, with contouring and ploughed in after harvest was select for both crops in residue control menu.**

5) **Annual cropping soybean mono-cropping, with the same soil management of scenario number 4.**

6) **Bare soil .**

For each scenario an erosion hazard index (EHI) map will be presented by using both USLE and SLEMSA models.

The codes of the 12 scenarios presented are the letters U for USLE and S for SLEMSA model followed by the number of the scenarios above, like : U1, S1, U2, S2, U3, S3, U4, S4, U5, S5, U6 and S6.

The scenarios S1 and U1 with the actual **land use as showed in SOTER** will be compared with the **"ground truth"** of the area GLASOD-Wt map (degradation water type Wt- sheet and rill erosion).

Manipulation of the results in ilwis

The maps were created from the predicted values in tons/ha/year of both models USLE and SLEMSA, because both models are not calibrate for the area, there is no reliability for qualitative values.

Therefore the maps were classified in 5 qualitative classes as in GLASOD map, shown in table 6.
The 5 top classes intervals used are extracted from an similar study in the Brazilian Parana state, where approximate correspondence between erosion rates from low to high and soil losses (ton/ha/year) for different soil types.
The soil type "Podzolico" in FAO system Orthic acrisols gives the highest erosion rates, which was used for classified the maps S1 and U1 (Lantieri, 1990).

Histogram U1 map			Histogram of S1 map		
top-class interval predicted values (ton/ha/year)	class (%)	class value created	top-class interval predicted values (ton/ha/year)	class(%)	class value created
0	25.0	0 NONE	0	45.6	0 NONE
10	62.0	1 LOW	10	52.2	1 LOW
50	3.7	2 MEDIUM	50	1.7	2 MEDIUM
200	0.6	3 HIGH	200	0.6	3 HIGH
1000	0	4 VERY HIGH	1000	0	4 VERY HIGH
-1	8.8	MISSING VALUES	-1	0	MISSING VALUES

Table 2.8. Map Classification Procedure.

2.9. Statistical Analysis of the SOTER Parameters

The software program SPSS/PC+ was used for the statistical analysis of the numerical variables sited in 2.4.1..
The program was used to determine : Mean, std.Dev., S.E.Mean, Range, Max., Min., Sum., Histogram frequency, Percentiles : 10, 25, 50, 75 and 90.

The purpose of the statistical analysis was to find the base values for each input variable in both models, and use this base values to performance a sensitivity analysis.
See the base values in the table 3.3. chapter 3.

2.10. Sensitivity Analysis for the Model Parameters:

- This analysis was conducted to determine the relative change in the model output with respect to changes in the selected inputs.
-Each input variable was decreased and increased by 50 and 25 percent, one at the time, while the others were kept constant.
-The output values were analyzed to determine their change in relation to the base values.
-Base values were taken from average values.
Sensitivity was defined as follows:

$$SENS = [X_{+50\%}-X_{-50\%}] / X_{base}$$

where; SENS : sensitivity for change in the variable
$X_{+50\%}$: output value when variable increased with 50%
$X_{-50\%}$: output value when variable decreased with 50%
X_{base}: base value of variable

2.11. Sediment Yield Data from the IBICUI Basin

2.11.1. Method

The Ibicui basin is an important basin at the right margin of the Uruguay river in the LASOTER area crossing different geological, geomorphological, soils and land use provinces. In the Ibicui basin 7 gauging stations are present to collect routinely measurements on suspended loads in rivers and consecutive discharge data during several years.

Samples are taken as suspended-sediment periodically during flow events and discharges from the same day, this data can be used to compute annual sediment discharge.

These data are part of an Brazilian small scale river-sedimentology survey by the ELETROBRAS governmental institution. The methodology used to calculate sediment yield of each basin
is described by (ELETROBRAS, 1992), as;

- the annual estimation of the average sediment yield or deposition rates (ton/Km^2/year) are calculated just from stations with more than 5 months of data.

- the formula $S = 0.0864 * C * Q_n$, where C is the monthly average of the daily concentration in (mg/l), Q_n is the monthly average of the daily discharge from the same day of the concentration samples, and the S is the monthly sediment (ton/month).

- if it is not possible to determine daily discharge $Q(m^3/s)$ from the same day of collection than the daily average from the station for the same month is used.

- the monthly C values are obtained from the average of the all daily measurements of a respective month, since the establishment of the station.

Denudation Rates were calculated dividing the total predicted or measured sediment yield by the basin area resulting values of Tons/Km^2/Year.

Sediment Delivery Ratio (SDR) % , was calculated as (Y/T)*100 where T : total material eroded, where used as the results from the models EHI and Y : sediment yield at measuring point as the data available, where DR_r was used to calculated the Y .

Station	Annual Avg Conc(mg/l)	Bas. area (km^2)	DR_r (ton/ km^2/year)	Upst. total area (km^2)	DR_t (ton/ Km^2/ year)
1	67	3310	35	3310	35
2	66	12077	23	12077	23
3	80	1826	31	1826	31
4	48	2296	85	2296	85
5	67	9812	69	29321	45
6	50	5942	33	5942	33
7	45	7235	(-92)	42498	20

Table 2.11.1. Measured sediment yield, were;

- DR_r : denudation rate of the basins on the basis of the individual area, calculated from the sediment yield related to this specific area.

- DR_t : denudation rate of the basin on the basis of the total area upstream from the measuring point, which could belong to more them one basin, calculated from the sediment yield related to this total upstream area.

For this study were used the DR_r Sediment yield from the individual area.

2.11.2. Description of the IBICUI Basin

The 7 river gauging stations within the ibicui basin have the follow description;

RIVER AND STATION NAME	/ TOTAL AREA (Km²)	/ AREA CONCERNED
1) Toropi, Ponte Toropi	3310	3310
2) Santa Maria, Rosario do Sul	12077	12077
3) Cacequi, Cacequi	1826	1826
4) Jaquari, Jaquari	2296	2296
5) Ibicui, Manuel Viana	29321	9812
6) Ibirapuita, Alegrete	5942	5942
7) Ibicui, Passo Mariano Pinto	42498	7235
TOTAL	**42498**	**42498**

These 7 river gauging stations and their respective basins or drainage areas were digitized as overlay of the LASOTER units map and corrected to (Albers Conical Equal Area Projection).

The area of the SOTER units was determined per each basin. The calculations of the predicted sediment yield with both models and compare with the measured one was manipulated in Lotus software.

Chapter 3 - Results

3.1. Rainfall Factor

3.1.1. R Factor USLE Model

Annual R factors were calculated with the four methods proposed in SWEAP using average monthly precipitation from climate station El Molino-UR9.

1) Bols : 6326 metric units
2) Fournier index : 585 metric units
3) Ateshian : 32039 metric units
4) Linear Roose : 723 metric units

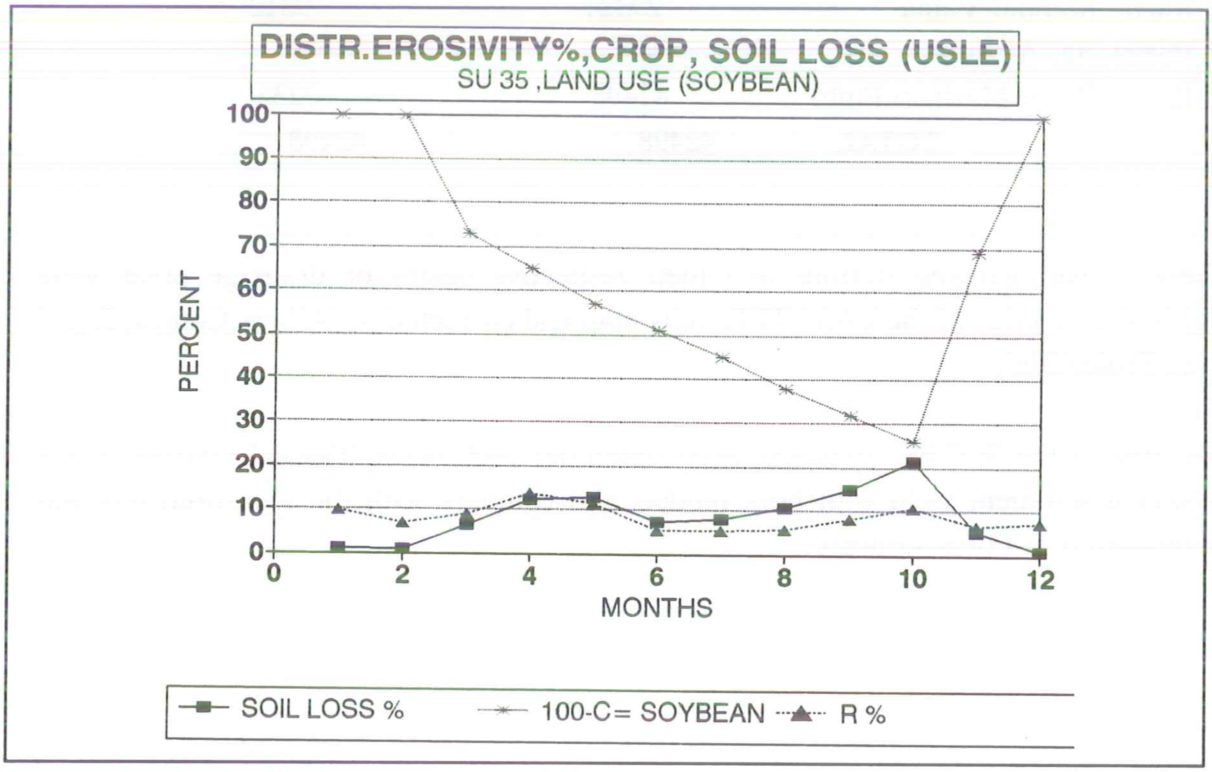

Figure 3.1. Graphs of Rainfall R factors calculated with adjusted linear method, (100 - C factor) and the seasonal soil loss from SWEAP, of SOTER unit 35 from climate station Alegrete (Brazil).

The figure 3.1. show the highest soil loss on october, correspond to an increasing of the R factor and decreasing of the soil cover (crop factor).

Within the 3 different countries, the data from Argentina and Brazil are average monthly precipitation data from more then 10 years, but the one from Uruguay is monthly precipitation by year as a raw data, them the statistic parameters was determined the variation within these 25 years of data, and the respective calculated R factor from the average plus or minus the standard deviation was calculated.

The two most appropriate methods for the calculation of the R factor from average monthly precipitation data was : modified Fournier index (Arnoldus, 1980) and linear equation (Roose, 1980).

- The modified Fournier method :

$$F_m = \Sigma_{i=1,12} P_i^2/P_{ann}$$
$$R_{Arnoldus,i} = a + bF_m$$

where,

$R_{Arnoldus,i}$ is the estimated R factor for month i in metric units (Ton per ha x cm per hour);

F_m The modified Fournier index

P_i average rainfall in month i (mm);

P_{ann} annual rainfall;

a and b are site specific empirical constants.

As SWEAP works on a monthly basis the program uses the monthly value of the modified Fournier index ($F_{m,i}$) to estimate R_i.

- The linear Roose method :

$$R_{Roose,i} = (0.5 \pm 0.05)P_i,$$

where,

$R_{Roose,i}$ is the estimated R factor for month i in metric units (Ton per ha x cm per hour);

P_i is the average monthly rainfall in mm.

The two alternative methods have been tested with regression analysis against R values (metric units) computed by Rojas, 1985 and Pannone, 1983 using Wischmeier & Smith, 1978 method. The R values where from 3 climate stations in Argentina and 3 in Uruguay.

Data regression analysis.

The name of the stations;
from Argentina : Rosario, Mercedes, Concordia;
Uruguay : Paysandu, Rivera, Paso de los Toros.

Alternative 1) Fournier/Arnoldus R factor showed the best fit of Fournier R ($R_{Arnoldus,i}$) to Wischmeier's R was a power function.
The follows four different types of regression equations; regression coefficients and the respective r squared are;

Exponent : $R = 20.44 * Exp(0.02 * R_{Arnoldus,i})$ n = 72, $r^2 = 0.54$

Linear : $R = 16.59 + 0.94 * R_{Arnoldus,i}$ $r^2 = 0.57$

Logarithmic : $R = -79.03 + 37.80 * Ln(R_{Arnoldus,i})$ $r^2 = 0.58$

Power : $R = 1.97 * (R_{Arnoldus,i})^{0.88}$ $r^2 = 0.70$

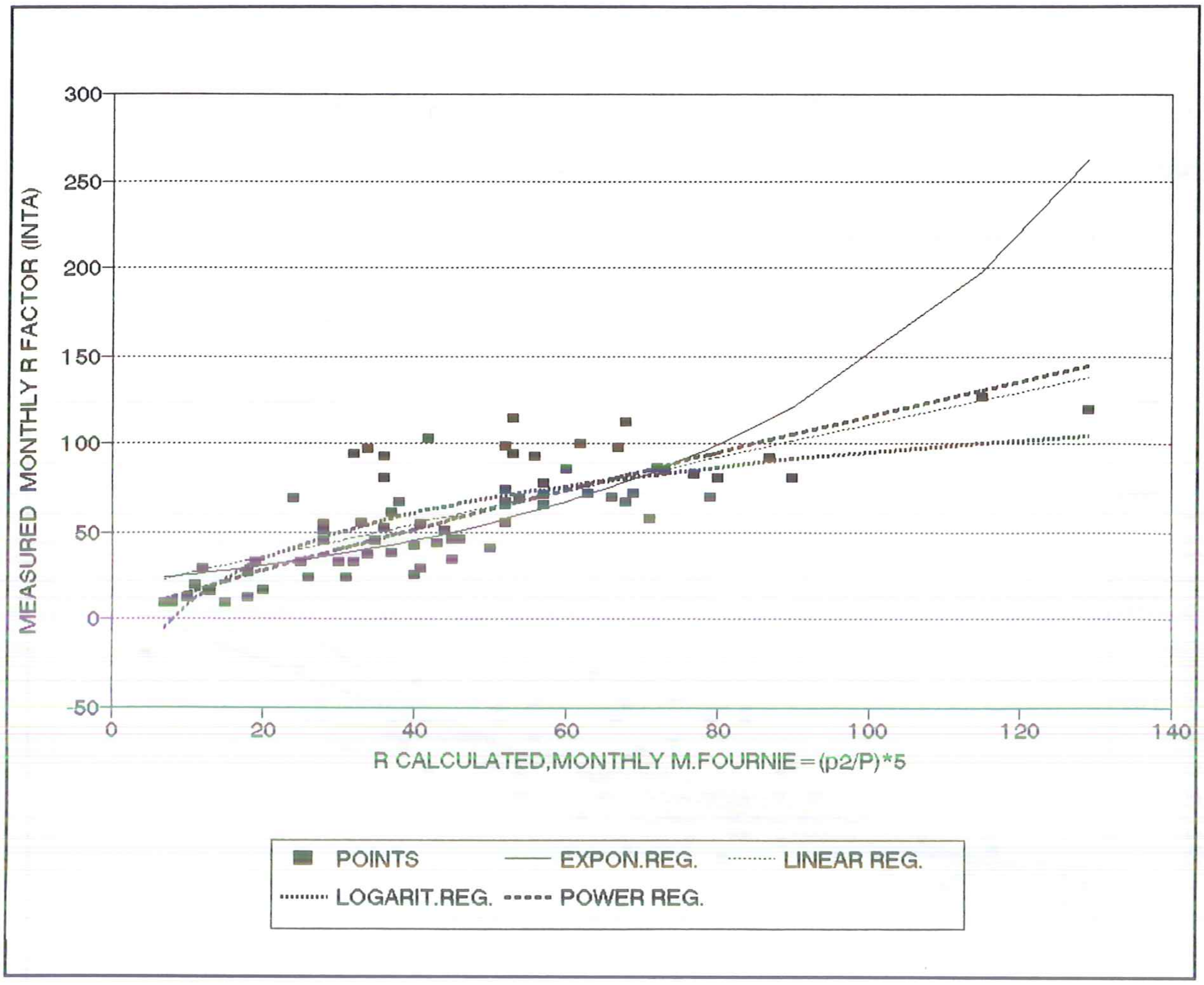

Figure 3.1.1. Regression equations with Fournier R values

Alternative 2) Linear/Roose R factor showed that the best fit relationship for Roose R method was a power relationship between ($R_{Roose,i}$) and R.
The follows four different types of regression equations; regression coefficients and the respective r squared are;

Exponent : $R = 8.48 * Exp(0.03 * R_{Roose,i})$ n = 72, $r^2 = 0.64$

Linear : $R = -21.59 + 1.44 * R_{Roose,i}$ $r^2 = 0.61$

Logarithmic : $R = -223.87 + 71.09 * Ln(R_{Roose,i})$ $r^2 = 0.59$

Power : $R = 0.07 * (R_{Roose,i})^{1.66}$ $r^2 = 0.70$

The relationship between P_i Monthly precipitation in mm and R gives the equation, which was chosen to used in this study;

