# TERMINOLOGY FOR SOIL EROSION AND CONSERVATION

Concepts, definitions and multilingual list of terms for soil erosion and conservation in English, Spanish, French and German


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**E. Bergsma**

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**F. Gibbons**

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Soon after it was formed in 1982, Sub-Commission C of the International Society of Soil Science identified two major barriers to effective communication and exchange of scientific information among professionals dealing with soil erosion assessment and conservation implementation. These are the different methods and terms used by researchers and practicioners in this complex milti-disciplinary arena. Such differences are easy to comprehend considering the fact that not only soil scientists but also engineers, geomorphologists, hydrologists, ecologists, and social scientists are involved in it and are doing so in many diverse geographic, economic, cultural, and political settings and at many spatial and temporal scales. The Sub-Commission has already sponsored a volume on methodology. The current volume deals with terminology.

Glossaries on this subject have been published by a number of national scientific organizations, e.g. in Australia and the `United States. This volume extends the scope into Illustrated Concepts which capitalize on such glossaries and also builds on the latest developments on each as reported in international meetings and publications. The team of co-authors, with lead from Mr. Eelko Bergsma, was deliberately selected to render an important balance to this effort from a number of important perspectives, including disciplinary, geographic, and linguistic aspects. This first volume is in English, but the ISSS intends to follow with publications in other languages as well.

We thank the co-authors and the ISSS leadership for bringing this high priority objective into reality and feel confident that the scientific community will find the book valuable for education, training, and research purposes.

Chair and Past Chairs of Sub-Commission C of the
International Society of Soil Science,

Samir A. El Swaify
Ildefonso Pla Sentis
Christian Valentin.

The heavens declare the glory of God,

and the firmament showeth his handywork.

Psalms 19:1

Extensive experience in soil conservation over a great numer of years has led to the recongition of the practical value of certain principles to be observed in planning and developing conservation farming. The recognition of these principles results from much trial and error. The principles are put here in a separate preface, as acknowledgement to those who have by their effort contributed to the establishment of these principles, working often under difficult circumstances and by persevering even when guidance from earlier research efforts and results was meagre or not available. This glossary of terms in erosion and conservation is built on their results.

It is not only the advancement of conservation science that benefitted from the research and implementation of soil conservation. The concept of land husbandry is kept alive by all those who care for the land, and who look for a sustainable use of the land and the right way to go about it. This practical view is of importance when trends in emphasis on conservation may shift and pressure for other considerations in land use decisions are applied.

The heart of soil conservation lies in an attitude of caring for the land. With current widespread overuse of natural resources, and an increasing misuse leading to pollution of the environment, an important contribution to the preservation of creation can come from continued stimulation of this attitude. In agriculture this is expressed by conservation farming.

The principles resulting from experience in soil conservation include (Shaxson, Hudson, Sanders, Roose & Moldenhauer 1989):

a. Planning must be long term, at least 10 years;
b. Having flexibility in planning and execution;
c. Including farmers at all stages;
d. Considering conservation together with production, not separately;
e. Structural measures complementing biological conservation measures, not replacing them;
f. Considering short term benefits as essential to the farmer's interest;
g. Realising that successful projects result in minimised risks, increased income, more reliable yields, reduced imputs and/or reduced drudgery of farm life;
h. Practices fitting easily into the prevailing farming systems and being within the the physical and managerial abilities of the farm families;
i. Expanding testing gradually;
j. Using local people and skills;
k. Keeping a record of progress while planning and evaluating situations regularly;
l. Maintaining measures and practices is essential;
m. Follow-up and re-appraisal being very desirable, providing for assistance by government, non-government or volunteer organisations after the project has ended or project money runs out.

Following up on point h, about the importance of the practices to fit the prevailing farming systems, one may recommend to be attentive to local knowledge, experience and wisdom about the use of the land (Indigenous Knowledge 1993).

The suggestion and encouragement to start and persevere with the compilation of a glossary of terms in erosion and conservation came from Dr. Klaus W. Flach, as chairman of Subcommission C, Soil Conservation and Environment, and Dr. Wim Sombroek, as Secretary General of the International Society of Soil Science, as early as 1984.

Progress was made in stages, fitted in between mountains of duties at ITC. This led to several drafts dated Enschede, ITC, 3/84-8/84-4/85-5/85-2/87-3/88-10/88-8/89-1/91-9/91-3/93. One of the first contributions came from Dr. J.M.Roels who was willing to review an early draft in March 1984. At conferences of the International Soil Conservation Organisation discussions were held about the way to proceed. In Maracay in 1985, Dr. T.de Meester strongly supported the work and the meeting helped to draw up a plan of work. Peter Charman, Soil Conservation Service of New South Wales, Australia, gave support by encouraging comments right from 1984, and he was willing to make a complete critical review in 1987. This speeded up the work, helped also by Frank Gibbons, of the Soil Conservation Authority of Victoria, Australia, who completed an overview of conservation practices in 1987. To my regret, Frank could not see the completion of this work. He passed away on 24 March 1996.

The hope of finalising the work was raised by Dr.W. Moldenhauer, who made a complete critical review of the fourth draft in 1988 and 1989. Other international contributions were given by Dr. Samarn Panichapong, with a review of the fourth draft in 1988 and 1989.

In 1990 a meeting with Dr.Hans Hurni in Maracay was followed by close cooperation to finish the work, in the form of postal contact and meetings in Berne during 1990 and 1991. His encouragement and contributions led finally to the completion of the work in the present form, which includes the German equivalent terms.

At the ISCO VII conference in Sydney, October 1992, Peter Charman offered to read the complete text of the list of definitions and the central concepts and to check the English language. This was a very substantial contribution, which I had hesitated to suggest to someone before. It proved to led to numerous improvements in the text, and some additions to the contents.

For the Spanish translation of the terms in the glossary, staff members of the Instituto de Geosciencias y Medio Ambiente (INGEMA) of the University of Tucuman, Argentina, helped with a substantial start on the Spanish equivalent terms in 1986.

A large contribution came from Hugo Villota, Division de Sciencias Naturales, Instituto Geografico Augustin Codazzi (IGAC) in Bogota, Colombia, who worked with me on the Spanish equivalents in the autumns of 1989, 1990 and 1991. References that were consulted at his suggestion were:

- Glosario de terminos tecnicos en erosion y conservacion de suelos, Manual de Conservacion de Suelos de Ladera, Gerencia Tecnica, Centro Nacional de Investigacion de Cafe, Federacion Nacional de Cafetéros de Colombia, Chincina, Caldas, 1975.
- Fernando Suarez de Castro: Glosario, Conservacion de Suelos, Salvat Editores S.A., Barcelona, Madrid, 1965.