Power : $R = 0.028 * (P_i)^{1.64}$ $r^2 = 0.71$

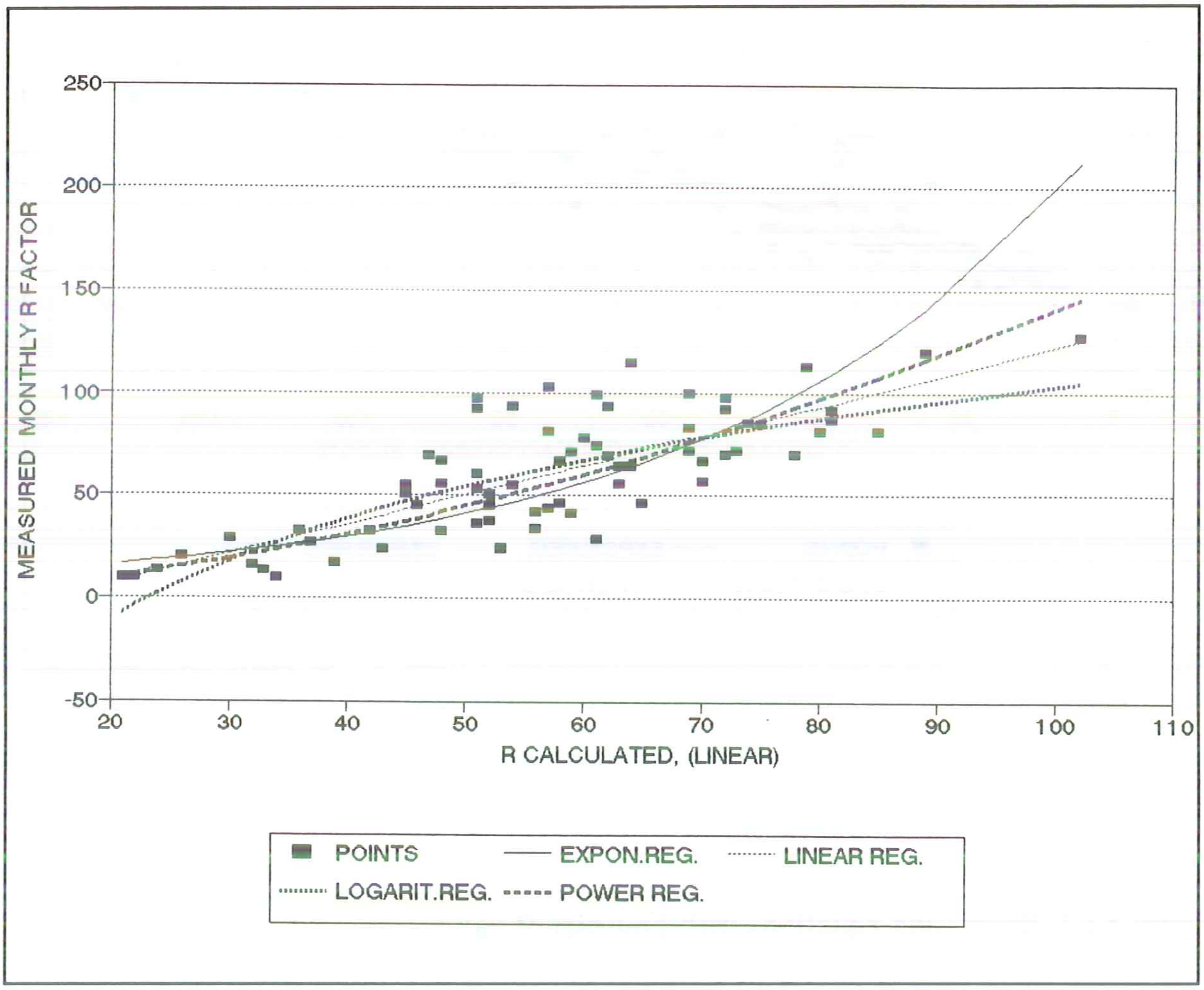

Figure 3.1.2. Regression equations with Roose R values

3.1.2. E Factor, Rainfall Energy (SLEMSA)

The follow linear equation relating rainfall energy $E(J.m_2)$ to average monthly precipitation P in (mm), was estimated from erosion plot experiments carried out four years by Dr Lombardi Neto, Instituto Agronomico, Campinas, Sao Paulo to compare soil losses under four different management systems (Stocking, 1982).

YEARS	EI_{30} (ton/ha x mm/hr)	kinetic energy, E (joules/m^2)
1973/74	844	
1974/75	596	
1975/76	902	
1976/77	770	
MEAN (4 years)	**778**	**15000 (estimated)**

The 22 year mean annual rainfall of the area is 1367mm, and from this data was derived an simple linear relation : **E = 12.0 P** , the reliability of this linear relation is not known because of the lack of data for the area.

This data has some limitations as : thy are not from the same area, and they were derived from a simple linear relation using average annual precipitation, but in SWEAP is used average monthly precipitation.

3.2. Mapping the Soil Erosion Hazard Index using ILWIS

The results of the SWEAP model is manipulated in the ILWIS GIS and displayed 12 erosion hazard maps, see on (Map annexo) **Figure 3.2.1. Scenario 1U to Figure 3.2.12. Scenario 6S..**

3.3. Discrepancies Between the GLASOD Map and SWEAP Results

The scenarios 1U and 1S results were compared with the qualitative map of present status of soil degradation with 5 classes from None to Extreme, a "ground truth" of the area, using the GLASOD methodology.

3.3.1. Scenario 1U and 1S Compared with the GLASOD Map

The comparison was possible after classify the scenario 1U map, from predicted value (tons / ha / year) in 5 qualitative classes as described in chapter 2 and subtract one map from the other.

Difference between SLEMSA scenario S1 (actual landuse from SOTER) and GLASOD-Wt map show that 44,6 % of the map area is equal, 52,3 % has an difference of one class, 3.1 % has an difference of two classes, which are SU numbers : 33, 35, 36, 54, 133, 137, 153 and 2048.

The difference between USLE scenario U1 (actual landuse from SOTER) and GLASOD-Wt map shown that 7.9 % are missing values, 44.6 % of the map area has the same qualitative class of EHI, 45,3 % has a difference of one class, and 2.1 % has a difference of two classes which are the SU : 33, 35, 2074, 2075 and 2076.

The differences between these two maps bigger than 1 were taken as check soil units to explain these differences between predicted erosion and actual erosion.

The following SOTER units where selected with the follow criteria :
1) occurs in the same qualitative class (from none to high) in the GLASOD map.

2) with difference bigger than 1 class in the map comparison.
They were aggregate to show the differences between predicted USLE and SLEMSA EHI values in tons/ha/year and the following qualitative classes and the actual erosion class in GLASOD map.

soil units numb.	36	54
Glasod map class	high	high
map 1U,(EHI)ton/ha and classified map	13 medium	13 medium
map 1S, (EHI)ton/ha and classified map	4 low	4 low

soil units numb.	19	21	18
Glasod map class	medium	medium	medium
map 1U,(EHI)ton/ha and classified map	2 low	2 low	2 low
map 1S, (EHI)ton/ha and classified map	3 low	5 low	5 low

soil units numb.	28	132	141	53
Glasod map class	low	low	low	low
map 1U,(EHI)ton/ha and classified map	0 none	0 none	0 none	11 low
map 1S, (EHI)ton/ha and classified map	0 none	0 none	0 none	7 low

soil units numb.	2074	2075	2076	51
Glasod map class	none	none	none	none
map 1U,(EHI)ton/ha and classified map	14 medium	14 medium	14 medium	4 low
map 1S, (EHI)ton/ha and classified map	3 low	3 low	3 low	1 low

Table 3.3.1. SOTER units erosion hazard index-EHI comparison

3.4. Sensitivity Analysis

The standard values for the variables of both models, indicated as 1) for variables of SLEMSA, and 2) for variables of USLE; investigated in the sensitivity analysis are presented in the Table 3.4.

SLEMSA :1 USLE: 2	VARIABLES	(- 50 %)	BASE VALUE	(+ 50 %)
1; 2	slope %	1	2	3
1; 2	slope length (m)	300	400	600
1; 2	surface rockiness %	3	6	9
1; 2	surface stoniness %	3	4	6
1	depth to parent rock (m)	0.6	1.2	1.8
1; 2	rootable depth (cm)	20	40	60
1; 2	internal drainage class	W	I	P
1	soil development	VE	GL	LU
1	sensitivity to capping	W	M	S
1	material below pedon	N	S	R
1	depth of lower boundary (cm)	20	40	60
1	abruptness of boundary	G	C	A
2	form of structure	1	2	3
2	organic carbon wt %	1	2	3

1	electrical conductivity mS/cm	1	2	3
1; 2	volume of coarse frag%	1	2	3
2	very fine sand wt %	1	2	3
2	silt wt %	20	40	60
2	clay wt %	10	20	30
1	texture classes	LS	SI	SIC
1	diagnostic properties	FL	TC	SO
1; 2	land use	AA4-50%	AA4:SOYABEAN	AA4+50%

Table 3.4. Values used in the sensitivity analysis.

USLE Model

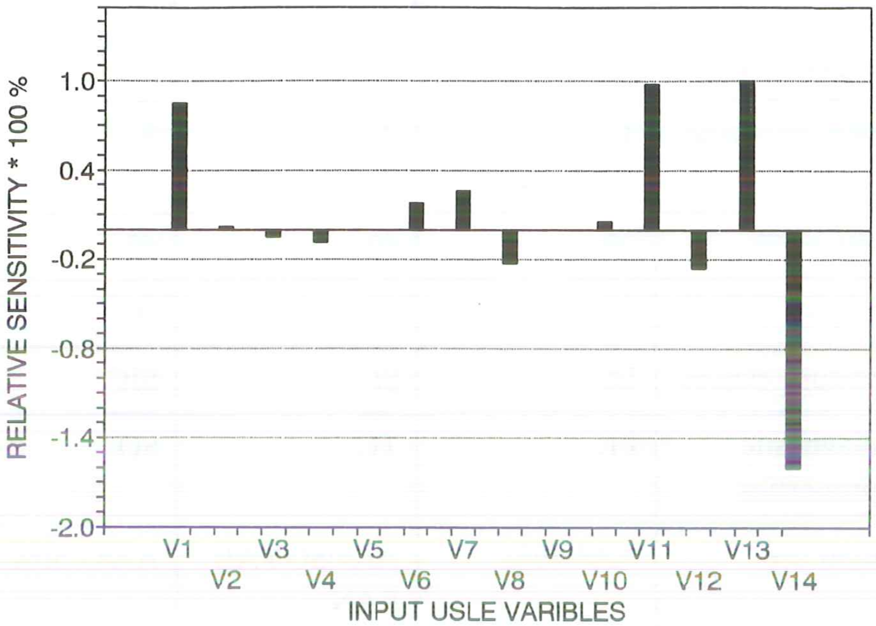

Figure 3.3.1. Sensitivity for the different parameters : V1 = slope, V2 = slope length, V3 = surface rockiness, V4 = surface stoniness, V5 = rootable depth, V6 = internal drainage, V7 = form of structure, V8 = organic carbon content, V9 = volume of coarse fragments, V10 = very fine sand, V11 = silt, V12 = clay, V13 = Rainfall, V14 = crop factor/land use.

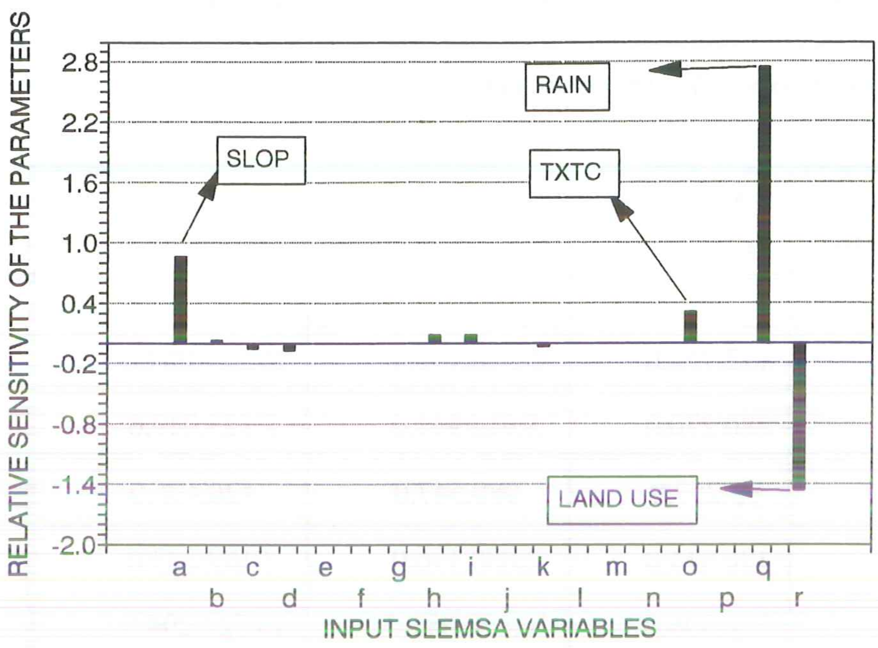

Figure 3.3.2. Sensitivity for the different parameters : a = slope, b = slope length, c = surface rockiness, d = surface stoniness, e = depth to parent rock, f = rootable depth, g = internal drainage, h = soil development, i = sensitivity to capping, j = material below pedon, k = depth of the lower boundary of layer, l = abruptness of boundary, m = electrical conductivity of saturation extract, n = volume of coarse fragments, o = Texture class, p = diagnostic properties, q = rainfall, r = crop factor/land use.

3.4. Validation for the IBICUI Drainage Basin

3.4.1. Measured and Predicted Total Sediment Output per Basin

Sediment Yield (tons/year)

BASIN NUMBER	MEASURED	USLE	SLEMSA
1	112.752.0	5.316.472.0	15.527.064.0
2	280.270.0	5.916.941.0	2.123.049.0
3	63.257.0	980.547.0	426.496.0
4	176.911.0	2.880.196.0	7.187.223.0
5	710.306.0	10.628.051.0	18.522.294.0
6	189.723.0	2.420.660.0	2.068.074.0
7	673.446.0	8.590.788.0	11.292.834.0

Table 3.4.1. Sediment yield (tons/year)

3.4.2. Denudation Rates (tons/km2/year)

BASIN Nº	MEASURED	RANK	USLE	RANK	SLEMSA	RANK
1	35.0	3º	1650.0	1º	4819.0	1º
2	23.0	C	482.0	A	208.0	C
3	31.0	B	480.0	B	209.0	B
4	85.0	1º	1383.0	2º	3453.0	2º
5	69.0	2º	1032.0	4º	1799.0	3º
6	33.0	A	421.0	C	359.0	A
7	-92.0 dep	D	1173.0	3º	1542.0	4º

Table 3.4.2. Denudation rates (tons/Km^2/year) The ranking are in descending order, the high values are assign with (Nº) corresponding to the basins with sediment yield mainly from acid effusive material like rhyolite, rhyodacite and dacite, and the low values (letters) corresponding to the basins with sediment yields mainly from Permian sedimentary rocks and basalt.

3.4.3. Sediment Delivery Ratio-SDR (Measured at the mouth of the basin / the total predicted by the models) * 100 %

BASIN Nº	USLE	RANK	SLEMSA	RANK
1	2.1	6º	0.7	6º
2	4.7	5º	11.4	2º
3	6.5	3º	14.8	1º
4	6.1	4º	2.5	5º
5	6.7	2º	3.8	4º
6	7.8	1º	9.2	3º
7	-7.8	7º	-6.0	7º

Table 3.4.3. Sediment Delivery Ratio-SDR %

3.5. Regression Analysis Between Predicted and Measured Sediments

The best fit relationship between predicted USLE sediment yield (tons/year) and measured values on the 7 basins, was an linear relation ;

n = 7 $Y = -50.5 + 0.069 * X_{usle}$ with an $r^2 = 0.82$

Where Y is measured value and X is the predicted values of the sediment yield.

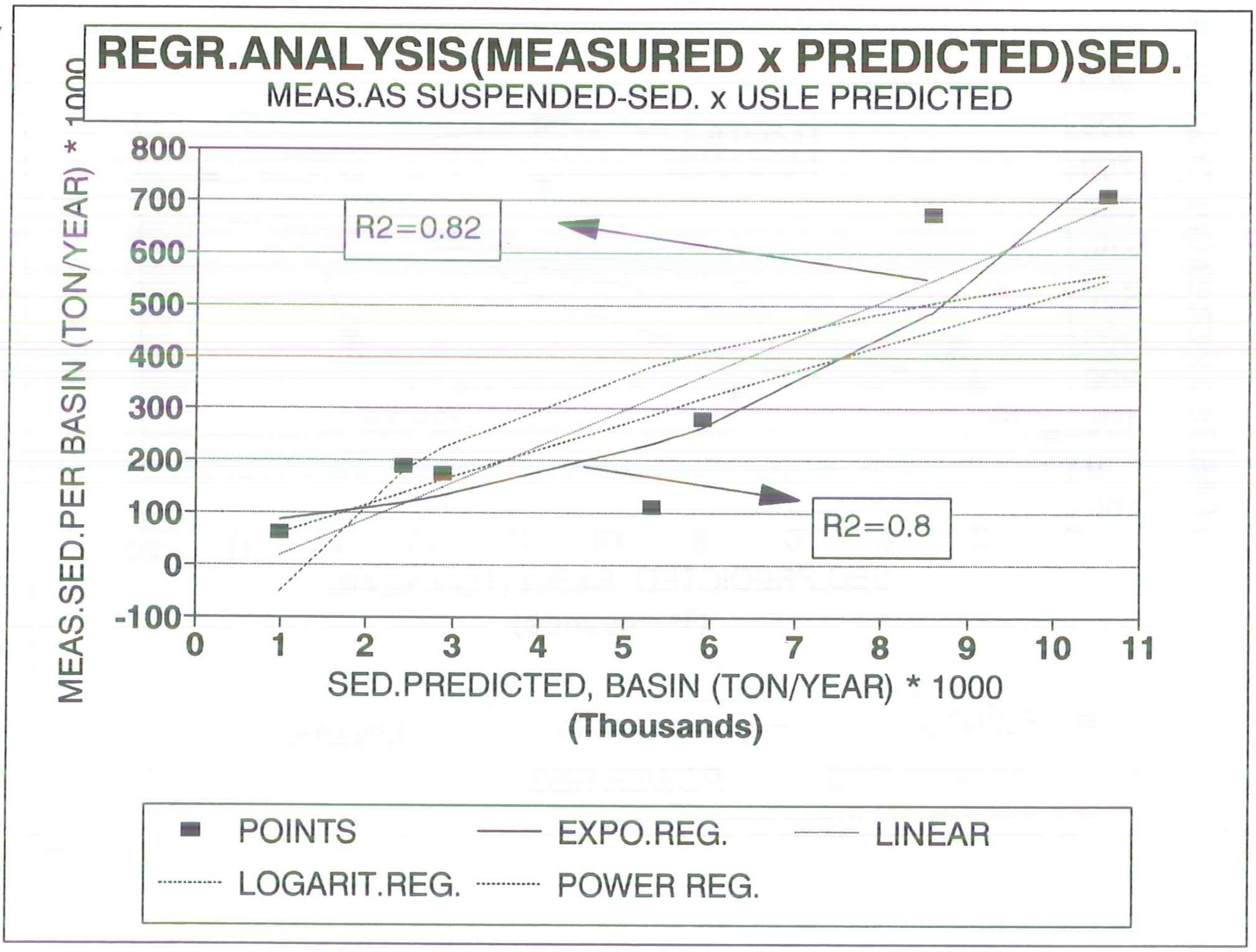

Figure 3.5.1. Regression Analysis using USLE values

From the regression analysis with SLEMSA values,was found an high fit according to the linear equation;

n = 7 $Y = 89.3 + 0.036 * X_{slemsa}$ with an $r^2 = 0.80$

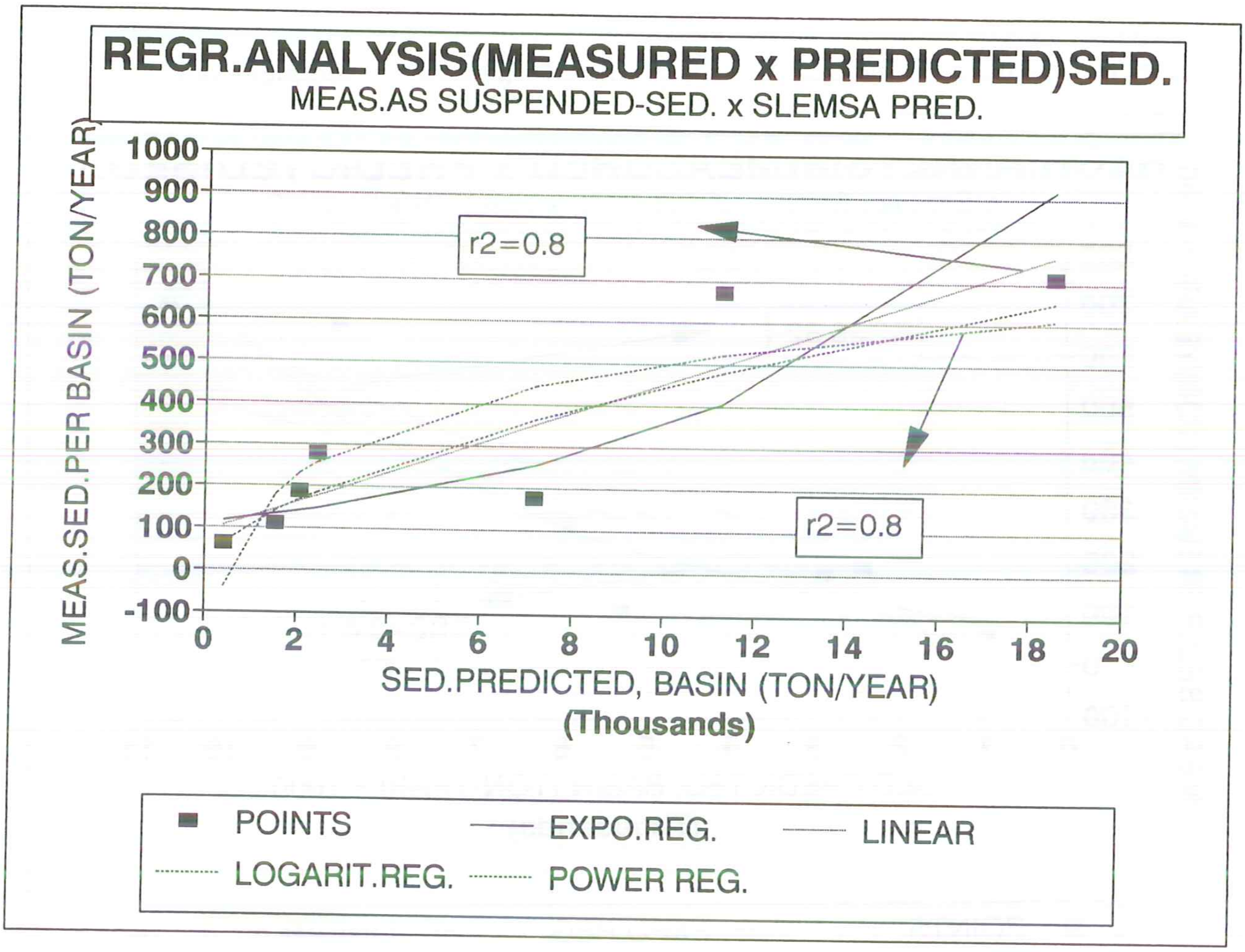

Figure 3.5.2. Regression Analysis using SLEMSA Values

3.6. Sediment Delivery Ratio (SDR) %

The Figure 3.6.1. shows the sediment delivery ratio (SDR) % , explained in iten 1.6.2. as (Y/T)*100 where T : total material eroded where used as the results from the models and Y : sediment yield at measuring point as the data available sited on iten 2.11 where DR_r was used to calculated the Y .

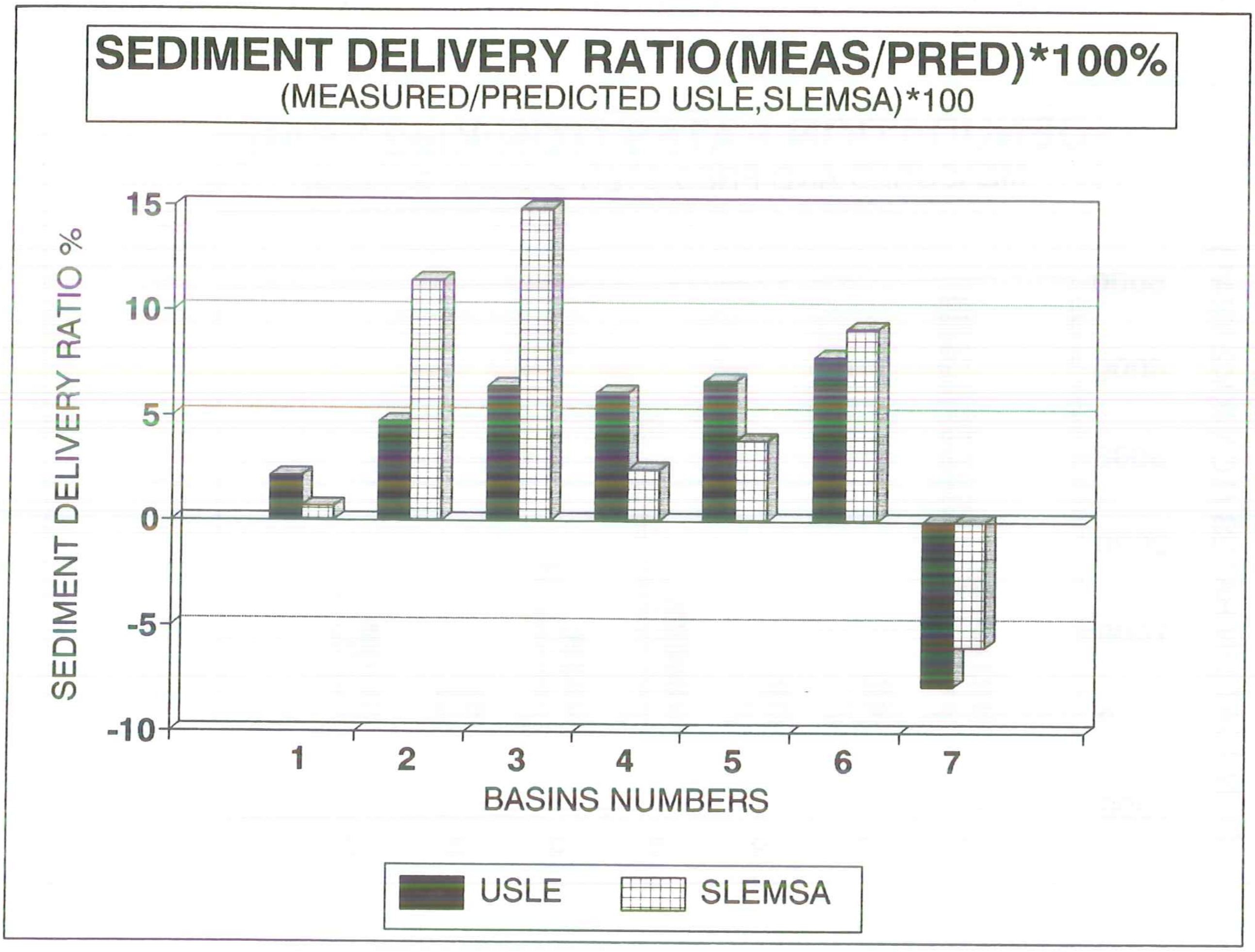

Figure 3.6. The Sediment Delivery Ratio (SDR) %

3.7. Denudation Rates (DR)

Figure 3.7. shows the denudation rates calculated as sited in iten 2.11..

The DR was calculated dividing the total predicted or measured sediment by the total area of the basin resulting values of Tons/Km^2/Year.

The measured values are very low compared with the predicted ones, due to the deposition within the basin and as well because of errors of the models over-estimation. The negative values of the measured sediments for the basin number 7 represents deposition rates of Tons/Km^2/Year, which both models don't consider, been an limitation of these models on that analysis of sediment yield within river basins.

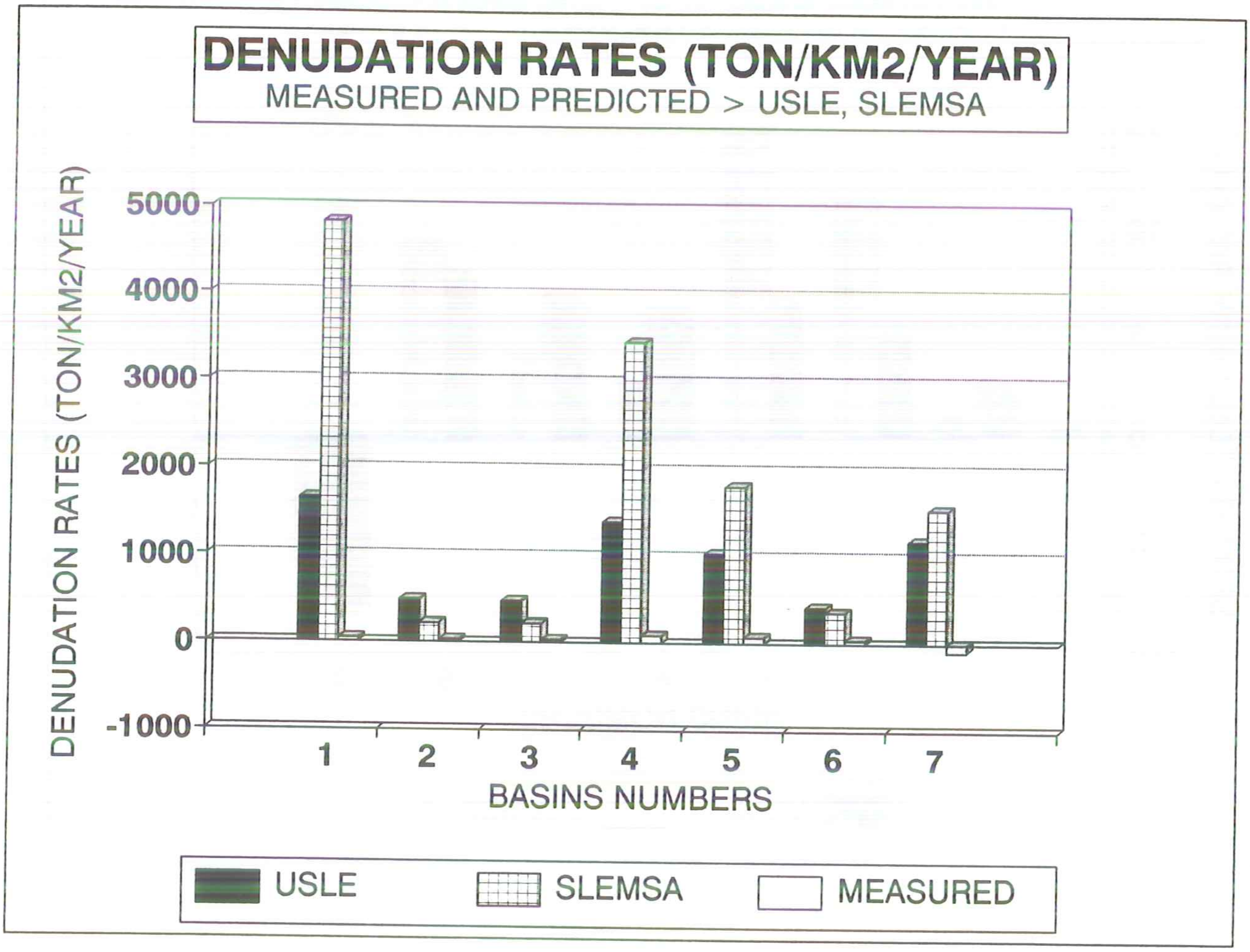

Figure 3.7. Denudation Rates

3.8. Relation between Geology, Geomorphology, Soil Type, Land Use x

Denudation Rates.

The map of the LASOTER area has the following criteria to determine the Polygons or SOTER units, based on soil and terrain characteristics;

- **SOTER unit or terrain** : is an area of terrain with a distinctive, often repetitive pattern of 1) surface form, 2) slope, 3) parent material, 4) soil and 5) climate (Shields, 1989).
- **Terrain component** : is a segment of the overall landscape of a polygon with often the repetitive pattern of 1) Soil parent material, 2) Texture class of parent material, 3) local surface form, 4) slope gradient, and 5) soil patterns.

The SOTER units were grouped on the basis of a unique combination of :
- Regional landform,
- Parent material,
- Text. class of parent material,
- Local surface form,
- Slope % class,
- Major soil grouping,
- Landuse,
- percentage of the basin area (for the main groups, no 100 %)
- percentage of the sediment yield by USLE,
- percentage of the sediment yield by SLEMSA,
- representatives SU of the basin.

The group of SOTER units with the specific combination of soil characteristics are described in the follow 7 tables, with the aim of comparing and explaining the measured and predicted sediment yield on the 7 basins.

Only the more representative groups of SOTER units were described on these 7 tables, that is reason because the sum of the areas % is not completing 100 %.