For the French equivalent terms Dr. Jean Riquier gave a basic contribution in 1986. His work was followed up by Dr. Clement Mathieu, presently at Purpan, Ecôle Supérieure d'Agriculture, Toulouse, who contributed to the list of French equivalent terms in 1990 and 1991 in several instalments of careful study of the meaning hidden in the English terms.

The source of the German equivalents was Dr. Hans Hurni, of the Geographical Institute, University of Berne, Switzerland. He contributed most of the equivalent terms in the summer of 1991.

During the ISCO VI conference in Addis Ababa, a meeting with Karl Herweg led to him taking on the design and production of handdrawn illustrations for a number of terms.

In 1993 the text was given to my colleague Hans van Baren at ISRIC, Deputy Secretary-General of the ISSS. He looked again critically at the text, leading to corrections. This gave me also an opportunity for additions and clarifications.
S&B Office Services did the typesetting and developed an attractive layout.

It is clear that all these contributions were a considerable and essential help to arrive at the present publication. All those who have contributed are very gratefully acknowledged.

Last, but not least, I wish to thank the organizations who provided financial support, bringing this publication within the reach of individual soil scientists, also in developing countries.

Looking back it is stricking that there is often a richness of knowledge, insight and evidence of experience in the consulted publications, which may be unrecognised and underestimated.

Eelko Bergsma.

This publication is a glossary. It is prepared for the International Society of Soil Science and deals with terms used in the study, prevention and treatment of soil erosion by rain.

The glossary is different from a list of definitions. The terms are described, explained, put into context, given consideration for practical use by "descriptive aspects", which are added to the "definition" proper. Related terms and sometimes synonyms are given, which also help the reader to understand the term in its meaning and use.

In separate sections, certain terms which are considered to have a central part in the study of rain erosion processes, rain erosion hazard and conservation planning have been described more extensively; these terms are called Central Concepts.

All terms defined and explained in the glossary are included in an alphabetical list of terms. This list also gives the equivalents in the Spanish, French and German languages.

It is felt that the way of presentation, used in this glossary, could also be useful for other fields of science such as hydrology, or remote sensing.

The aim of the glossary is to:
- contribute to a better understanding of commonly used terms;
- assist in clarifying erosion and conservation knowledge and insight for use in education, publishing, development projects, agricultural extension work and research;
- give an international point of view, emphasizing local experience and cultivation systems, without early recourse to practices of conservation needing high investment in the sense of money and technical complexity;
- be easily readable and attractive in presentation;
- given an overview of up-to-date knowledge on erosion and conservation to all persons interested around the world.

The glossary is restricted to rain erosion. Terms describing equipment, instruments and tools for laboratory and field investigations and for soil management are not included. A limited inclusion is made of terms related to mass movement.

The material is divided into the following parts:

CENTRAL CONCEPTS
Some terms are central to erosion study and conservation farming. These Central Concepts have been described separately in more detail. Terms chosen to be Central Concepts are commonly used important terms, having a relationship with many other terms of a less comprehensive nature, and thereby offering a context to these terms for the explanation of their meaning and differences. The discussion of the Central Concepts forms an important part of the publication.

The terms included as Central Concepts are the following:

Rain erosion features and processes:
1. Soil crusting and sealing
2. Overland flow
3. Rain erosion features
4. Rill erosion
5. Gully erosion

Factors influencing rain erosion hazard:
6. Rain erosivity
7. Relief effect
8. Soil erodibility
9. Soil cover
10. Soil conservation
11. Agroforestry

Factors in conservation planning:

12. Rain erosion hazard
13. Soil loss tolerance
14. Land and soil productivity

Tools in conservation planning:

15. Rain erosion mapping
16. Models of rain erosion
17. Multiband remote sensing and erosion

The discussion of the Central Concepts includes:

- the term
- related terms
- the definition
- descriptive aspects
- illustrative material
- references

DEFINITIONS AND DESCRIPTIVE ASPECTS OF TERMS

This is an alphabetical list of terms related to soil erosion and conservation, with their definitions. Very often descriptive aspects of the terms are giving to help the reader to understand the term better. Sometimes related terms are given, when this may help to place the term in context and in relation to other terms.

Terms that are also used outside the field of erosion, such as sealing, conservation, degradation, etc. are specified for their relation to soils, such as: soil sealing, soil conservation, land degradation, etc. When these terms are used in a clear context these additions may be dropped again.

Source specification for every single word has been made in case of the definitions, and is included up to the penultimate draft. For the descriptive aspects, exact quoting is the basis too, but sometimes words are added or parts rephrased as a link with foregoing or following text. In general no changes have been made anywhere, but original authors' statements are presented.

The definition given is the preferred one, sometimes chosen out of several existing ones. For those readers who want to study other definitions, and the sources, it will be possible to request the text of the penultimate draft.

ALPHABETICAL LIST OF TERMS

This is a list of all the terms that are defined and described in English with their Spanish, French and German equivalents.

REPORTS OF REGIONAL IMPORTANCE

It was found useful for readers of the glossary to have a more direct accession to important regional publications than through the references in the last chapter.

REFERENCES

This lists the references referred to in the whole glossary.

# CENTRAL CONCEPTS IN SOIL EROSION AND CONSERVATION

## RAIN EROSION FEATURES AND PROCESSES

1. SOIL CRUSTING and SEALING
2. OVERLAND FLOW
3. RAIN EROSION FEATURES
4. RILL EROSION
5. GULLY EROSION

## FACTORS INFLUENCING RAIN EROSION HAZARD

6. RAIN EROSIVITY
7. RELIEF EFFECT
8. SOIL ERODIBILITY
9. SOIL COVER
10. SOIL CONSERVATION
11. AGROFORESTRY

## FACTORS IN CONSERVATION PLANNING

12. RAIN EROSION HAZARD
13. SOIL LOSS TOLERANCE
14. LAND and SOIL PRODUCTIVITY

## TOOLS IN CONSERVATION PLANNING

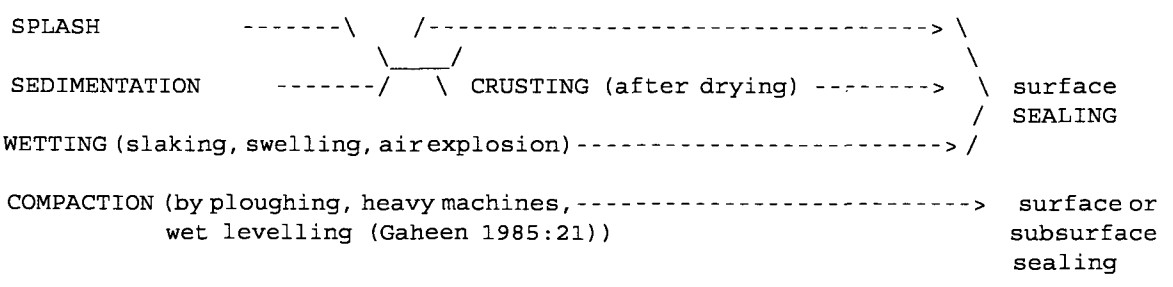
15. RAIN EROSION MAPPING
16. MODELS OF RAIN EROSION and CONSERVATION
17. MULTIBAND REMOTE SENSING and EROSION