Regional land form	Upland	Hilland	Upland	Upland
Parent material	Acid effusive rock as; rhyolite, formation 4	Basalt, formation 4 (on item 1.4.4)	Acid effusive rock as; rhyolite, formation 4	Sandstone, Siltstone, and claystone, formation 6
Text. Class of parent material	Sandy	Loamy	Loamy	Sandy
Local surface form	Rolling	Steep	Rolling	Rolling
slope% class and middle point	class from 4 to 9%, 6%	class from 30 to 59%, 40%	class from 4 to 9% , 6%	class from 4 to 9 % , 6%
Major soil groupings	Lithosols	Lithosols and Cambisols	Acrisols and lithosols	Acrisols
Landuse	Natural pasture	Natural pasture	Natural pasture	Natural pasture
SU Nº	28	35, 33	30	49
sed.yield % with USLE	9	77	2	3
sed.yield % with SLEMSA	2	95	1	1
% of the basin area	47	17	13	9

Table 3.8.1. Soil an Terrain Characteristics in Basin 1 (area=3310 Km^2)

Regional land form	Valley	Upland	Upland	Upland
Parent material	Recent alluvial material, formation 1	Claystone and Siltstone, formation 7	Sandstone, formations 5 and 6	Siltstone, formation 8
ext. Class of parent material	Loamy	Loamy	Sandy	Loamy
Local surface form	Level	Rolling	Rolling	Rolling
slope% class and middle point	class from 0 to 3 %, 2%	class from 4 to 9% , 6%	class from 4 to 9% , 6%	class from 4 to 9% , 6%
Major soil groupings	Planosol	Planosol and Acrisols	Acrisols	Phaeozems
Landuse	Annual crops wetland rice and pasture	Natural pasture, wetland rice, wheat, soybean and corn	Natural pasture, wetland rice, wheat, soybean and corn	Natural pasture
SU Nº	51, 140	70, 152, 125, etc.	80, 123, etc.	150, 131
sed.yield % with USLE	21	36	4	22
sed.yield % with SLEMSA	13	34	16	15
% of the basin area	26	21	17	14

Table 3.8.2. Soils and Terrain characteristics in Basin 2 (area = 12077 Km^2)

R.l.form	Upland	Valley	Upland	Upland	Upland
Parent material	Sandst., format.6	Recent alluv. materialform. 1	Clayst. siltst., form. 7	Siltst., form. 7	Sandst., siltst. clayst., form. 7
Text.Cl.par .Mat	Sandy	Loamy	Loamy	Loamy	Sandy
Local surf f.	Rolling	Level	Rolling	Rolling	Rolling
S % class, mid.P.	6 to 9 % , 6%	0 to 3 % , 2%	4 to 9% , 6%	4 to 9% 6%	4 to 9% , 6%
Major soil grouping	Acrisols	Planosol	Planosol and Acrisols	Phaeozem	Acrisols
Landuse	Natural pasture and annual crop as wetland rice, corn and soybean	Annual crop as wetland rice and pasture	Natural pasture and wetland rice, wheat, corn and soybean	Natural pasture	Natural pasture
SU Nº	67	72, 51	70	43, 41, 46	76
sed.y. % USLE	7	16	34	23	19
sed.y. % SLEMSA	17	9	35	20	19
% basin area	35	19	18	14	13

Table 3.8.3. Soils ans Terrain characteristics in Basin 3 (area= 1826 Km^2)

Reg.l.form	Upland	Upland	Hilland	Upland
Parent material	Acid effusive rock as; rhyolite, form.4	Acid effusive rock as; rhyolite, form.4	Basalt, formation 4	Sandst. siltstone claystone, form. 3 and 5
Text.of Part.M.	Loamy	Sandy	Loamy	Sandy
Local s. form	Rolling	Rolling	Steep	Rolling
S %, class middle point	4 to 9 % , 6%	4 to 9 % , 6%	30 to 59% , 45%	4 to 9% , 6%
Major soil groupings	Acrisols and Lithosols	Lithosols	Lithosols and Cambisols	Acrisols
Landuse	Nature pasture	Nature pasture	Nature pasture	Nature pasture
SU Nº	30, 29	28	33	45
sed.y. % USLE	7	0	63	5
sed.y.% SLEMSA	2	0	91	2
% basin area	32	26	12	9

Table 3.8.4. Soils and Terrain characteristics in Basin 4 (area= 2296 Km^2)

R.land form	Upland	Upland	Valley	Upland	Upla.	Hilland
Parent mat.	Sandst siltstclays tform.6	Sandstfor m.5	Recent alluv. m.f.1	Clayst. siltst.form. 6	Sed. rocksfor m.6	Basalt, form.4
Text.P.Ma ter.	Sandy	Sandy	Loamy	Loamy	Sandy	Loamy
Local S.F.	Rolli.	Undulati ng	Level	Rolling	Rolling	Steep
S%, middle point	4to 9% , 6%	4to 9% , 6%	0to 3% , 2%	4to 9 % , 6%	4to9%, 6%	30to59%, 40%
Major S. Gr.	Acrisols	Ferralsol s	Planosol	Planos. and Acriso.	Acrisol	Lith., Cambis.
Landuse	Natur. pasture	Natur. pasture	Annual crop wetl. rice and pasture	Natural pasture and wetland rice, wheat, corn, soybean	Naturpa st.,an. cropswe tl.rice,c orn, soyb.	Natural pasture
SU Nº	45,49, etc.	54, 36	51	64, 78, 53	67, 80	35, 33
sed.y.% USLE	14	22	7	13	1	40
sed.y.% SLEMSA	6	4	1	4	1	82
% basin area	19	18	17	15	13	5

Table 3.8.5. Soils and Terrain characteristics in Basin 5 (area=9812 Km^2).

Regional land form	Upland	Upland	Upland	Valley
Parent material	Basalt, formation 4	Sandstone, formation 5	Basalt, formation 4	Recent alluvial material, formation 1
Text. class of parent material	Loamy	Sandy	Loamy	Loamy
Local surface form	Rolling	Rolling	Rolling	Level
Slope% class and middle point	class from 10 to 15 %, 12 %	class from 4 to 9 %, 6 %	class from 0 to 3 %, 2 %	class from 0 to 3 %, 2%
Major soil groupings	Lithosols	Acrisols	Lithosols	Planasols
Landuse	Natural pasture	Natural pasture, and annual crops as wetland rice, corn and soybean	90% Natural pasture and 10% of annual crop as wetland rice	annual crop as wetland rice and pastures
SU Nº	81, 96, 95	80, 63, 94	85, 114, 93	84
sed.yield % with USLE	57	10	3	16
sed.yield % with SLEMSA	62	19	0	9
% of the basin area	43	25	14	11

Table 3.8.6. Terrain characteristics Basin 6 (area=5942 Km$^{2)}$.

Regional land form	Upland	Upland	Upland	Plain	Hilland
Parent material	Sandst., format.5 and 6	Basalt, format.4	Basalt, format.4	Basalt, format.4	Basalt, format.4
Text. class of parent material	Sand	Loamy	Loamy	Loamy	Loamy
Local surface form	Undulating	Rolling	Undulating	Undulating	Steep
Slope % class and middle point	4 to 9 % , 6%	0 to 3 % , 2%	4 to 9 % , 6 %	0 to 3 % , 2 %	30 to 59 , 40 %
Major soil groupings	Ferralsols	Lithosols	Ferralsols	Planosol	Litohsols and Cambisols
Landuse	Natural pasture	90% of natural pasture and 10% wetland rice	Intensive annual 2 crops/y. rotation wheat and soybean	Pasture and annual crops as; wetland rice, oats	Nature pasture
SU Nº	36, 54	61, 85	55, 42,	37	35
sed.y.% USLE	38	1	17	6	27
sed.y. % SLEMSA	9	0	7	0	74
% basin area	34	13	8	8	4

Table 3.8.7. Soils and Terrain characteristics in Basin 7 (area=7235 Km²).

The definition of the terms used in these tables as Surface forms, texture class according to (shields, 1989) see in appendix 2.

Chapter 4 - Discussion

The erosion hazard index-EHI pattern resulting from USLE and SLEMSA runs show an increase from the southwest to the northeast of the area.
These patterns are similar to the ones presented by GLASOD-Wt map, this qualitative map based on expert judgment shows 5 classes of the status on water erosion, type loss of top soil (figure 2.3.3. in map annexo).

The increase in EHI could be explained by the following factors; climate (rainfall intensity, duration and total); terrain (relief and slopes); soils (erodibility or erosion susceptibility, infiltration and soil depth, or the presence of a textural B horizon under natural vegetation, these factors can increase runoff, mass movement and consequently magnitude of the erosion hazard.

The R factors (rainfall) from USLE model calculated with four different methods sited on iten 3.1.1. has shown very high disparity from 585 to 32039 metric units, for the same climate station.

Empirical relationships are valid only within the range of experimental conditions, and there is no justification for expecting the same relationship to hold beyond the measured range (Hudson, 1980).

The regression analysis between calculate R factor with (Fournier/Arnoldus and Roose) methods, and R factor calculated as (Wischmeier, 1978), give an reasonable $r^2 = 0.7$ with values from 6 stations.

The **sensitivity analysis** for the calibration of the model at the study area show an high variation (sensitivity %) among the input variables of both models sited on iten 3.3..
On the USLE model the varible **land use** which is the basis for the calculation of the C factor calculation give the highest sensitivity about 160 % as show on the figure 3.3.1., stressing the importance in the accuracy of this data.

The **rainfall data** (precipitation) gives an sensitivity of 100 % expressing the R factor importance in erosion hazard assessment at scale of 1:1 million the climate is an dominant factor which define the EHI assessment as show table 4.1. on this chapter.

The **slope %** variable has about 80 % an slope length 2 % of sensitivity, they both define the LS factor which is not calibrated for slope values higher than 25 % (steep), given an over-estimation of EHI for the SU with steep slope class.

The variables which controlling K factor and their sensitivity (%) : **silt** 100 %, volume of fine sand 10 %, organic matter content 20 %, structure 25 %, internal drainage 20 %, stone 10 % and rock 5 %; in this case silt is determining the K factor, that agree with the figure 1.6.2.2..

SLEMSA model shows similar pattern in the sensitivity analysis, **rainfall** was the most sensible variable with 270 %, determining the E factor, that value express the importance of the E factor in tropical and sub-tropical climates introduced in the model given an over-estimation of EHI values.

Some scale-linked pattern of controlling factors as erosion rates, sediment yield from the rives is provided by studies of drainage density (Gregory and Gardiner, 1975).

Drainage pattern was used as crude indication of runoff and is often used as an index of the severity of erosion. Broad variations in drainage density on a **macro-scale** are associated with differences in **climate**.
At the **meso-scale**, regional variations can be related to differences in **rainfall volume** but the pattern is complicated by variations due to **lithology, and relief**. At **micro-level** differences in **lithology**, normally expressed through **soil type**, and the **frequency and intensity of individual climatic events** become more important. Studies of the sediment yield of rivers reveal a similar pattern of denudation rates for the effect of the scale (Fournier, 1960).

Scale of analysis			**Evidence**
Macro	Meso	Micro	
climate	lithology relief		Sediment yield of rivers
climate	lithology relief	micro-climate lithology (soil)	Drainage density
climate	altitude relief		Studies of erosion rates
climate		plant cover micro-climate	Studies of soil loss from hillslopes

Table 4.1. Factors influencing soil loss at different scales.

Prediction of erosion, estimation, approximation are by definition similar concepts; But to what degree of approximation is appropriate and acceptable for SOTER users e.g. decision makers working at a regional scale of 1:1 million ?

The EHI analysis at that scale give an high level of abstraction, and can be propagate this with some assumptions as for the slope values were taken as class middle point from SOTER database which has 6 slope classes.

The following factors are influencing this question : **the scale 1:1 million** which is linked to the purpose of SOTER methodology, **the reliability and the accuracy of the available SOTER database.**
At a scale 1:1.000.000 1cm^2 being the minimum mappable SU which in reality represents 100 Km^2, which is assign maximum three soil units with : class of slope, roots depth, textural class, structure, etc.
Some of the soil characteristics as internal drainage have very high spatial variability shown high difference of magnitude in one Km^2.

The LASOTER database has about 7.9 % missing values for the USLE model variables, but is complete for the run of the SLEMSA model.
The input variables are different for USLE and SLEMSA models.

Comparison between SLEMSA scenario S1 (actual landuse from SOTER) and GLASOD-Wt map show that 44,6 % of the map area is equal, 52,3 % has an difference of one class, 3.1 % has an difference of two classes, which are SU numbers : 33, 35, 36, 54, 133, 137, 153 and 2048.

These discrepancies can be explained as for the group of SU 36, 54, 133, 137, 153 and 2048; has the same characteristics as regional land form, upland, slope range from 4 to 9 %, parent material sandstone, mainly soil group Ferralsols, texture of the parent material "sand", local landscape undulating, land use is natural pasture.

The SU 36 and 54 have an combination of soil characteristics as : low PH values, low soil fertility, low water holding capacity , coarse texture and pasture land use resulting a median susceptibility to erosion and a process of desertification is taking place, shown by the GLASOD-Wt map (see on map annexo).

GLASOD-Wt map is the assessment of actual soil degradation induced by human activity according to (Oldeman, 1988) using expert judgement, giving different ratings of importance than the models.

The scenarios comparisons show high sensitivity to land use for both models, **the difference between USLE scenario U1 (actual landuse from SOTER) and GLASOD-Wt map** shown that 7.9 % are missing values, 44.6 % of the map area has the same qualitative class of EHI, 45,3 % has a difference of one class, and 2.1 % has a difference of two classes which are the SU : 33, 35, 2074, 2075 and 2076.

The U1 scenario gives a pattern as in the GLASOD-Wt map, therefore the map comparison don't differ too much unless for SU 33 and 35 which were assign as high EHI in U1 and are over-estimated by the model, contrary to the GLASOD-Wt map where they were assigned as low EHI.
This could be explained by the fact that the topographic USLE factor (slope) values are not calibrated for values higher than 20 %.

The EHI is mainly determined by **land use, rainfall, topsoil texture and slope**, as shown by the sensitivity analysis in the study area.
The few SU assigned as high EHI class in the GLASOD-Wt map are medium in U1 and low in S1 scenario, and some SU which are assign as stable in GLASOD-Wt map show low and medium actual degradation by loss of top soil for the S1 and U1 scenarios.

The assumed sources of these discrepancies are :

1) The classification of the S1 and U1 map with these 5 classes intervals of erosion rates (Ton/ha) used in a similar study in the Brazilian Parana state by FAO (Lantieri, 1990); The manipulation of that classes range can modify the results of the final qualitative map S1 and U1.
That classes range could be more precise if the GLASOD methodology can be translated in a more quantitative approach.

2) The SOTER land use attribute which determine the C factor in the two scenarios U1 and S1 has an very high level of abstraction as given for the whole study area.
There exist 6 types of land use like : Extensive grazing, Intensive grazing, shifting cultivation, rainfed arable cultivation, Irrigated cultivation and non irrigated tree crop cultivation.

In the SWEAP programme the information of the actual landuse is extracted from an file ANNCROP.TAB which have the information of annual crops factors, or PERENN.TAB were the information of perennial crop is given, therefore the values taken in these two scenarios S1 and U1 (actual land use) are ruth standard average values of C factor, e. g. : land use rainfed arable cultivation has the average factors determined by the codes as AA4 C1=0.5; C2=0.2; C3=0.05; Lmax=4.0; k=0.7; V_{resid}

MAX=80 more is described about C factor in appendix 7, and in reality annual crops in LASOTER area has an large variation of these factors on rainfed arable cultivation.

3) The soil management as soil tillage practices, soil conservation practices, are important on the erosion prediction, but in the SOTER database they are not considered for the scenarios U1 and S1 (actual landuse from SOTER).
Some experiments (Vieira et al., 1977) shown that these practices combined can reduce the erosion from 10 to 80 % depending of the slope class.

4) The slope gradient formula has not been calibrated for slopes of over 25 %, given an over-prediction.

5) The factor F_{base} and $F_{modifiers}$ in the SLEMSA model are very sensible especially at high erodibility levels (Stocking, 1982) and they still need refinements in SWEAP, for this purpose could be used the ratings of erodibility as in (Lantieri, 1990) to rating more properly the erodibility of the soils in the LASOTER area using local data to complete the file FTAB.CNT in SWEAP.

S1 scenario Actual land use (from SOTER database) gives some difference in the SU : 151, 137 and 133. They are classified as high actual top soil erosion by the GLASOD-Wt map but low for S1. The major soil type in these SU are Plinthic Acrisols with an "argic B horizon" and Lithosols, both with a low natural fertility and a slope of 9 % resulting in a high actual erosion hazard.
But some information as soil characteristics (Plinthic horizon) could not be used from the SOTER database, which probably are causing these difference on the SLEMSA model.

There are other possibility to improve land use data collection sited by (Hellden, 1987) and (Lantieri, 1990) with the use of satellite data, where can be better determined the spatial and temporal variability of the land use.

U2 and S2 scenarios (ranching-extensive grassing) gives very high EHI, similar to bare soil, the reason could be because both models has been developed for arable farming and is over-estimating the erosion in the study area where most of the land use is grazing with natural pasture with much more diversity in types and density of grass and trees than the assigned contant value in the model during the year and they are not realistic values.

The scenarios U3 and S3 : annual crop rotation with 2 crops, soybean in summer, sow in November and harvest in February, and wheat in winter, sow in April and harvest in August, contouring, no-tillage, has show an low EHI, indicating an sustainable management system from the point of view of soil conservation.
One of the limitations in this system is the climate, is necessary to have 2 growing seasons per year to produce enough dry matter as soil cover, which occurs at the study area.

The scenario U4 : (USLE) annual crop rotation as in the scenario 3, with contouring, ploughed in the crop residue after harvest for both crops , shows an increase from low to medium EHI compared with U3.
In the U4 scenario for example SU numbers : 54, 36 which are classified with a high EHI in GLASOD-Wt map.
They consist of sandstone parent material and the major soil groups are Ferralsols and Planolsols, with a low natural fertility and show a high susceptibility to erosion even on gentle undulating slopes.
The low % of clay and a week soil structure is increasing the effect of water and wind erosion in these soils, moreover some processes of desertification are taking place in the SU 36 with well developed gully erosion as a result of the very low grass cover protection the soil.

The scenario S4 : (SLEMSA) annual crop rotation as in the scenario S3, with contouring, ploughed in the crop residue after harvest for both crops shows higher EHI values compared with scenario U4.
Some SU assigned as high class of EHI : 2, 4, 16, 9 and 34 all of them with slope class of 22 %.
That confirm the high sensitivity for slope as shown in sensitivity analysis.

The S4 scenario assigns more SUs as medium EHI than scenario U4, this is showing the over-estimation of the SLEMSA model.

Scenario U5 : (USLE) soybean mono-cropping, contouring and plough in the crop residue after harvest gives values of EHI similar to S4, the EHI has increased to medium and high classes.
Which most of the SU have slope classes of 22 %, a texture of silty clay and are located in the northeast of the area and resulting in a high R factor.

Soybean mono-cropping has shown not to be a sustainable land use, even with contouring. Some studies as (Vieira et al., 1977) testing rainfall simulator with 4 different tillage systems in a sandy clay loam soil (6% slope, reddish brown lateritic dystrophic soil) cultivated with soybean show the following results:

-a) Soil erosion of **13 ton/ha using conventional tillage** (1 plough plus 2 disks, with wheat straw burned);
-b) Soil erosion of **14 ton/ha using reduced preparation 1** (1 plough plus 1 disk, with wheat straw burned);
-c) Soil erosion of **3.3 ton/ha using reduced preparation 2** (1 disk plus wheat straw partially incorporated);
-d) Soil erosion of **3.1 ton/ha using no tillage** (direct sowing over wheat straw on soil surface).
The results are showing that erosion processes are the consequence of several factors such as;
- A 'plough pan' induced by the excess of traditional soil preparation.
- The lack of soil cover as a result of the low production of dry matter,
- The low biological activity and resources of soil exploited by the mono-cropping system.

Comparing the results of scenario c) 3.3 (ton/ha) of this experiment with the values of the predicted EHI of 45 (tons/ha/year) calculated with USLE, for the LASOTER area, with a similar slope % and soil Major grouping Ferralsol, soybean monocropping and plough in residue after harvest, there is an over-estimation.
The explanation of that over-estimation can be;

- Rainfall where on the scenario c) was used rainfall simulator, and on the scenario U5 was calculated the R factor by the adjusted power equation sited on the iten 3.1.1.

- The K value (Wischmeier ,1978) is a fixed value within the year, but a study on tropical soils show that measured K values at different periods within the year show an high variability of the K factor values erodibility (Vanelslande, et all.).

Scenario S5 : (SLEMSA) soybean mono-cropping, contouring and plough in the crop residues after harvest; shows some SU assigned as a very high class of EHI, which was high class in the scenario U5 scenario, most due to the higher sensitivity of the SLEMSA model for the following factors : slope, rainfall energy and soil covering.

Scenario U6 : (USLE) bare soil shows potential erosion according to the physical factors; slope-(topographic), rainfall-(R Factor), soil-(erodibility) and independent of soil cover, land use.

This scenario shown an large area assigned as a very high class of EHI, located in the Missoes plateau and Ibicui and Negro depression. **The different geomorphological**

provinces show different limiting factors like;

- **On the Missoes Plateau** steep slopes occurring in combination with strong rainfall erosivity,

- **The Depression of Ibicui and Negro river** show a high soil erodibility for the major soils (Acrisols) see item 1.4.7. and (Vertisols),

- **On the Araucaria Plateau** steep slopes occurs and are susceptible to strong rainfall erosivity,

- **On the Campanha Plateau and Cuesta Basaltica** show a high soil erodibility for the major soils (Lithosols),

- **The Sul Rio Grandense Plateau** shows a high soil erodibility for the major soils (Acrisols),

- **On the poor drained Peneplain (Ibera depression)** salt affected soils occur; They are heavy textured and compacted by overgrazing,

- **On the well drained Peneplain** Vertisols, compacted by overgrazing and susceptibility to crusting occur,

Scenario S6 : Bare soil scenario for SLEMSA shows, not as expected, over-estimation of the EHI values but to a lesser extreme of the U6 scenario.

The under-estimation of EHI values in this scenario is probably due to the difference of the sensitivity of the following variables : silt %, structure, internal drainage which determines the K factor.
The USLE model has higher sensitivity for these variables than SLEMSA models see on the figure 3.3.1 and 3.3.2.

The Universal Soil Loss Equation may be used to make an estimate of the gross erosion occurring within a basin (Williams, 1975).
Rates of sediment yield of watersheds are comparable only if their gross erosion rates per unit of area are approximately the same. Otherwise their delivery ratio must be compared and evaluated for a specific hydromorphological unit within a climatic region.
In the Ibicui basin the magnitude of the **Denudation Rates (DR)** can be grouped in **basins with high values** of DR like basins Nº : 1, 4, 5 and 7 and; **basins with low values** of DR like basins Nº : 2, 3 and 6 (see table 3.4.2.). According to both, predicted and

measured Denudation Rates (DR), therefore they will be compared just within these two groups.

Small parts of a watershed may be the source of a considerable part of the erosion. This is the case for the group of high DR values, where the SU Nº 33 and 35 produce the majority of the predicted sediment yield of these basins as shown from tables 3.4.5.1. to 3.4.5.7.. Several factors as relief, soil type, land use and climate are important in sediment yield estimates. Steep watersheds with well defined channels attain higher values than watersheds of low relief and poorly defined channels (Rees, 1967).

Slope, lithology, soil type, land use and rainfall are important factors for erosion susceptibility assessment.
Among the factors affecting processes of erosion by water, the morphological characteristics of the slope such as gradient, length, micro relief are of major importance (Stocking, 1972).

On steep slopes the velocity of overland flow tends to be relatively high and infiltration rates are lower than on gentler slopes of the same material. Long slopes tend to build up large quantities of overland flow and consequently erosion.

The lithology is an important aspect in the erosion process, for instance weathered parent material (mafic rocks) in a humid tropical climate resulting in a deep layer of weathered material and soil, in case it is denuded may produce large quantities of debris. Soft clastic or weakly metamorphosed rocks may also produce considerable quantities of debris and generally speaking are more easily erodible than the mafic volcanic materials. The susceptibility of different lithology to erosion has not yet been clearly defined in literature, however some values from (Rutten, 1975) and (Meyerink, 1975).

- In a basin with a surface of 10.000 Km^2 and with a volcanic lithology produces a sediment yield from 875 to 1500 tons/Km^2/year; (which is of the same magnitude as basin Nº 1).

- For smaller basins of about 700 Km^2 with a mixed volcanic and sedimentary lithology values from 750 to 7500 tons/Km^2/year are quoted.

- Then smaller basins of 50 Km^2 with a sedimentary lithology sediment yields from 9250 to 12500 tons/Km^2/year.

The **geological formations** in the study area show an **erodibility rating in descending order** as follow :

a) Jurassic sandstone, poorly cemented, deposited in an desertic environment, (Formation Botucatu),

b) Tertiary sandstone, consisting of coarse heterogenic material, gravel layers and located on the top of the landscape,

c) Triassic sandstone with carbonate concretions,

d) Jurassic sandstone which are underlies by the Cretaceous basalt,

e) Pleistocene eolian material,

f) Permian siltstone, and limestone of marine and fluvial origin,

g) recent alluvial material,

h) Igneous acid and metamorphic rocks granite and gneiss mainly Precambrian.

The lithology rating was made on basis of the sediment yield of these basins, the respective erodibility of major soils and slopes, sited by (RADAMBRASIL-1986).

The soil types in descending order of erodibility : Lithosols, Acrisols, Cambisols, Planosol, Ferralsols and Nitosols.

The land use is affecting the sediment yield in terms of soil cover variation, soil management, residue, soil conservation and level of technology as intensive or extensive systems.

The average annual rainfall in the Ibicui basin area is ranging from 1500 to 1600 mm consequently an annual R factor from 504 to 750 (tons.mm/ha.hour) was determined by (Chevallier e Castro, 1991).
The adjusted Power equation item 3.1.1. used in this study give an over-estimated values of R factor as 1160 tons.mm/ha.hour.

Areas with 1600 mm of annual rainfall are located in the highest part of the basin Nº 5 on the undulating Campanha Plateau on sandstone, border with the basalt formation, these high precipitation combined with steep slope and shifting cultivation is a high source of sediments consequently high denudation rates.
Bordas and Canali, (1980) reported the sedimentological behaviour of four experimental basins located within the Forqueta River catchment (3000 Km^2) in an adjacent area of

the Ibucui basin. In this area seven storms between December 1978 and June 1979 were used to characterize the hydrological and sediment responses of the small basins.

(a) Catchment characteristics

Catchment	A1	B1	A3	C3
Slope	40	20	40	50
Cover	Crops	Crops	Forest	Forest
Area (*ha*)	922	532	678	334

(b) Storm rainfall

Rainfall	No	Date	Max intensity (mmh^{-1})	Mean intensity (mmh^{-1})	Duration (h)	Total rainfall (mm)
Group 1						
Simple isolated rainfall events	24	12.02.79	23	7.3	4	29
	37	18.05.79	16	3.8	9	34
	38	22.05.79	26	4.9	11	54
Group 2						
Two simple events separated by 24 hour interval	27	9/10.05.79	20/21	2.5	20/17	50/41
	29	4/5.04.79	12/12	2.8/4.6	21/5	60/23
Group 3						
Complex storm pattern	30	15.04.79	10	1.7	21	35
	39	04.05.79	10	2.1	19	40

Table 4.1. Storm rainfall and sediment production in four pilot basins of the representative basin of the rio Forqueta, South of Brazil.

It was concluded that slope have practically no influence on the overland flow and sediment production under forest cover; on more easily erodible terrain, erosion is not significant except when the rainfall intensity exceeds 10 mm/h with a duration of more than 4 hours.

The threshold value for significant erosion rates was observed to depend on the amount of water in the soil at the beginning of the storm rainfall. It was noted that the highest sediment discharge had a concentration of 39000 mg/l and that during October 1969 the reservoirs for trapping sediment were completely buried for three times.
Instead in Ibicui basin were daily data was collected not according to storm events, the values for the concentration of suspended sediment going from 10 to 360 mg/l and annual averages data from 45 to 80 mg/l.

The report (Diagnostico das condicoes sedimentologicas dos principais rios Brasileiros-ELETROBRAS, 1992) at scale of 1:5.000.000 assigned for the Forqueta river basin a deposition rate of less than 50 tons/Km^2/year instead for the Ibicui river basin was assigned for the basin Nº 7, with an area of 7235 Km^2, the denudation rates DR of 50 to 200 tons/Km^2/year.

The terrain characteristics of the pilot areas in the Forqueta basin are not comparable to the basin Nº 7 in the Ibicui basin due to the different sizes of basin and the magnitude of sediment transported, but gives an idea of the variation of the sediment yield on a more detailed in time and space.

The magnitude and proportion of bed load is however surprising high compared with the one cited by literature as assumption of less than 10 % of the total sediment discharge.

The particle-size distribution and slope factors may be responsible for the apparently large difference.

(c) Sediment production (C=bed load, S=suspended load, T=total load)

Rainfall No.	Load type	Sediment load ($kg\ km^{-2}$) A1	B1	A3	C3
Group 1					
24	C	3680	3513	0	0
	S	1020	654	X	X*
	T	4700	4167	X	X
37	C	0	0	0	0
	S	754	2068	0	X
	T	754	2068	0	X
38	C	3880	14676	1032+	0
	S	1802	12173	1708+	X
	T	5682	26849	2740+	X
Group 2					
27	C	4149	4020	0	0
	S	2900	616	1.3	X
	T	7049	4636	1.3	X
29	C	x	x	0	0
	S	1334	8946	1	X
	T	X	X	1	X
Group 3					
30	C	X	X	0	0
	S	208	7040	>1	X
	T	X	X	>1	X
39	C	0	0	0	0
	S	150	81	2.3	X
	T	150	81	2.3	X

*Non-zero, but not determined.

Figure 4.2. Sediment production of Forgueta pilot basins (C=bed load,S=suspended load,T=total load), (Bordas and Canali, 1980).

The data of river **suspended-sediment** from the **Ibicui basin** is independent of the SOTER database and is used as an "ground truth" to compare in terms of correlation and magnitude with the predicted sediment yield by the models on seven drainage basins. The regression analysis show an good correlation (r^2 = 0.8) for both USLE and SLEMSA models.

For the **group of basins with high Denudation Rates-(DR) basin Nº 1** is an example, with an area of 3310 Km^2. It consists for 60 % of acid effusive rock (rhyolite) and 17 % of basaltic parent material forming the Araucaria Plateau. The rest located on the depression of Ibucui and Negro river consist of Triassic sandstone.

The boundary between these two geomorphological provinces consist of a steep landscape developed on basalt. The geomorphological structures of the landscapes are proving the accelerated process of erosion by Cuestas, remnants hills, table, "Morro Testemunho" showing the original level covered by the effusive rock.

The erosion has taken place on steep basaltic area and soft easily eroded sedimentary rocks, on Triassic and Jurassic sandstones forming the depression area and the actual Ibicui river valley, see **Figure 1.4.4.** on iten 1.4.4. and **Figure 1.4.6.B) Ibicui basins and geomorphological provinces** on map annexo.

Most of the river valleys are developed in these two formations and in the Permian claystone and siltstone of the depression area, forming large flat alluvial valleys filled with recent sediments. Contrary to the basaltic Plateaus, where the lithology is harder and the rivers valleys are more dissected and narrow.
This basin has the highest predicted values of DR 1650 tons/Km^2/year for USLE values, and 4819 tons/Km^2/year for SLEMSA (table 3.4.2.), instead on the basis of measured values this basin is in the 3º position on descending order.

That the models predictions were over-estimated, could be because of the same 5 reasons discussed above in the scenario discussion.
According to the combinations of soil and terrain characteristics in each group of SU as indicated in (table 3.8.1.). The group Soil Unit-(SU) of the basaltic (Serra Geral) parent material has a slope class from 30 to 59 % while the major soils are classified as Lithosols and Cambisols. The land use is natural pasture for example the SU Nº 33 with an area of 17 % of this basin explains 77 % of the sediment yield predicted by the USLE, and 95 % by the SLEMSA model.

The land use of SU Nº 33 for example is described as shifting cultivation, which combined with average slopes of 40 % show an over-predictions by the models. The suitable land use is Nature protection and the misused of this area is causing erosion as mass movement, sheet and hill, with off-site problems as sedimentation, and water pollution.

Farmers in these areas use a low level of technology. Lacking of soil and water conservation structures. These soil degradation problems also has a social origin as example land ownership has been concentrated in these last 20 years.

The small farmers which produce the basic food products for the Brazilian market as maize, rice and beans have been pushed to these steep lands areas as global effect of the land's monetary speculation.

This give an scathing picture of the land ownership and the need of land reform which never happen in Brazil.
Government subsidized cash crops as soybean and sugarcane on large scale farmer systems using high technology, given secondary priority to basic food products.

The research institutes and universities are cash crops and high input systems oriented. The research are usually on level to undulating slopes, not on 45 % on shifting cultivation which is the small farm scenario.

The others groups of SU in the basin Nº 1, originally from the same geological formation but with an average slope class of 6 %, yielding less sediment.

The average crop factor for shifting cultivation is not representing the real distribution thorough the year. This factor was taken from literature, and is very crude estimated.

The basin Nº 4 with an area of 2296 Km^2 is similar in terms of soil characteristics to basin Nº 1, and is classified as 2º value of Denudation Rates (DR).

Basin Nº 5 (9812 Km^2), is similar to basin Nº 1 and 4 and has a small area with steep slopes yielding the higher sediment of the basin.
Within the group of basins with high DR basin Nº 5 has low values of DR, ranking at 3º and 4º. The steep Araucaria Plateau contributes on 40 % (USLE) and 82 % (SLEMSA) to the total sediment yield of the basin, showing the high discrepancies between this Plateau and the other areas of the basin.

For example the EHI predicted on the SU Nº 33 and 35 which are located in the Araucaria Plateau are equal to 77 and 277 tons/ha respectively for USLE and SLEMSA models.