## 1. SOIL CRUSTING and SEALING as Central Concept

### Introduction.

The terms soil crusting and soil sealing are sometimes used as synonymous.
Soil crusting has for many an association with a dry state, where a firm and brittle laminar soil surface *structure* exists. The term soil sealing implies a strongly reduced soil surface porosity for water and/or air.
In the following a distinction is proposed between soil crusting and soil sealing. Soil crusting is the more general name for thin and dense platy surface soil rearranged by influences of *splash,* wetting and *deposition* .
Typical crusting occurs in soils with a high content of non-swelling clay and with *dispersion* on wetting. Crusts are difficult to break and frequently form an obstacle for seedling emergence.
Soil sealing is the name for the reduction of porosity in the soil surface with lower *permeability* for soil water movement and air. Pores have become closed by the rearrangement of particles through the collapse of soil surface structure, swelling of wetted clays, mechanical *compaction* , and maybe other causes. While drying is often a process leading to crust formation, it usually tends to break up a seal by causing cracks in the soil surface.
The changes in the soil surface matrix brought about by rainfall and drying affect both mechanical strength and hydraulic resistance. Generally, most changes in the hydraulic impedance of this surface zone take place during early stages of rainfall, when the soil matrix approaches saturation, while changes in the mechanical strength (penetration impedance) occur during the post rainfall of the drying phase. Hence, the usage of the terms *crust* and crusting is more appropriate for drying conditions, whereas *surface sealing* refers to wet surface conditions (Romkens a.o. 1990).

The processes which may cause crusting, possibly together with sealing, operate singly or in combination:




**SOIL CRUSTING, surface crusting, crusting (when context is clear),**

**Equivalent term** : capping

***Related* term** : hardsetting

**A soil crust is a surface soil layer, ranging in thickness from a few mm to perhaps as much as 3 cm, that is much more compact, hard and brittle when dry, than the material immediately beneath it.**

a) The concept
b) Types of crust
c) Factors of formation
d) Sensitivity to crusting
e) Measurements of crusting
f) Effects of crusting
g) Practices against crusting

## SOIL CRUSTING

a) The concept

a1) It is often a sign of *actual land degradation* (Dudal 1981:5), caused by deteriorating conditions for *plant cover* and *soil structure* formation such as overcropping or *overgrazing*.

a2) It is a dense, thin, about one mm to a few cm thick, laminar soil packing or platy *soil structure* (Soil Sci. Soc. Am. 1978; Baver a.o. 1972: 219-220).

a3) It reduces soil surface porosity (Soil Sci. Soc. Am.1978; Baver a.o. 1972:219-220).

a4) It relates to moderately soil thick layers of about 0.5 - 2.0 cm (Soil Sci. Soc. Am. 1978; Baver a.o. 1972:219-220).

b) Types of crust

b1) A classification of crusts would have to take into account:
- formation
- composition
- thickness
- function
- dynamic nature

b2) Types of crusts are related to the forming processes (Norton a.o. 1986:68):
- a dense seal of low *permeability* due to *compaction* by raindrops
  When crusts form under the influence of *splash* and rain *infiltration*, the upper part is often coarse in *texture* (type 2 of Norton a.o. 1986). This crust may be called STRUCTURAL.
- a composite crust consisting of a thin layer of mineral grains stripped of fine material overlying a compacted zone. This crust apparently has been at first compacted and then undergone selective removal of fine material, carried away in *runoff*.
  *Raindrop impact* and dispersed soil particles seal the soil and form a crust. This crust often comprises two parts, a very thin non-porous layer and a zone up to 5 mm thick of INWASHED fine particles. The soil in the in-washed zone is more dense than the soil below (Evans 1980:114).
- thin laminae of primary mineral grains and *aggregates*. This crust had the lowest porosity and was DEPOSITIONAL in origin.
  When formed by fine *depositional* layers (laminae), the upper part is often fine in texture. This type of crust may be called "depositional" (Kooistra & Siderius 1986:14; Courty 1986:38).

b3) Some *depositional* crusts show a micro-form of foreset bedding in a deltaic pattern (Kooistra & Siderius 1986:14) (inclined layers accumulated as sediment rolls down the steep frontal slope of a delta).

c) Factors of formation

c1) A crust is a product of a complex interaction of a number of mainly physical processes: *compaction*, destruction of *aggregates*, redistribution and filtering out of disaggregated separates, and there is the possibility that a chemical process is involved (Bryan 1968:25).

c2) Crust and seal formation depend on the cumulative *rainfall energy* and the rain intensity regime. Rainfall-*runoff* relationship for fields and *watersheds* with soils that seal need to take those into account as well as several other issues: depth and degree of *surface ponding*, character of topsoil, soil slope conditions, *soil surface roughness*, etc. (Romkens a.o. 1986:235).
High intensity rain gives weaker crusts than more gentle rains, and the effect develops later (Romkens a.o. 1986:232,234). The strength of crusts is strongly correlated with soil moisture content and the cumulative *kinetic energy* of preponding rainfall (Valentin 1986:367).

c3) Very intense rainstorms may produce enough *sheetwash* to *erode* the crust and increase the *infiltration* by as much as 30 %.

c4) The reduction of the *infiltration* over time in the first hour of rainfall is due to processes like swelling of colloids, decrease of the *gradient* of water potential as the wetting penetrates to greater depth, and the development of a surface crust (Dunne & Dietrich 1980).

c5) Chemical factors such as the low electrolyte concentration of the rainwater or a high ESP of the soil may play a role in crust formation, as is shown by data of Fedoroff (Courty 1986:33).

d) Sensitivity to crusting

d1) A soil's sensitivity to crusting is related to the absence of a certain grain size fraction. It is suggested that in these cases the finer particles can then fit in the openings between the larger particles (Sombroek & Zonneveld 1971; Sombroek 1986:4; Poesen 1986:375). It is suggested that a gap in the presence of grain sizes at 250-125 mu may be caused by the stronger abrasion of these particles through *saltation*, compared to the rolling transport for the heavier and larger particles and the transport in *suspension* for the smaller

and lighter particles.

e) Measurements of crusting

e1) Crust strength can be measured by a penetrometer or a torvane. A needle form of penetrometer, driven in at 10-15 mm/min was found to be the best way (Woo-Jung La a.o. 1986:164). Currently there is no technique that can measure the strength of the very thin crusts (1 mm or less) that are often very important for seedling emergence, aeration, and *infiltration* (for instance Farres 1986).