The SU Nº 51 represent 17 % of the basin area located on the large flat alluvial valleys filled with recent sediments. On the hydrological point of view these areas functioning as buffer areas catch the rivers sediments on floods events, contributing to the water balance for the neighbouring area.

The second problem of erosion is the loss on water by runoff causing an decrease on the water cycle, and consequently adversely affects the crop production.

The SU Nº 54 and Nº 36 described before are located in that basin, a process of desertification is taking place with mass movement, gully erosion and wind erosion on the SU Nº 36, influenced by the high erodibility of the Jurassic sandstone parent material and fluvial erosion process.

The combination and interactions between these different sub-compartments of the basin makes it possible an reasonable to assess the sediment yield of the study area.

Basin Nº 7 (7235 Km^2), situated on the Campanha low Plateau on basaltic lithology, shows a high level of deposition rates which is not considered in the models. These deposition processes could be caused by different factors such as,

1) The change in the topography on the boundary between the Campanha low basalt Plateau and the depression area. The river valleys are changing from wide, on the rolling sandstone lithology,to confined, structure oriented on the to gently undulating basaltic lithology.

2) The sediment yield by gully and sheet erosion in SU Nº 36 and Nº 54 in combination with the desertification process occurs mainly on Ferralsols, with a loamy sand to sandy texture and a weak structure in the top soil.
On intensive annual cropping systems in SU Nº 55 and 42 high sheet erosion occur.

Within the group of basins with low values of DR; Basin Nº 2 (12.077 Km^2), located mainly in the depression area encompassing 14 % of the igneous acid (granite) and metamorphic (gneiss) rock Plateau.
Within this basin the distribution of the sediments are homogeneous. The general slope angle is about 6 % and respective different geological formations with annual crop an natural pasture as landuse.

The lithology which shows a high erodibility reflected by sediment yield within the basin is the Permian siltstone, claystone and some limestones. The major soils are classified as Planosol and Acrisols.

The major soil group of Acrisols represent 20 % of the basin area. The relief is rolling while on the top soil has a sandy loam texture. There is an abrupt horizon boundary between the A and B horizon. The soils are usually developed on Triassic sandstone (formation Rosario do sul).

The common landuse on this soils are, intensive annual agricultural of wheat, barley or oats in winter and soybean or corn in summer. The land use causes soil erosion proved

by gullies aggravated by the formation of a (plough pan).
The predicted EHI of these soils ranges from 1 to 16 tons/ha on the Plinthic Acrisols. The principal limitations for agriculture on these soils are, bad drainage and low natural fertility associated with acidity.

Basin Nº 3 (1826 Km^2), is located in the depression of Negro and Ibicui river. In the GLASOD-Wd (see on Map annexo) map of rill and gully erosion this basin show medium and low values of actual soil degradation.

The parent material claystone and siltstone given origin to major soils classified as Acrisols, Planosol and Phaeozems. As an example on the SU Nº 70 occurs major soil classified as Gleyic Phaeozems, Acrisols and Gleysols. The Gleyic phaeozems with vertic properties and clay texture, with a (montmorilonitic and kaolinitic) clay mineralogy. These soils have high natural fertility, but with problematic physical characteristics as shrink and swelling resulting on very short tillage period, for that reason is more used for pasture. This SU represent 35 % of the sediment yield of the basin.

Basin Nº 6 (5942 Km^2), is located on the Campanha Low Plateau.
The major soils developed from the basaltic parent material are Lithosols. Land use is mainly natural pasture on a rolling relief with slopes ranging from 3 to 15 %. The SU Nº 96 on the steep slopes is yielding 10 to 15 ton/ha sediment.
The main limitations for agriculture are, soil depth and the steep slopes, resulting in a predominant landuse of natural pasture.

The group of basins with **low DR** are raking high values of Sediment Delivery Ratio (SDR) (table 3.4.3.), instead on the group of basins with **high DR** shows low values of SDR. Therefore can be interpreted that basins with high DR usually has more storage of sediments than the basins with low DR values.
The storage are on the surface compartments of the basin as alluvial on the river terraces or colluvial on the Toeslopes areas.

The Sediment Delivery Ratio $(SDR)=(Y/T)*100$ was calculated dividing the measured sediment yield from a gauging station per the total predicted sediment of the basin.
The DR is calculated on the basis of the total sediment yield T of the basin divided by the area, than for an fixed Y : measured sediment yield the higher DR the lower will be the SDR, confirming the affirmation before.

The disadvantages of a parametric approach like the USLE model are, the long time periods needed to establish an accurate model and, the impossibility of extrapolating the results. The USLE model is the most widely-known method of predicting rates of soil loss, this is an advantage because much data are available from local experiments.

In spite of the problems with their application, both of the cited models are being used to produce small scale maps. However, a few publications provide a reference for calibration or validation made at small scale. The reason is the lack of data as ground truth that can be compared with model results.

Chapter 5 - Conclusions and Recommendations

- This study shows that in spite of the limited information available, satisfactory results have been achieved, in terms of the analysis of discrepancies between the erosion models results and the GLASOD-Wt map. The same applies for the comparison and correlation between the model results and the measured data of material transported in suspension from the Ibicui basin.

- Model variables such as rainfall, vegetation cover, steepness of slopes and soil texture used for a sensitivity analysis show a high instability. That means, a small measurement error of these factors cause a significant error on the model results. Therefore proper data collection of these variables is of utmost importance to avoid magnification of errors during the application of the models. In spite of that, results of the qualitative assessment of water erosion, demonstrates reasonable results for both models.

- The evaluation of both models, USLE and SLEMSA gave erosion predictions of approximately the right magnitude for sloping areas to of maximum of 20 % slope angle. For steeper sloping areas both models over-predicted EHI values.

- The correlation analysis between the measured data of sediment yields from the Ibicui river basins and the calculated erosion as gross rates from both models, is reasonable ($r^2 = 0.80$ for SLEMSA values and $r^2 = 0.82$ for USLE values).

From one point of view the measured sediment yield compared with the calculated gross erosion show a great difference in erosion rates. This is due to 2 reasons : 1) the over-estimation of the models, 2) the limitation of the models by not taking into account the deposition of sediment but just removal of sediment by erosion. These over-estimation and limitations are propagated in the calculation of DR and SDR values

There is an high amount of sediment stored on these 7 basins, which can be inferred from SDR of 14 to 18 % as cited in literature by : Maner, 1962. Consequently 86 to 82 % of the gross erosion is deposited within the basin as colluvial and alluvial material.

- The SLEMSA and USLE models, can be improved on the basis of the results of this study. Such as transfer functions or tables for:

Precipitation data --> Rainfall erosivity, this is an important factor at 1:1 million scale.

Landuse/vegetation data --> Cropping factor, this could be derived through remote sensing techniques, satellite images (D.lantieri, 1990).

Soil data --> Erodibility

Changes due to different management --> adjustment of crop factors and erodibility.

Erodibility due to steep slopes --> Slope factor,
(There is a limitation of scale to derive accurate slopes factors. On a 1:50.000 scale there is an reasonable representation of the actual landscape in terms of slope, instead on 1:1 million scale there is an high abstraction of the real slope).

The study on erosion hazard analysis is giving only qualitative indications, but local calibration will be necessary for quantitative inferences.
Rough indications of "erosion costs" e.g. through nutrient losses may be possible when transfer functions are incorporated.

- It seems that existing models developed to assess erosion susceptibility, are not suitable to all environment conditions found in the study area such as steep areas, with shifting cultivation. The Universal soil loss equation-USLE is not "universal" for all the factors used.

- The limitations of both models; USLE and SLEMSA, are related to the fact that they are based on standard experimental plots which can not calculate depositions of sediments. The SLEMSA model is more flexible as F_{base} and $F_{modifier}$ can be rated according to local experimental conditions followed by a sensitivity analysis.

- The best approach would be to build a model based on the USLE approach and local experience on soil erosion with measurement of soil losses from experimental plots of the different soils, land use, management and slope conditions.

- Both models, USLE and SLEMSA, can be used for qualitative mapping of the water erosion susceptibility and used to identify priority areas, on a national level for soil and water conservation purposes. It allows regional maps of erosion hazard to be constructed relatively quickly; and shows the comparative range and degree of erosion problems.

-The ultimate aim is to use this information on a 1:1.000.000 scale in future, for the identification of priority areas at detailed scales and at project level.

Bibliographical References

Almeida, F.F.M. (1981). Sintese sobre a tectonica da bacia do Parana.In:SIMPOSIO REGIONAL DE GEOLOGIA, 3, Curitiba, 1981. *Atas.*Curitiba, Sociedade Brasileira de Geologia, 1981.v.1,p.1-20.

Arnoldus, H.M.J., 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation. In: *Assessment of erosion* (eds. M. de Boodt and D. Gabriels; based on the proceedings of the workshop on Assessment of Erosion in USA and Europe; Faculty of Agricultural Sciences, State Univ. Ghent, Belgium, Febr. 27th to March 3rd, 1978). John Wiley & Sons; pp. 127-132.

Ateshian, J.K.H., 1974. Estimation of rainfall erosion index. *Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, 100 (IR3)*: 293-307.

Bergsma, E., 1981. Indices of rain erosivity: A review. *ITC Journal 4*: 460-484.

Bolline, A., A. Laurant, P. Rosseau, J.M. Pauwels, D. Gabriels and J. Aelterman, 1980. Provisional rainerosivity map of Belgium. In: *Assessment of erosion* (eds. M. de Boodt and D. Gabriels; based on the proceedings of the workshop on Assessment of Erosion in USA and Europe; Faculty of Agricultural Sciences, State Univ. Ghent, Belgium, Febr. 27th to March 3rd, 1978). John Wiley & Sons; pp. 111-120.

Beasley D.B. & L.F. Huggins & E.J. Monke, 1980. ANSWERS : A Model for Watershed Planning. *Transactions of the ASAE* vol. 23 (4), 938-944.

Berg, M.van den. 1992. SWEAP : *A Computer programme for the assessment of water erosion applied to SOTER.*ISRIC, Wageningen.

Carvalho, A.P., 1975. E.U.A. Department of Agriculture. Soil Conservation Service.*Soil Taxonomy;*a basis systems of soil classification for making and interpreting soil surveys.Washington,D.C.,Government Printing Office,754p. (Agriculture Handbook, 436).

Carvalho, A.P., 1978. *International soil classification workshop* ,1. Rio de Janeiro, 1977. *proceedings.*Rio de Janeiro, EMBRAPA-SNLCS. 376p.

Costa,J.E., 1975. Effects of agriculture on erosion and sedimentation in Piedmont Province, Maryland: *Bull. Geol. Soc.Amer.*, v.86, 1281-1286.

CPAC 1981. *Relatorio tecnico Anual do Centro de Pesquisa Agropecuaria dos Cerrados,*1979-80. EMBRAPA-CPAC, Planaltina DF.

Diaconu, C., 1969. Resultants de l'etude de l'ecoulement des alluvions en suspension des rivieres de la Roumanie, *Bull. Assoc. Scient. Hydrol.* **14,** 51-89.

Douglas,I., 1967, Man, vegetation and sediment yields of rivers:*Nature*, v.215, 925-928.

ELETROBRAS, 1992. Diagnostico das condicoes sedimentologicas dos principais rios Brasileiros, IPH, Universidade Federal do Rio Grande do Sul. Rio de Janeiro:*ELETROBRAS,*. 100p.

Elwell, H.A. and Stocking, M.A. 1982. Developing a simple yet practical method of soil-loss estimation. Trop.Agric.(Trinidad),59:43-48

Eppink,L.A.A.J., 1992. Lecture notes for the course on Land Drainage are not official publications, Wageningen.

Elwell, H.A. and M.A. Stocking, 1982. Developing a simple yet practical method of soil-loss estimation. *Tropical Agriculture. (Trinidad), 59:* 43-48.

EMBRAPA-SNLCS. *Relatorio Tecnico GLASOD-SOTER Brasil.* A UNEP-ISRIC-EMBRAPA Publ. EMBRAPA Rio de Janeiro/SNLCS Curitiba, Brasil. 93p.

Fournier, F. 1960. *Climat et erosion; la relation enter l'erosion du sol par l'eau et les precipitacions atmospheriques,* Presses Universitaires de France.

Fundacao Instituto Brasileiro de geografia e estatistica (1986). *Folha SH/SI.22/21 Porto Alegre/Uruguaiana/Lagoa Mirim* : Geologia, Geomorfologia, Pedologia, Vegetacao, Uso potencial da terra. IBGE Rio de Janeiro, Brasil.

Gregory,K.J. and Walling, D.E. 1973. *Drainage basin form and process,* Edward Arnold.

Hudson, N.W., 1980. Erosion prediction with insufficient data. In: *Assessment of erosion* (eds. M. de Boodt and D. Gabriels; based on the proceedings of the workshop on Assessment of Erosion in USA and Europe; Faculty of Agricultural Sciences, State Univ. Ghent, Belgium, Febr. 27th to March 3rd, 1978). John Wiley & Sons, pp. 279-284.

Iriondo, M.H., 1984. The Quaternary of Northeastern Argentina.In:*Quaternary of South America and Artartic Peninsula 2* (ed.J.Rabassa). A.A.Balkema,Rotterdam,v.2, p.51-79.

Iriondo, M. & Cerutti, C, 1981. *Las unidades geomorphologicas fluviales del extremo noroeste de Entre Rios y su relacion con los asentamientos pre-hispanicos.*Revista Asociacion Ciencias Naturales Litoral, 12: 72-84. Santa Fe, Argentina.

Jovanovic, S. and Vukcevic, M, 1958. Suspended sediment regimen on some watercourses in Yugoslavia and analysis of erosion process, *Assoc. Scient. Hydrol. Pub.* **43**, 337-59.

Kassam, A.H., H.T. van Velthuizen, A.J.B. Mitchell, G.W. Fischer and M.M. Shah., 1991. *Agroecological land resources assessment for agricultural development planning. A case study of Kenya. Resources data base and land productivity. Technical Annexo 2, Soil Erosion and Productivity.* FAO/IIASA, 54p.

Knisel, W.G., Jr. (ed.) 1980a. CREAMS: A field scale model for chemicals, runoff and erosion from agricultural management systems. *U.S. Department of Agriculture, Conservation Report no. 26.* 640 p.

Kuiper, M. 1988. *Land degradetion in South of Brazil.* Thesis Agricultural University Wageningen,the Netherlands.

Langbein, W. B. and Schumm, S. A. 1958. Yield of sediment in relation to mean annual precipitation, *Trans. Am. Geophys. Un.* **39**, 1076-84.

Lal, R., 1990. *Soil erosion in the tropics: principles and management.* McGraw-Hill, New York etc., 580p.

Lantieri, D., 1990. Use of high resolution GIS for soil mapping, *FAO, RSC series* , Nº 56.

Leenaers, H. 1990. Estimating the impact of land use change on soil erosion hazard in the Zambezi river basin, *Working papers*, WP-90-024, IIASA, Laxenburg, Austria.

Low, F.K. 1967. Estimating potential erosion in developing countries,*J. Soil and Water Conserv.*22, 147-8.

Meyer, L.D., 1981. Modelling conservation practices. In: *Soil conservation, problems an prospects.* (ed. R.P.C. Morgan) Proceedings of CONSERVATION 80, the International conference on soil conservation; National College of Agricultural Engineering, Silsoe, Bedford, UK, 21st-25th July, 1980, pp. 31-44.

Morgan, R.P.C. (1976) 'The role of climate in the denudation system: a case study from West Malaysia', in Derbyshire, E.(ed.), *Climate and geomorphology*,Wiley,317-43.

Mutchler, C.K. and C.E. Murphree, 1981. Prediction of erosion on flatlands. In *Soil conservation, problems an prospects* (ed. R.P.C. Morgan). Proceedings of CONSERVATION 80, the International conference on soil conservation; National College of Agricultural Engineering, Silsoe, Bedford, UK, 21st-25th July, 1980, pp. 321-325.

Oldeman, L.R., R.T.A. Hakkeling and W.G.Sombroek(Edditors). 1991. *Word map of the status of human-induced soil degradation*:An explanatory note, Wageningen, International Soil Reference and Information Centre;Nairobi: United Nations Environment programme.-I11., in cooperation with Winand Staring Centre-ISSS-FAO-ITC.:34p.

Peters, W.L. 1990. *Final Report LASOTER pilot area* ,August 1990. Internal Report-ISRIC , Wageningen, The Netherlands.

Rademacher, F.E.P., 1991. *Using the SOTER database for soil erosion assessment, with examples for a pilot area in South America.* ISRIC Working Paper and Preprint 91/8, ISRIC, Wageningen.

Robinson, A.R., 1979. Sediment yield as a function of upstream erosion. In: (Peterson, A.E. & Swan, J.B. ed.). Universal soil loss equaton: Past, present and future.*SSSA special publication* nº 8, Soil Science Society ofAmerica, Madison Wiscosin. 53p.

Roose, E.J., 1980. Approach to the definition of rain erosivity and soil erodibility in West Africa. In: *Assessment of erosion* (eds. M. de Boodt and D. Gabriels; based on the proceedings of the workshop on Assessment of Erosion in USA and Europe; Faculty of Agricultural Sciences, State Univ. Ghent, Belgium, Febr. 27th to March 3rd, 1978). John Wiley & Sons, pp. 153-164.

Rooseboom, A. and Annandale, G.W., 1981. Techniques applied in determining sediment loads in South African rivers, *Int. Assoc. Scient. Hidrol. Pub.* **133**, 219-24.

Shelton, I.J., G.J. Wall, and D.R. Coote. 1991. Water erosion risk : Ontario South, Land Resource Research Centre, Research Branch, Agriculture Canada, Ottowa, *Ont.Agric.Can.Publ.* 5277/B.

Shields, J.A. and Coote, D.R. (compilers) 1989. *SOTER procedures manual for small-scale map and database compilation. Including proposed procedures (For Discussion) for interpretation of soil degradation status and risk.* ISRIC Working paper and preprint 89/3, ISRIC, Wageningen, the Netherlands, 206p.

Stocking, M.A., Q., Chakela and H.A. Elwell, 1988. An improved method for erosion hazard mapping. Part I: The technique. *Geografiska Annaler, 70 (A.3)*: 169-180.

Stocking, M. and Elwell, H.A., 1976. Rainfall erosivity over Rhodesia, *Trans. Inst. Br. Geogr.* **1**, 231-45.

Stocking, M.A., and Elwell, H.A., 1973a Prediction of subtropical storm soil losses from field plot studies, *Agric. Met.* **12**, 193-201.

SOTER, 1986. *Project proposal for a World Soils and Terrain Digital Database at a scale of 1:1M (SOTER).* International Society of Soil Science, Wageningen, the Netherlands, 23p.

Van Engelen, V.W.P. and J.H.M. Pulles., 1991. *The SOTER manual. Procedures for small scale digital map and database compilation of soil and terrain conditions.* 4th edition, ISRIC Working paper and Preprint 91/3, ISRIC, Wageningen, 92p.

Wischmeier, W.H. and D.D. Smith, 1978. *Predicting rainfall erosion losses - a guide to conservation planning.* US Dept. f Agriculture, Agricultural Handbook No. 537, 58p.

Appendix 1. SOTER Methodology and Map Legend

The SOTER methodology will be accessible to a broad array of international, regional and national decision-makers.
It will be transferable to, and usable by, developing countries for national database development at a larger scale (M.F.Baumgardner, 1988)

The SOTER methodology produces maps which distinguish the following three levels in the major separating criteria are :

- The SOTER unit or TERRAIN unit, is defined in the 1^0 Level by the analyses of different factors : Regional Landform, Slope, Lithology, Soil and climate.

- The Terrain component, defined in the 2^0 Level by the analyses of different factors : Local landform, slope, soil pattern.

- The Soil as defined in the 3^0 Level by the analyses of different Soil characteristics ; e.g. thickness of major layer/horizons, texture, pH, CEC and organic C.

Soil information was not used as a differentiating criterion as is described in the original version of (SOTER, 1989).

The definition in (Shields, 1989) of the **regional surface form** which occurs in the Ibicui river basin are :

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.
Slopes generally 10-30% and relief generally less than 100m.

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 continuous, gently sloping piedmont plain 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 relative long distance.
Slopes generally < 6%, relief generally less than 10m.

Extent generally more than 5 Km in one direction.

Valley : Comprise major spillways, drainage ways 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.

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% and relief generally< 50 m.

Texture class of soil parent material:

Sandy : Includes all loamy sand, and sandy loam texture classes and their gravelly or cobbly modifiers.

Loamy : Includes all loam and clay loam texture classes and their gravelly or cobbly modifiers.

Local surface forms :

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%, examples : floodplain, lake plain.

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.

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 underlying material.
Examples : escarpments

Undulating : A very regular sequence of gentle slopes that extends from rounded, sometimes confined concavities to broad rounded convexities producing a wavelike patter of low local relief. Slope length is generally less than 0.8 Km and the dominant gradient of slopes is usually less than ^%, but may range up to 8%. It lacks an external drainage pattern.
Examples : some ground moraine, peneplain.

Appendix 2. Conversions and correlation of the SOTER versions, from 2 to 4

- **PDEP(m) depth to parent rock** parameter used in SLEMSA model :
In the SOTER 4 version (1991) the parameter PDEP(m) was in the terrain component file, one legend level higher than the soil file, on the one hand this change makes the data more reliable if the profile descriptions were deep enough to find the parent material.
On the other hand, the parent material may be deeper than the profile depth, as in many tropical regions.
In this assumption, for the purpose of SLEMSA, PDEP parameter is used in the modification of the K factor, within the range from PDEP=0.75m to 0.25m according to lithic contact, as show below:
For the presence of a lithic contact:

If MSUB is Unconsolidated or Stones or Unknown,
or If PDEP > .75 then XLIT=0

If MSUB is Petroplinthite or weathered rock then XLIT=0.5*LIT

If MSUB is unweathered hard rock then XLIT=LIT

If PDEP > .25 then F = F + XLIT*(.75-PDEP)/.5

If PDEP ≤ .25 then F = F + XLIT

where

LIT is the basic adjustment factor , read from file FTAB.CNT, dependent on type of soil development.
MSUB, the SOTER input variable for material below the pedon,
PDEP, the SOTER input variable for the depth to parent material (m)
XLIT, the temporal modification factor, according to MSUB.

SWEAP gets basic F factors for dependence of texture class and type of soil development from file FTAB.CNT, see (van den Berg, 1992). The basic F factor can be modified for dependence of soil management, internal drainage, salinity, the presence of a lithic contact, the presence of abrupt horizon boundaries or the sensitivity to capping.

-SCAP (sensitivity to capping) used in SLEMSA:
The physical condition of the topsoil is the resultant of two types of processes; physical degradation processes (dominant in the rainy season) and physical regeneration processes (dominant in the dry season). All processes are determined by physical,biological and human factors. Examples are the soil's texture (% clay and silt), soil organic matter content, biomass production, fraction of the land use and type of land use.
An indicator for physical soil degradation is crust formation this happens when soil % organic matter (O.M.) is too low for a given % clay plus silt (Pieri, 1989)
Degradation risk is a function of :
for the first layer according to the formula

MCAP = (((CARB * 1.8) / (CLAY + SILT)) * 100)

MSUB (Material below pedon) used in SLEMSA .

This parameter was created from the parent material, transferring the three classes N from (unconsolidated rock), R from (unweathered hard rock), U from (unknown), the other codes of SOTER version 4^0 were not created through lack of data.

Appendix 3 GLASOD Legend

The GLASOD methodology was applied in the LASOTER area in 1988 based in the fourth version of the operational manual.
The GLASOD methodology has been revised in october 1991.

-DEGREE of present degradation :

1) **Slight** : in deep soils (rooting depth more than 50cm) : part of the topsoil removed, and /or with shallow soils (rooting depth less than 50cm) : some shallow rills at least 50m apart.
In pastoral country the ground cover of perennial of the original/optimal vegetation is in excess of 70 %.

2)**Moderate** and 3)**Severe**, see more about in (Oldeman, 1991)

Appendix 4. Concepts of Raster and Vector maps:

A vector map is represented by a number of intermediated points 'nodes' each with coordinates X and Y, and the first one the same as the last one where a polygon makes the boundaries of an enclosed area, with topology defining the way in which geographical elements are linked together.

A raster map is a pixel data structure as matrix with each number is an pixel value with grid size determining the resolution, in the LASOTER raster map the pixel size is 1 Km square than the resolution is 1 km, there are three types of raster maps: bit, byte and integer depending of the range of the pixel value.
The ILWIS program works with both types of map; on the one hand a raster map is more easy to handle and display, do calculations, overlay and creation of new maps but on the other hand raster maps occupied more memory space.

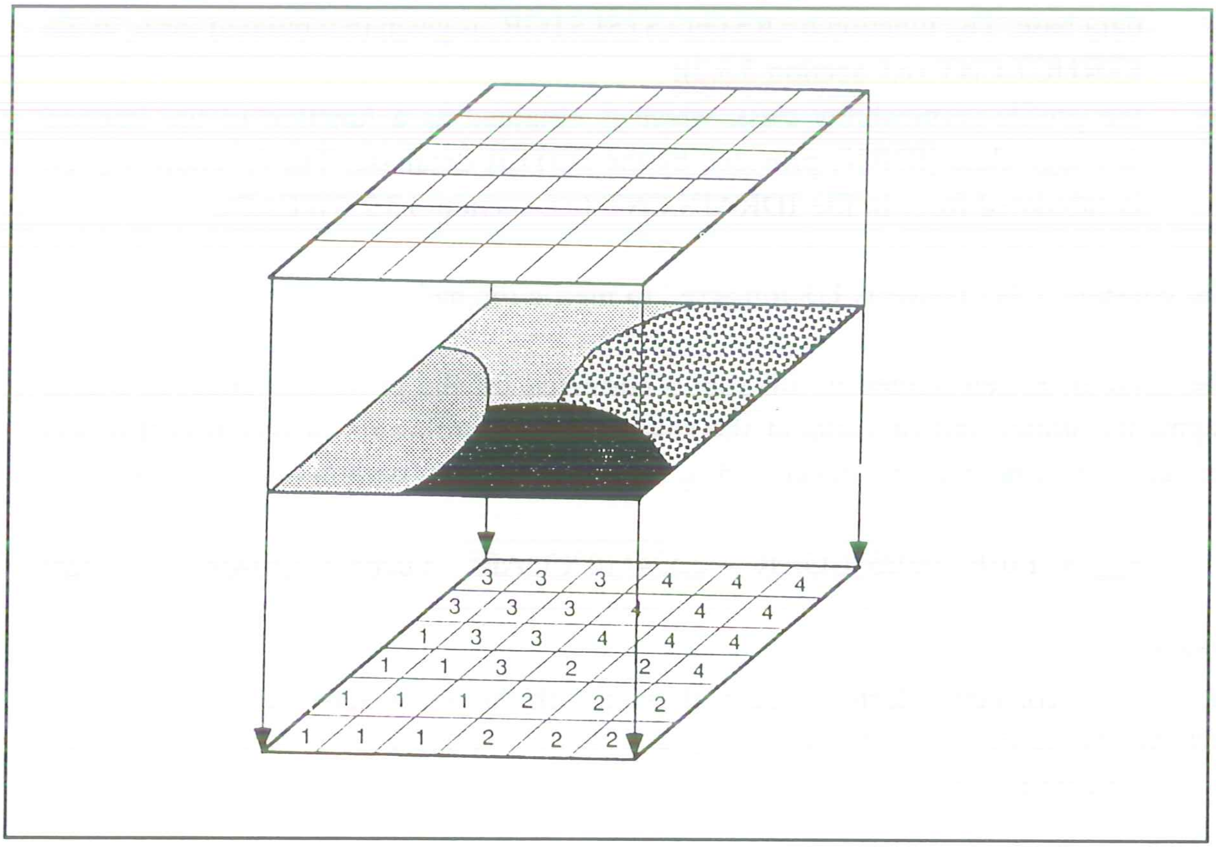

Figure A4: Vector/Polygon-to-raster conversion

Appendix 5 Modification of the models (USLE and SLEMSA) factors as in SWEAP.

The K factor

$$100K = 2.241*[2.1*10^{-4}*(SILT+VFSA)^{1.14}*(12-OM) + 3.25*(b-2) + 2.5*(c-3)] \quad (27)$$

Where,

SILT+VFSA is the content of silt plus very fine sand (%), given in the SOTER data base;

OM, Organic matter content, estimated by OM=CARB/0.6, where CARB is the organic carbon content of the fine earth fraction provided by the SOTER data base;

b, the soil structure code, which is obtained as a function of structure form (STFO), structure size (STSI) and structure grade (STGR), all provided by the SOTER data base. The function b=f(STFO,STSI,STGR) is given in tabulated form, in file STRUCT.CNT (c.f. section 3.3.2);

c, the profile-permeability class, which is obtained as a function of the internal drainage class (IDRN) provided by the SOTER database. The function is given in tabulated form in file IDRAIN.CNT (c.f. section 3.3.2 SWEAP).

The constant 2.241 converts US-ton.acre^{-1} to metric ton.ha^{-1}.

The value of K determined in this way is corrected for the protective effect of coarse fragments, stones and/or rocks at the soil surface according to an equation that was derived from a nomograph developed by the US Soil Conservation Service (1980):

$$F_{coar} = 1.026 - 0.025*COAR + 2.534*10^{-4}COAR^2 - 1.026*10^{-6}COAR^3 \quad (28)$$

Where

F_{coar} is the correction factor to be multiplied with the uncorrected K;

COAR, the maximum of (1) coarse fragments in the first layer or (2) % surface covered with stones or rocks.

The present version of SWEAP does not account for temporal K variability.

The K factor soil-erodibility is calculated according to the equation of Wischmeier and Smith (1978), which gives and constant K factor for the whole year.

The variation of K factor for some tropical soils within a period of one year going from 0.06 to 0.26 tons.ha^{-1}.year^{-1}.(rainfall erosion index unit)$^{-1}$, and the one calculate with the equation of Wischmeier is keep fixed at 0.06; this experiment was in an Oxic Paleustalf at Heinpang, Vanelslande et al.(1984). This can be an source of error in USLE model.

The LS factor

Several methods have been developed to estimate the LS factor from slope length and gradient. The differences between these methods only become appreciable for very gentle or very steep slopes (i.e. <1% or >20%).

SWEAP uses the equations proposed by Mutchler and Murphree (1981) that give practically the same results as the ones provided by Wischmeier and Smith, but require fewer program statements and do not have discontinuities:

$$L = (SLEN/22.13)^m$$
$$S = 65.41*\sin^2(a) + 4.56*\sin(a) + 0.065$$
$$m = 1.2*(\sin^2(a))^{1/3}$$
$$\sin(a)=\sin(\tan^{-1}(SLOP/100))$$
$$LS = L*S$$

where SLEN is the slope length in m, and SLOP the slope gradient in %, both given by the SOTER input file.

The C factor

The monthly C factor, C_i, is calculated as follows:

1. Check if land use/vegetation data are provided by the user or if the information from the SOTER data base is to be used. If the landuse is "annual crops" then planting and harvest dates must have been indicated by the user or the program must have been ordered to calculate potential growing season(s) from

---

A growing season is defined as a period of at least three consecutive months with average temperature $>T_{cr,av}$, minimum temperature $>T_{cr,min}$ and the ratio between actual and potential evapotranspiration must exceed a critical value $R_{Eac,Epot}$. SWEAP calculates potential evapotranspiration according to the method of Penman or Thornthwaite (chosen by the user). If the method of Penman is chosen the program checks first whether potential evapotranspiration according to Penman is provided in the climate file (variable PETP). If this is not the case, then the SOTER variables TMIN, TMAX, RADI, SUNH, VAPP and WIND (see section 3.1) are used to calculate PETP according to Frère and Popov (1979). If data on RADI (radiation) are not available then the program calculates RADI from SUNH (hours of sunshine) according to the method of Prescott (1940):

$$RADI = OUTRAD * (A + B*SUNH/DL) \quad (1)$$

where,

OUTRAD is the extraterrestrial irradiation , MJ.m-2.day-1
DL is the daylength, hours
A and B empirical constants, dimensionless.

OUTRAD and DL are calculated by the model from the latitude, and the time of the year. $T_{cr,av}$, $T_{cr,min}$, $R_{Eac,Epot}$, A, B and the desired method for calculating potential evapotranspiration are to be provided by the user in file CONSWEAP.CNF (see section 3.3.3). Most countries have at least 1 meteorological station that can provide representative values of A and B. Indicative values used by F.A.O. (Frère and Popov, 1979) are: A=0.18, B=0.55 for cold and temperate zones; A=0.25, B=0.45 for dry tropical zones; and A=0.29, B=0.42 for humid tropical zones.

If data on VAPP are not available they will be calculated by

$$VAPP=HUMI/100. * SVAP, \quad (2)$$

where,

HUMI is the relative air humidity, %
SVAP the saturated vapour pressure, mbar.

HUMI is input from the SOTER database (see section 3.1 SWEAP). SVAP is calculated from the average temperature and the altitude above mean sea level, according to Goudriaan (1977).

Moisture availability is calculated with a simple water balance module, governed by the equation:

$$H_i=H_{i-1} + RAIN_i - Epot_i \quad (3)$$

Where H_i and H_{i-1} are the available water (mm) at month i and month i-1 respectively; $RAIN_i$ is the precipitation in month i (mm) and $E_{pot,i}$ is the potential evapotranspiration (mm) in the same month.
H_i is limited by the minimum value 0 and the maximum value STORGCAP. SWEAP assumes a storage capacity of 1mm per cm depth from the topsoil to the maximum rooting depth RDEP or (if RDEP>120cm) 120mm.

If the land use type involves the application of irrigation then water availability is assumed to be not restrictive for the determination of growing seasons.
The first month of each calculated growing season is assumed to be the month of planting, whereas the last month is assumed to be the month of harvesting. The number of growing seasons per year is assumed to be the number of crops planted per year.