f) Effects of crusting

f1) Effects of crusting and sealing can be listed as follows (Sombroek 1986:5):
Negative effects
- reduced rainfall *infiltration*, less moisture enters the soil
- downslope *soil erosion* through *sheetwash* and *rill* formation
- mechanical impedance of seedling emergence
- lack of aeration just below the crust, retarding root development
- more force needed for tillage operations
- need for repeated tillage

Favourable effects:
- protection against wind erosion. This may be very temporary.
- more economic distribution of irrigation water (longer length of *furrows* )
- *water harvesting*.

f2) Crusts will cause less *interrill erosion* , through their resistance to *splash* and protection of the underlying material. Sealing crusts will increase the *rill erosion hazard* . On gentle slopes crusts remain intact longer than on steep slopes, where the detached material is removed sooner (Poesen 1986:183).

f3) Though a crust may be thin, it may reduce the evaporation from the soil, the aeration of the soil, the GERMINATION and SEEDLING EMERGENCE in a *seedbed* .
"Sensitivity to crusting" is used as a *land quality* in *land evaluation* . It is one of the determinants of the *soil productivity* (FAO 1983).
The resistance to penetration in sandy soils increases mainly with increasing cumulative energy of preponding rainfall. Clay surfaces harden mostly by drying (Valentin 1986b:369).

f4) A favorable aspect of crusting is the use of the crusted surface as a *catchment area* for *runoff* harvesting, to benefit a cropped area of limited extent nearby (Valentin 1986a:46).

f5) Crusts may reduce eolian deflation (Valentin 1986a:45), and increase eolian transport.

g) Practices against crusting

g1) Practices against crusting are often in the nature of *crop residue* management aimed at increasing the organic matter content and reducing *raindrop impact* , so increasing the resistance to crusting (for instance Nyamapfene & Hungwe 1986:328).

g2) Tillage methods affect crusting mainly by controlling residue, *plant cover* and surface porosity (Norton a.o. 1986:68).

g3) Soil conditioners may be used (Shaviv a.o. 1986; Yli-Hallo a.o. 1986) or *hydroseeding* (Gorke & Stoye 1986).

g4) *Soil management* practices to be recommended are planting on ridges or on hillocks (group seeding). Then the soil surface topography makes breaking of the crust easier, and the force of several seedlings is combined (Hanegreefs & Nelson 1986:267). Timely wetting of the soil surface by irrigation, especially sprinkling, is another common practice which weakens the crust allowing seedling emergence. Also tillage is reduced to a minimum (Nyamapfene & Hungwe 1986:328).

**SOIL SEALING, soil surface sealing, surface sealing, sealing (when context is clear)**

**The layering of fine particles of the soil surface under the influence of splash, slaking, swelling, sedimentation and in some cases subsequent drying, rendering it relatively impermeable to water.**

a) The concept
b) Sealing and erosion
c) Sensitivity to sealing
d) Indices of sealing
e) Effect of sealing
f) Recognition by remote sensing
g) Practices against sealing

a) The concept

a1) Soil sealing typically occurs due to the effect of raindrop water on bare soil and results in a reduction of *infiltration*; *runoff* and the potential for *soil erosion* are thus increased (Houghton & Charman 1986:132).

a2) The sealing usually takes place at the soil surface, but subsurface sealing together with *compaction* is reported for *ploughsoles* at the foot of the Ap-horizon. It can be considered a form of compaction.

a3) A seal is constantly being disturbed during rain. *Rainwash* material in transit becomes the seal when rainfall and *runoff* stop (Gabriels & Moldenhauer 1978:957).
The percentage of the largest *aggregate* fractions in *wash* and *splash* material decrease with time, and the percentage of silt increases with time. The percentage clay did not change and is generally less than one fourth of the original soil's clay content (Gabriels & Moldenhauer 1978:958).

b) Sealing and erosion

b1) *Overland flow* in *rainulator* experiments always start at rainfall intensities 5 - 10 times lower than the *infiltration rates* of the soils, which have been determined from ring infiltrometer tests under *ponding*.
The explanation must be in the sealing by *rainsplash* (Boon & Savat 1981:312-313).
The change in *infiltration* is especially related to a reduction in the macroporosity (Bork & Rohdenburg 1981:293-302).

b2) Experiments on loess samples showed the effect of surface crusting is to reduce *rainsplash* by 70% but to increase *rainwash erosion* by 50 times (Cai 1986:104).

b3) Sealing can often have an important place amongst the causal soil factors of *rain erosion*. It is considered together with rainfall, porosity, *aggregate stability* and *antecedent moisture* (Bork and Rohdenburg 1981:293-302).

b4) Rains with a high cumulative energy cause sealing later, and to a smaller degree than lower cumulative rain energies (Romkens a.o. 1986:234).

b5) A layer of flowing water such as in *rills* acts as a buffer against the action of raindrops and prevents the formation of a well defined seal. Water flowing over a surface on which a seal has already formed can result in the breaking up of the seal or at least reduce its effectiveness. Thus in a rill system of *erosion* the *infiltration* in the interrill area is less than the infiltration in the rills due to the sealing effect of the impacting raindrops on exposed soil.
Between rills, initial infiltration is high and rapidly decreases as the formation of a surface seal occurs, except in depressions where accumulated water may intercept the rainfall *kinetic energy*. Within the rills, a protective layer of *overland flow* water accumulates, preventing the formation of an effective surface seal and allowing infiltration rates to remain comparatively high (Young & Onstad 1986:79).

b6) Soil sealing is not always evidence of high *erodibility*. A surface crust is smooth, and the low *hydraulic roughness* does not contribute to turbulent *erosive* flow. *Splashed* and fine material may be incorporated into the crust, resisting transport in that way, till the crust is broken up, which takes time (de Ploey 1981:149; Morgan & Morgan 1981:332). A decrease of erodibility can be caused by a decrease in *surface roughness*, related to progressive crusting (de Ploey 1981:149). Soil seals may be *eroded* by *overland flow* and form again after a while during the rain.

c) Sensitivity to sealing

c1) Soils that break up into smaller stable micro-structural elements give high *splash* losses and low rates of surface sealing, while soils that disintegrate into primary particles more readily seal and give rise to lower *splash erosion* rates (Farres 1986:89). This is in agreement with the conclusions of Poesen & Govers (1986:192).

c2) Soils that are sensitive to sealing are the silty and fine sandy soils, soils sensitive to *liquefaction* , the swelling clays and the dispersive clays. The swelling clays probably do not crust because of the cracking and *aggregation* on drying (Charman pers. com. 1984).
The main soil conditions inducing sealing are a low content in organic matter, a clay fraction with reduced activity, high silt content, dominance of fine and flat particles in the sand fraction, as single factors or in combination (Pla Sentis 1981:136).
Initial high *infiltration rates* of Alfisols are often greatly reduced during the early rainy season by surface sealing (Pathak a.o. 1985:354).