---

1. Method used to calculate potential growing seasons.

geographical latitude, elevation and monthly climate characteristics, according to the method described in Textbox 1.

2. For perennial crops and natural vegetation read C_* from file (PERENN.TAB or VEGETAT.TAB), or read the percentage ground cover (V) and calculate C_* from a tabulated relation with V, given in file INTRCPT.CNT (see section 3.3.2 SWEAP).
For annual crops get the crop coefficients for the month of planting ($C_{crop,1}$); the first month after planting ($C_{crop,2}$) and consecutive months ($C_{crop,3}$). The $C_{crop,i}$'s can be obtained directly from file (ANNCROP.TAB), or calculated from leaf area index and crop geometry, according to the method described in Textbox 2.

3. If the type of land use is permanent, e.g. perennial crops, livestock, forestry, or if the land is covered with natural vegetation, then C_i is assumed to be constant and equal to C_* during the entire year.
If the type of land use is annual crops, then C_i is calculated as the product of $C_{crop,1}$, $C_{crop,2}$, or $C_{crop,3}$ with $C_{resid,i}$, the C factor for residues from a previous crop in month *i*. The calculation of C_{resid} from the cover of crop residues (V_{resid}) is explained in textbox 3.

To estimate the factors $C_{crop,1}$, $C_{crop,2}$ and $C_{crop,3}$, SWEAP first calculates the percentage ground cover according to Kassam et al., 1991 [in analogy with an equation for light interception (Montheith, 1969)]:

$$V_{crop} = 100(1-e^{-kL}) \quad (1)$$

where,

V_{crop} is percentage crop ground cover;
k, a constant based on crop geometry,
L, Leaf area index ($m^2.m^{-2}$)

V_{crop} is transformed to a C factor by means of a tabulated relationship, provided in file INTRCPT.CNT. L_{max}, the leaf area index of the crop at full development, *k* and a reference to a column in INTRCPT.CNT are extracted from file ANNCROP.TAB (see section 3.3.1). SWEAP assumes a value of $L=0.1L_{max}$ for the calculation of $C_{1,crop}$; $L=0.6L_{max}$ for $C_{2,crop}$ and $L=L_{max}$ for $C_{3,crop}$. When more than 1 crop is grown at the same time on the same field (e.g. intercropping), SWEAP imposes an upper limit for total L of 6.0. In these cases equation (1) is applied to the lumped value of L.

---

2. Method to calculate C factor for annual crops.

Indicative values for length of growing period (LGP, days), maximum leaf area index (L_{max}, $m^2.m^{-2}$), *k*, and percentage groundcover of crop residues, in relation to maximum ground cover of living standing crop ($\%V_{resid}$) are given in Table 3. Relationships between percentage ground cover and C factor for several types of cover are given in Table 4.

The C factor for residuals of annual crops left after harvest (C_{resid}) is calculated as:

1. Consider the cover of residuals V_{resid}, expressed as percentage cover.
   The maximum uncorrected value of V_{resid} (only economic crop organs removed, residuals left standing or evenly spread on the field), is extracted from file ANNCROP.TAB, as a percentage of the maximum crop cover ($V_{crop,max}$). $V_{crop,max}$, which is calculated according to eq. 1 of Textbox 2, with $L=L_{max}$. If k or L_{max} are missing, then $V_{crop,max}$ is estimated as $100(1-C_{crop,3})$.
2. Correct V_{resid} for residual treatment (e.g. burning, incorporation etc.) by multiplication with a factor extracted from file RESIDC.TAB (see section 3.3.1). Residual treatment may occur in the month of harvest, or in the month of planting or sowing a new crop.
3. V_{resid} is assumed to decay with a constant factor 0.825 per month, which implies that hypothetically 90% of the effective cover breaks down in one year.
4. Transform V_{resid} to C_{resid} by means of a tabulated relation between % cover and relative soil loss, extracted from INTRCPT.CNT (see section 3.3.2).

3. Calculation of C-factor for crop residues.

Table 3. Indicative values of length of growing period (LGP, days), maximum leaf area index (L_{max}, $m^2.m^{-2}$), k, and percentage groundcover of crop residues, in relation to maximum ground cover of standing crop ($\%V_{resid}$). Derived from Kassam et. al., 1991.

Crop	LGP	L_{max}	k	$\%V_{resid}$
barley	105-175	4.0-5.0	0.7	90
cassava	>240	3.0	1.0	95
cotton	170	3.0	1.0	95
cowpea	90	3.0	0.85	85
green gram	70-90	2.5-3.0	0.85	85
groundnut	90	3.0	0.85	85
maize	80-150	2.5-4.0	0.7	95
oats	105-175	4.0-5.0	0.7	90
pearl millet	70-90	3.0-4.0	0.6	90
phaseolus bean	>105	3.5-4.0	0.85	90
pigeon pea	>140	4.0	0.45	90
rice	90-130	3.5-5.0	0.6	85
sorghum	80-150	2.5-4.0	0.6	90
soybean	120-150	4.0	0.45	80
sugarcane	>270	5.0	0.70	99
sweet potato	120-150	3.5-4.5	0.85	90
wheat	105-175	4.0-5.0	0.7	90
white potato	100-150	3.0-5.0	0.85	95

The P factor

The P factor is extracted from file PTAB.CNT in dependence of the user specified type of erosion control factor (section 3.3.2 SWEAP). The P factor is assumed to be constant during the year.

SLEMSA

A schematic representation of the SLEMSA model is given in Figure 1
The basic equation of the model is:

$$Z = K*C*X,$$

where

- Z is the estimated soil loss ($t.ha^{-1}yr^{-1}$);
- K, Mean annual soil loss ($t.ha^{-1}yr^{-1}$) from a standard weed-free bare fallow field plot (30m length at a slope of 4.5%)
- C, The crop ratio, i.e. the ratio of soil lost from a cropped plot to that lost from bare fallow land;
- X, The topographic ratio, i.e. the ratio of soil lost from a plot of length L and slope S, to that lost from the standard plot.

For the same reason as given in section 2.1 for USLE, it is better to interpret the results of SLEMSA in terms of abstract erosion hazard units (EHU) and not as quantitative soil loss estimates.

For SLEMSA the program SWEAP calculates Z as the sum of 12 monthly values:

$$Z = \Sigma_{i=1,12} K_i*C_i*X$$

2.2.1 The K factor

SLEMSA's K factor is the result of the interaction between erosive forces of rainfall and runoff and the erodibility of the soil. SLEMSA accounts for this interaction on a yearly basis by the equation 2.12 (Elwell and Stocking, 1982):

$$K_{ann} = e^{[(0.4681 + 0.7663F).ln(Eann) + 2.884 - 8.1209F]}$$

where

K_{ann} is the K factor (ton.ha.yr^{-1}),
F is a soil erodibility rating, that may vary from 1 (extremely erodible) to 10 (extremely resistant);
E_{ann}, the rainfall energy (J.m^{-2}.yr^{-1}).

SWEAP works on a monthly basis. Therefore equation 2.13 was modified to:

$$K_i = K_{ann}.E_i/E_{ann} \tag{2.14}$$

SWEAP gets basic F factors for dependence of texture class and type of soil development from file FTAB.CNT which need to be filled to complete (c.f. section 3.3.2 SWEAP). The basic F factor can be modified for dependence of soil management, internal drainage, salinity, the presence of a lithic contact, the presence of abrupt horizon boundaries or the sensitivity to capping.
This is done in the following way:

For soil management:
Modifiers for F are read from file FMANMOD.CNT (section 3.3.2 SWEAP). The value of the modifier, which depends on slope and type of management is added to F. The modifiers may be positive or negative.

For internal drainage:

If IDRN = Imperfect then F = F + 0.5*DRN
If IDRN = Poor then F = F + 0.7*DRN
If IDRN = Very poor then F = F + 1.0*DRN

where
IDRN is the soil's internal drainage status, as given in the SOTER database;
DRN, the basic adjustment factor, read from file FTAB.CNT, dependent on type of soil development.

For salinity:

If SALINE then F = F + SAL

where
SALINE is a boolean variable, that becomes true if the soil has salic properties or if the ECE exceeds 4. This information is obtained from the SOTER file.
SAL is the basic adjustment factor, read from file FTAB.CNT, dependent on type of soil development.

For the presence of a lithic contact:

If MSUB is Unconsolidated or Stones or Unknown,
or If PDEP > .75 then XLIT=0
If MSUB is Petroplinthite or weathered rock then XLIT=0.5*LIT
If MSUB is unweathered hard rock then XLIT=LIT
If PDEP > .25 then F = F + XLIT*(.75-PDEP)/.5
If PDEP ≤ .25 then F = F + XLIT

where

LIT is the basic adjustment factor, read from file FTAB.CNT, dependent on type of soil development.

MSUB, the SOTER input variable for material below the pedon,

PDEP, the SOTER input variable for the depth to parent material (m)

For an abrupt lower boundary of the first layer:

If ABRTXT then XABR = ABR
If BOUN is abrupt and not ABRTXT then XABR=0.5*ABR
If BOUN not abrupt, or LDEP>75 then XABR = 0.
If LDEP > .25 then F = F + XABR*(.75-LDEP)/.5
If LDEP ≤ .25 then F = F + XLIT

where

ABR is the basic adjustment factor, read from file FTAB.CNT, dependent on type of soil development.

ABRTXT is a boolean variable, indicating the presence or not of an abrupt textural change as diagnostic property,

BOUN, the SOTER input variable for abruptness of the boundary from the first to the second layer,

LDEP, the SOTER input variable that indicates depth from the first to the second layer (cm).

For sensitivity to capping:

If SCAP = Weak then F = F + 0.3*CAP
If SCAP = Moderate then F = F + 0.5*CAP
If SCAP = Strong then F = F + CAP

where,

SCAP is the SOTER input variable for sensitivity to capping

CAP,the basic adjustment factor, read from file FTAB.CNT, dependent on type of soil development.

SLEMSA is very sensitive to F modifiers, especially at high erodibility levels. Therefore it is crucial that the basic adjustment factors be established experimentally. If there is no experimental basis to define these factors, a sensitivity analysis can be useful to show the results for different assumptions.

Data on rainfall energy (E) are not available in the SOTER data base, and must be derived from monthly precipitation records. The regression parameters are to be defined by the user in file CONSWEAP.CNF (c.f. section 3.3.3 SWEAP). A few examples of regression equations obtained or derived from literature are given in Table 5. All consulted works found approximately linear relations between E and P_{month}; none of them mentioned application in regions with freeze and thaw. Nevertheless, options for the same types of equations for rain and snowmelt as for USLE (section 2.1.1 SWEAP) are available.

The influence of coarse fragments is calculated according to the same method as described (in section 2.1.2 SWEAP) for the USLE model.

Table 5. Regression equations relating Rainfall energy, E ($J.m^{-2}$) to amount of precipitation (P, mm).

E = 18.85 P	-	Zimbabwe, for areas prone to drizzle	Stocking et. al., 1988
E = 17.37 P	-	Zimbabwe, for aggressive climates	Stocking et. al., 1988
E = -120 + 41.4 P	r=.99, n=18	Individual rainstorms	Kowal and Kassam, 1976
E = 36.1 P	r=.99, n=18	Accumulated rainstorms	Kowal and Kassam, 1976
E = 27.6 + 24.5 P	r=.81, n=?	Individual rainstorms(?)	Lal, 1982, cited by Lal, 1990
E = 20.03 P	r=.96, n=20	Monthly data of Jinxian (1984) and Jurong (1985), S.E. China.	Marx, 1988

The C factor

The C factor of the original SLEMSA model is calculated as a non linear function of rainfall interception, i.e. ground cover. That method is compatible with the method used for the calculation of the USLE's C-factor from leaf area and crop geometry described (in section 2.1.4 SWEAP) for USLE.

The X factor

The X factor for SLEMSA is calculated in the same way as the LS factor for USLE. However there is a conversion factor of 2.147, to correct for the standard plot, which is of different length and has a different slope gradient than the USLE standard plot.

Appendix 6 Example of ASCII soil input file

```
*SUID SLOP SLEN ROCK STON PDEP PROP RDEP IDRN SDEV SCAP MSUB LDEP BOUN STFO STSI STGR CARB ECE CFVO VFSA SILT CLAY
TXTC DIAP DIAP DIAP LUSE VEGE CLIMFIL   ICLIM
1 6 600 0 0.01 1.5 70 15 R FA S U 35 D 2 # # 1.3 1.0 1 9 10 77 C # # # AA4 # LACLIMC.DAT 202
1 12 225 1 0.01 1.5 30 15 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 202
2 22 225 5 50.00 0.3 70 35 R CH W U 30 A 2 # # 2.5 1.0 8 23 17 35 SC # # # AA4 # LACLIMC.DAT 202
2 12 225 1 0.05 1.5 30 150 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 202
3 2 600 5 50.00 0.1 60 35 W CH M U 15 C 2 # # 1.3 -1.0 60 30 28 17 SL # # # HE V LACLIMC.DAT 202
3 2 600 5 50.00 1.6 30 35 W LU S U 30 A 2 # # 1.3 -1.0 1 12 50 25 L # # # HE V LACLIMC.DAT 202
3 1 600 0 0.01 1.2 10 35 I VE N N 15 G 2 # # 5.5 -1.0 1 2 43 52 SIC # # # HE V LACLIMC.DAT 202
4 22 225 5 50.00 0.3 70 35 R CH W U 30 A 2 # # 2.5 1.0 8 23 17 35 SC # # # AA4 # LACLIMC.DAT 202
4 12 225 1 0.05 1.5 30 150 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 202
5 2 600 5 50.00 0.1 60 35 W CH M U 15 C 2 # # 1.3 -1.0 60 30 28 17 SL # # # HE V LACLIMC.DAT 202
5 2 600 5 50.00 1.6 30 35 W LU S U 30 A 2 # # 1.3 -1.0 1 12 50 25 L # # # HE V LACLIMC.DAT 202
5 1 600 0 0.01 1.2 10 35 I VE N N 15 G 2 # # 5.5 -1.0 1 2 43 52 SIC # # # HE V LACLIMC.DAT 202
6 22 225 5 50.00 0.3 70 35 R CH W U 30 A 2 # # 2.5 1.0 8 23 17 35 SC # # # AA4 # LACLIMC.DAT 208
6 12 225 1 0.05 1.5 30 150 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 208
7 22 225 5 50.00 0.3 70 35 R CH W U 30 A 2 # # 2.5 1.0 8 23 17 35 SC # # # AA4 # LACLIMC.DAT 208
7 12 225 1 0.05 1.5 30 150 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 208
8 22 225 5 50.00 0.3 70 35 R CH W U 30 A 2 # # 2.5 1.0 8 23 17 35 SC # # # AA4 # LACLIMC.DAT 208
8 12 225 1 0.05 1.5 30 150 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 208
9 22 225 5 50.00 0.3 70 35 R CH W U 30 A 2 # # 2.5 1.0 8 23 17 35 SC # # # AA4 # LACLIMC.DAT 202
9 12 225 1 0.05 1.5 30 150 W LI S U 15 C 2 # # 1.3 1.0 1 8 26 61 C # # # AA4 # LACLIMC.DAT 202
10 2 600 5 50.00 0.1 60 35 W CH M U 15 C 2 # # 1.3 -1.0 60 30 28 17 SL # # # HE V LACLIMC.DAT 202
10 2 600 5 50.00 1.6 30 35 W LU S U 30 A 2 # # 1.3 -1.0 1 12 50 25 L # # # HE V LACLIMC.DAT 202
10 1 600 0 0.01 1.2 10 35 I VE N N 15 G 2 # # 5.5 -1.0 1 2 43 52 SIC # # # HE V LACLIMC.DAT 202
```

Example of ASCII input file with climate data

*ID	LAT	ELEV	VAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
105	-29.50	57	RDAY	8.0	6.0	7.0	5.0	5.0	6.0	4.0	4.0	5.0	8.0	6.0	6.0
105	-29.50	57	RAIN	103.0	123.0	154.0	95.0	52.0	46.0	32.0	31.0	64.0	103.0	109.0	124.0
105	-29.50	57	VAPP	21.9	21.5	21.2	16.8	14.8	13.7	12.3	12.3	13.9	16.9	17.6	18.7
105	-29.50	57	WIND	2.2	2.0	2.0	2.0	1.8	2.4	2.2	2.8	3.4	3.0	2.6	2.6
105	-29.50	57	PETP	164.0	137.0	115.0	67.0	41.0	27.0	34.0	63.0	83.0	102.0	149.0	181.0
105	-29.50	57	RADI	21.0	19.6	17.5	13.5	10.0	6.9	9.2	12.2	15.1	16.4	22.0	21.8
105	-29.50	57	TMAX	33.6	32.5	30.2	25.4	23.1	19.8	20.9	22.9	24.7	26.4	30.1	31.6
105	-29.50	57	TMIN	19.3	18.8	17.3	12.0	10.5	9.0	7.7	8.7	10.7	13.7	15.9	18.0