c3) Increasing the maximum size of *clods* changes the amount of *rain energy* needed to initiate *runoff* very little. Only as the minimum clod size was increased was there a significant increase in rain energy needed to initiate runoff (Moldenhauer 1970:676).

d) Indices of sealing

d1) An index of sealing is suggested by Pla Sentis (1981:128,131 and 132) as the decrease in *hydraulic conductivity* of the surface soil plotted against accumulative *rainfall energy* . Graphs of this relationship plotted for different soils show distinct differences. Fine sand, silt and clay promote sealing, while coarse sand resists compact sealing.
A variation of this approach is to use, as an index of sealing sensitivity of a soil, the minimum constant value of the hydraulic conductivity and the cumulative *kinetic energy* of falling water drops required to reach this value (Pla Sentis 1986:154).
This index is similar to the index of sealing proposed by Poesen (1986:357) to be the relative decrease in percolation rate with time.

d2) Another index of sealing has been developed for Belgian loess loams. It is the difference in the moisture percentage contained in a soil at the point of 5 and the point of 10 strokes by the Casagrande apparatus when determining the liquid limit. This difference in moisture percentage is called the *consistency index* (de Ploey 1981:140-142).
For certain soils an index greater than 3 indicates stability against sealing, an index equal to or lower than 2.5 indicates sensitivity to sealing.
Stable soils in this area have higher clay and organic matter content, they show higher biological activity, larger variation in pore size diameter, and the presence of cementing agents such as carbonates (de Ploey 1981:140-142).

e) Effect of sealing

e1) Sealing soils often generate more *surface runoff* , and these soils have therefore a greater hazard for *rill erosion* (de Ploey 1981:149-150).

e2) Soil sealing explains the great difference found in *infiltration* measurement by ring infiltrometer and by *rainfall simulation* (Boon & Savat 1981:312).

e3) Sealing reduces the *rainfall acceptance* , as surface *infiltration* is reduced. The sealing may be fast in soils with unstable surfaces caused by swelling of a clayey *dust mulch* . Sealing may also be slow, as in the case of the wetting and swelling of a clay soil under grass. In the former case the time to *ponding* will be short and Horton *overland flow* may occur; in the latter case a delayed Horton overland flow will occur.

f) Recognition by remote sensing

f1) Recognition of *slaking* and crusting is sometimes possible from airborne scanners. Most often the many other influences that may give the same registration by the scanner cannot be distinguished from that caused by crusting. In one study soil surface radiant temperature was decreased by about 2 degrees Celsius, which could be detected by infrared line scanning. In dry conditions false colour aerial photography may be preferred (Lamers 1985).

g) Practices against sealing

g1) Tillage to break the seal is not effective if seals quickly form anew. In these cases the tillage may even reduce the remaining continuous pores that are available for *infiltration* of rainwater and systems of limited tillage are to be preferred in some sandy soils (Valentin 1986a:46) and in clays (Pagliai & Guidi 1986:366).

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## 2. OVERLAND FLOW as Central Concept

***Related terms:*** surface runoff
overland flow competence

**The part of the rainfall that flows off over the surface of the land in non-concentrated form or in temporary, very shallow, channels.**

a) The concept
b) Sediment transport by overland flow
c) Surface processes leading to overland flow
d) Types of overland flow
e) Mapping of overland flow

a) The concept

a1) Overland flow is a shallow widespread *surface runoff*.

a2) It includes the flow that causes *interrill* and *rill erosion* . Subsurface flow may contribute to overland flow after it surfaces to become non-concentrated *surface runoff*.

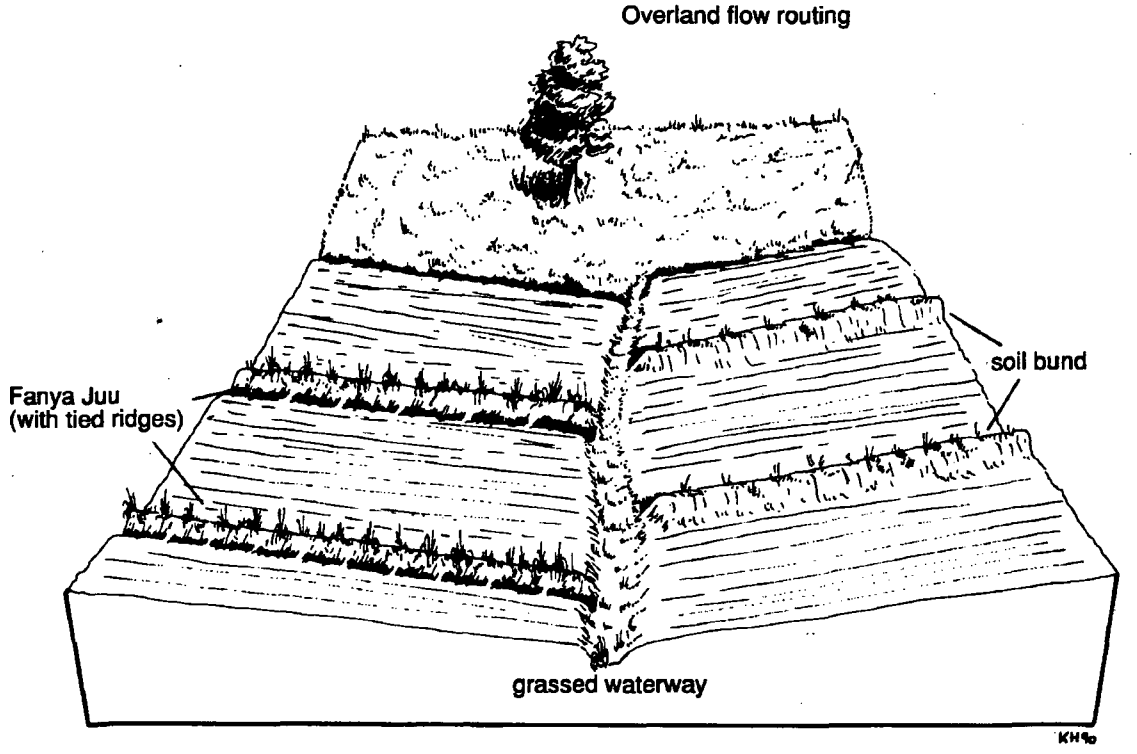
a3) Overland flow mostly contributes to the *erosion* process through TRANSPORT, while *SCOURING* takes place when the flow is turbulent and of great velocity, which often is only achieved when its volume leads to a depth largely out of range of the *surface roughness* (Meyer 1981:36).

a4) *Erosion plots* should be of a size to include the overland flow patterns, and to demonstrate the types of overland flow.

b) Sediment transport by overland flow

b1) *Transport COMPETENCE* of overland flow needs to be included in *models* based on processes. It will describe cases where *transport capacity* of the overland flow is not exceeded, but the velocity of flow is too low to carry the size of particles available for transport. This distinction of *transport capacity* and transport competence is particularly important for soils that contain large amounts of sand-size elements (primary particles or structural elements) (Morgan & Morgan 1981:332).

b2) When *splash* is impacting on overland flow, it increases the *erosive* capacity of the flow, because it increases its *turbulence* . When falling on a water layer deeper than 3 drop diameters, splash becomes ineffective in this way.



b3) Mobilisation of soil particles by flow is called *entrainment*. The velocity at which this starts to occur is the entrainment velocity. The force is called the *tractive force* (Toy 1977:13; Bryan 1977:65,66,68).

b4) SEDIMENT TRANSPORT by overland flow depends on flow volume and sediment concentration. The *discharge* by overland flow depends on (Renard 1977:32):
- hydraulic properties of flow
- physical properties of the soil
- surface characteristics of the land

The *sediment concentration* will depend on (Renard 1977:32):
- *Reynolds number*
- *Froude number*
- slope
- porosity
- surface roughness

The load carried by concentrated *runoff* depends on (Meyer 1981:34):
- sediment size, shape and density
- flow amount, velocity and *turbulence*
- *channel* cross-section, steepness and *hydraulic roughness*

b5) The ratio of inertial and gravity forces acting on flow, resulting in velocity and depth of flow is characterised by the *Froude number* (Houghton & Charman 1986:55). It is one of the determinants of *sediment concentration* of overland flow (Renard 1977:35). Overland flow has typically low *Reynolds numbers* of less than 100, and Froude numbers of less than 0.05. Values of *Manning's* roughness factor n are in the 0.2 to 0.5 range (Morgan 1981:518).

b6) The overland flow hydraulics are characterised by the *Reynolds number* (Carson & Kirkby 1972:37). This is the dimensionless ratio of the inertia force and the hydraulic force, or in other terms: the mean flow velocity x hydraulic radius x density of water divided by the dynamic molecular viscosity. When viscous forces predominate, the flow is *laminar*, and the Reynolds number has values less than about 500. When the Reynolds number is greater than 2000, the flow is turbulent. Field studies indicate that overland flow typically has low Reynolds numbers, less than 100 (Morgan 1981:518; Boon & Savat 1981:314).

b7) Flow VELOCITY is usually less than 1 metre/second (Meyer 1981:32)

c) Surface processes leading to overland flow

c1) Part of the rainfall may not be reaching the ground due to *INTERCEPTION* by the *canopy* or vegetative residue.

c2) *Surface storage* and the *infiltration* together form the *RAINFALL ACCEPTANCE* for the rain reaching the soil surface. It includes the *depression storage* or *surface ponding* as well as water entering the soil by infiltration.

The excess rainfall over infiltration is first stored in the depression storage before overland flow takes place (Houghton & Charman 1986:32). *Surface ponding* in arable land depends strongly on the land management practices. Overland flow may amount to 20-30 % on arable land that is used intensively (meeting of the French Erosion Network, September 1990).

c3) The sum of *surface detention* and *channel storage* is the *detention storage*, representing at any given moment the total water enroute to an outlet from an area or *watershed* (Soil Cons. Soc. Am. 1982:172).



*Concentration of overland flow on a barley field, Maybar, Ethiopia (photo H. Hurni).*

c4) Whether rainwater can be stored in the soil profile depends strongly on the amount of *SOIL SEALING* of the surface.

If sealing is unimportant, the rainwater may be stored during the rainfall in the soil pores, mainly the non-capillary pores or macroporosity. Its availability for storage will depend on the *antecedent moisture content* related to the drainage condition of the site. The *non capillary porosity* may change with the degree of wetness of the soil profile in the case of swelling clays.

c5) Overland flow may start at RAINFALL INTENSITIES that are five to ten times lower than the *infiltration rate* of the soil, computed from ring infiltrometer tests. The difference is probably due to *surface sealing* by *raindrop splash* (Boon & Savat 1981:312), the effect of *translatory flow* and the effect of splash concentrations in hollows and plough furrows (Zaslavski & Sinai 1981).

c6) Not only the rain intensity, but also the subsurface concentration of water from rainfall may lead to overland flow by "*return overland flow* ", or *exfiltration* flow, subsurface water emerging to the land surface from lateral *throughflow* (Dunne & Leopold 1978:265,262 ). The emergence is forced by a rising watertable or by progressive saturation of soil above a relatively impermeable *soil layer* or *horizon* . After emerging at the surface the water contributes to overland flow.
The name "return flow" is used for the returning flow in case of streamflow *diversion* (Soil Cons. Soc. Am. 1982:136).

c7) Terms related to overland flow categories (after Ward 1975:238):

runoff - surface runoff - overland flow - interrill flow
- rill flow
- channel flow (~~peak flow,~~ base flow) - gully flow
- streamflow

- subsurface runoff, subsurface flow, lateral flow, throughflow, interflow, ~~seepage flow, return overland flow~~

d) Types of overland flow (see also appendix)

d1) ~~Overland flow shows different types: the HORTON OVERLAND FLOW, which is also~~ called *infiltration* excess overland flow, where the rain intensity is larger than the rain infiltration into the soil, and the SATURATION OVERLAND FLOW, where a rising watertable prevents further rain infiltration. This can also be called *Return Overland Flow* . The two occur in very different landscape positions and have a different water supply (Ward 1975:244-254).

d2) The Horton overland flow sometimes occurs only after some time, during which a *sealing* process develops. This is termed DELAYED HORTON OVERLAND FLOW (Bergsma 1983:172).

d3) It is probably of practical value to distinguish between SATURATION OVERLAND FLOW where a groundwater rise occurs, and *TOPSOIL* SATURATION OVERLAND FLOW (Bergsma 1983:172) where a temporary semi-saturation of a shallow topsoil-layer above a relatively impermeable layer plays a role. Here rain *infiltration*, *antecedent moisture* , and *seepage* flow combine to largely saturate the soil above a relatively impermeable layer or *soil horizon* . The resulting overland flow is a consequence of the displacement of stored soil water by newly falling rain and seepage, acting by *translatory flow* .
The two overland flow types occur in very different landscape positions and have a different water supply.

d4) Topsoil Saturation Overland Flow occurs especially in hollow topographic positions and concave slopes, where flow lines converge and moisture is supplied by *translatory flow* . Lateral flow in the *topsoil* occurs by displacement of stored water by later rainfall.
The wet zone between a pseudo groundwater table on a hillslope and the shallow, relatively impermeable *soil horizon/layer* in the soil below, can be called a *saturation wedge* . It points upslope, while its upper surface intersects with the land surface at some point down the slope, leading to "topsoil saturation overland flow" from that point down.
There often exists a relationship between soil water transmissivity, steepness, slope form, soil depth and the *seepage* zones with their extent and upper boundary (O'Loughlin 1981).

d5) The *PARTIAL AREA* or VARIABLE SOURCE AREA for overland flow implies that most methods of working with *sediment* source and *sediment yield* data are inadequate and largely unrealistic. If small areas of *basins* are contributing most or nearly all of the *runoff* and sediment yield measured at the basin mouth, serious misconceptions will result about processes operating in the *watershed* if basinwide averaging techniques are used. It may lead to a simplistic, speculative exercise (Campbell 1985:135).
In case of complex lithology, runoff is controlled by the behaviour of surface materials and can expand or

contract much more swiftly than the standard variable source area model predicts (Hodges & Bryan 1982:46).

d6) Types of *HYDROGRAPHS* OF OVERLAND FLOW with different forms have been distinguished (Bork & Rohdenburg 1981:296-298):
- steep rise and flat maximum
- gentle rise to high rate
- steep rise and decline to a medium level
- irregular.

d7) The Horton model is valid for later stages of rainshowers, when the soil has become largely saturated, but for the initial stages of showers the overland flow is determined by *rain storage* in the soil profile (Johnston a.o. 1980).

d8) The soil moisture storage has been shown to be more important than the final *infiltration rate* in determining *time to runoff* and total *runoff* volume, in a study of spatial variations in hydrologic behaviour of semi-arid hillslopes.
A complex spatial relationship exists between storage, final infiltration rates, runoff generation and surface soil characteristics. Soil storage volumes are associated with spatial patterns of particle size distribution, themselves subject to change by *erosion* and *deposition* (Scoging 1982:109-112).

e) Mapping of overland flow

e1) Representation of the types and if possible the expected FREQUENCY of the occurrence of overland flow on a map is an important step in the *rain erosion hazard* survey (Bergsma 1983:170).
During soil survey and mapping, relations between pedologically mapped units and the reaction of the soil to the water dynamic (*infiltration* and *aggregate stability*) should be considered (Roose 1980:161).

e2) The SOURCE AREAS of overland flow are of interest for *erosion* and *erosion hazard* study. The source areas have a different position in the landscape for different types of overland flow, and the size of the source area can vary with the season in case of Saturation and Delayed Horton Overland Flow.
In less pronounced relief the saturation zones may not show a relationship with the surface spur-and-hollow topography. *Subsurface flow* conditions of downstream "spill over" processes occur. Hillslope and *channel gradient* should be referred to in these cases (Anderson & Kneale 1982).

e3) Flow zones of overland flow can be distinguished on airphotos depending on the photoscale and the moment of flight. The accumulated effect of surface flow causing *erosion* and/or *deposition* can be recognised on smaller scales by GREYTONE MOTTLES of certain contrast, PATTERN and POSITION in the landscape (Bergsma 1974).

e4) The pathways of the overland flow in a (sub)*catchment*, or the overland flow *routing*, is of importance to *conservation* planning.

e5) The length over which overland flow occurs down the slope is called the *EROSION SLOPE LENGTH*, or erosion slope. It is the length of uninterrupted overland flow, from the beginning of flow (by modal rainshowers) to where *deposition* starts, or flow enters into well defined *channels*, such as gullies (Wischmeier & Smith 1978). The erosion slope length will vary with the type of rain, the *antecedent moisture* conditions, flow zones of the surface and *subsurface flow*.

e6) A greater VOLUME of overland flow strongly increases the *erosion hazard*, increasing the chance for *rill erosion*. *Soil loss* from *rills* is much more severe than from *interrill erosion* (Morgan 1979:6). The *mapping* of the occurrence and the types of overland flow is an important step in the rain erosion hazard survey.

e7) Rating the *runoff* potential of soils can be done by considering internal drainage, depth over impervious bedrock or above relatively impermeable layers and *soil horizons*, *soil texture*, slope and geological characteristics (Sie Ling Chang 1971). This is similar to the approach which recognises soil differences by physiographic mapping units, using aerial photographs (Bennema & Gelens 1969; Bergsma 1986:89).

To characterise the hydrological conditions in relation to soil profiles, Hydrological Soil Groups have been established. From the previous descriptive aspects it will be clear that the criteria used in the description of these groups are not always decisive; for instance the physiographic position may have a dominant influence. The hydrologic soil groups are (Schwab a.o. 1966:105).

| ***Soil Group*** | ***Description*** |
|---|---|
| A | Lowest runoff potential.<br>Includes deep sands with very little silt and clay, also deep, permeable loess. |
| B | Moderately low runoff potential.<br>Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting. |
| C | Moderately high runoff potential.<br>Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after presaturation. |
| D | Highest runoff potential.<br>Includes most clays of high swelling character, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface. |

## APPENDIX OVERLAND FLOW

### TYPES OF FLOW IN HEADWATER AREAS OF DRAINAGE BASINS
(after Derbyshire a.o. 1979:57,58).

QUICKFLOW - SURFACE RUNOFF

| | |
|---|---|
| Overland flow | Surface flow of water occurring as rainfall intensity exceeds infiltration velocity. Also referred to as Horton overland flow or infiltration overland flow. Occurs in semi-arid areas where rainfall intensities are high and vegetation *cover* is sparse. Also in humid areas adjacent to stream *channels* or in topographic hollows where water flow converges. Flow velocities 3-15 cm/sec on slopes of 40%, less than 1 mm/sec on gentle slopes under thick vegetation. Percolation velocities range up to 100 mm/h depending on soil properties. |
| Saturation overland flow | Surface flow of water which occurs because soil is largely saturated; may occur even when infiltration velocity has not been exceeded by rainfall intensity. Occurs in locations usually close to stream channels or in hollows where water tables rise rapidly to the soil surface during rainstorm events. |

SUBSURFACE RUNOFF

| | |
|---|---|
| Throughflow or interflow | Movement of water downslope in the soil profile usually under unsaturated conditions. Also referred to as unsaturated throughflow. Occurs on slopes with well-drained soils and is often encouraged by discontinuities in the soil profile. Lateral flow will occur in soil if this meets less resistance than vertical percolation of water. Flow velocities may range from approx. 50-80 cm/day. |
| Saturated throughflow or interflow | Lateral flow in soil under saturated conditions. During storms a saturated wedge will extend upslope in the soil profile and saturated throughflow occurs immediately above this. Flow velocities in the order of 20 cm/h, and values of 0.2 - 40 cm/h. |
| Translatory flow | Lateral flow in soil occurring by displacement of stored water due to addition of "new" water. Occurs on slopes which have soils with a saturated zone. |
| Pipe flow | Flow through a subsurface network of interconnected anastomosing pipes or channel tubes, larger than other soil voids and possibly up to 1 metre in diameter. Occurs in a variety of areas including steep slopes, where an erodible layer lies above less permeable layers, or on floodplains marginal to channel banks. Flow velocities in the order of 10 to 20 cm/sec. |

DELAYED FLOW

| | |
|---|---|
| Groundwater flow | Water that has infiltrated into the ground, has reached groundwater and is *discharged* to the surface from springs or as seepage at a rate determined by the hydraulic head. Occurs in areas where groundwater storage is possible due to the character of subsurface materials. |

CHANNEL FLOW

| | |
|---|---|
| (gullies) | Flow velocities in the order of 45 cm/sec. |

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## 3. RAIN EROSION FEATURES as Central Concept

***Related terms:***

airphoto greytone
airphoto texture
airphoto structure
airphoto mottle
airphoto pattern
airphoto flow pattern
airphoto stereothreshold

arroyo
pedestal
badland
bad spots of erosion
braid or braided rill
braidwash
colluvium rill
floodbraidwash
flute
gully, including: shallow gullies
deep gullies
very deep gullies
gully classifications
gully fan
incision rill
interrill erosion
lavaka
microrilling
prerill
rainsplash
rainwash
ravine
rill erosion
rill fan
rillwash
sheet erosion
sheetflood zones
sheet wash
soil sealing
talud
tunnel erosion

**Modifications of the soil surface by rain erosion.**

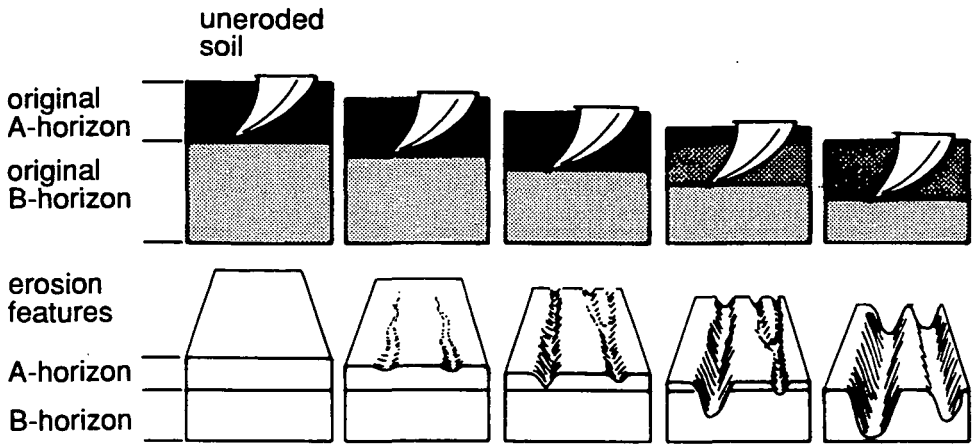
a) Rain erosion as a category of erosion.
Rain erosion is only one of the CATEGORIES OF EROSION. Erosion by different agents such as ice, wind, stream, and rain are called glacial erosion, eolian erosion, *fluvial erosion* and rain erosion respectively (Toy 1977:7), as is shown in the following figure:

EROSION CATEGORIES
(after Toy 1977:7; Carson & Kirkby 1972:190)

| Erosive agent | wind | water | | | ice | gravity |
|---|---|---|---|---|---|---|
| | | rain | sea | stream | | |
| Categories of erosion | wind or eolian erosion | RAIN or PLUVIAL EROSION | marine erosion | coastal erosion | fluvial erosion | glacial erosion | "mass movement" |
| Features of erosion or deposition | dunes, sand covers, deflation plain | decapitation rills, gullies | cliff terrace | river scarps, river banks, gullies | | falls, slides, slumps, flows. |

b) Relation between features and processes.
Rain erosion features include features of REMOVAL (detachment, entrainment), TRANSPORT and *DEPOSITION*.

**Progressive surface erosion of a soil profile under arable land use**




Note the different proportions of material of the A and B soil horizon forming the plough layer over time.



*Ravine, Brazil (photo J. Bennema).*

c) Overview rain erosion features
List of main features of rain erosion and deposition.

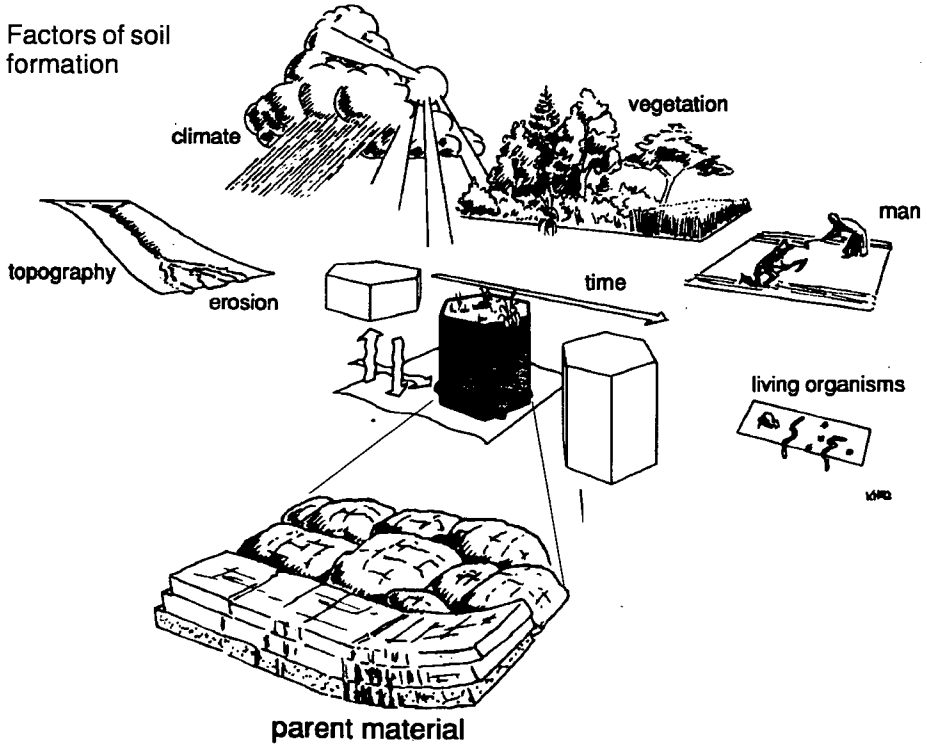
Surface erosion features:
- *rainsplash* - differentiated fine and coarse material
- concentration of fine material in vegetation when surrounded by bare land, such as in grass tussocks
- *pedestals* under gravel, twigs, or leaves
- *sealing*
- *rainwash* - microchannel pattern
- outwashed *surface gravel* and coarse sand
- *prerills*
- *rillwash - incision rills*
- *braided rills*
- *master rills*

Linear erosion features:
- *gully* (shallow gullies, deep gullies, very deep gullies, and hollow roads, gilgai gully)
- *ravine*
- *lavaka*
- *arroyo*
- *badland*

Transport features:
- *braidwash*
- *braided* rill

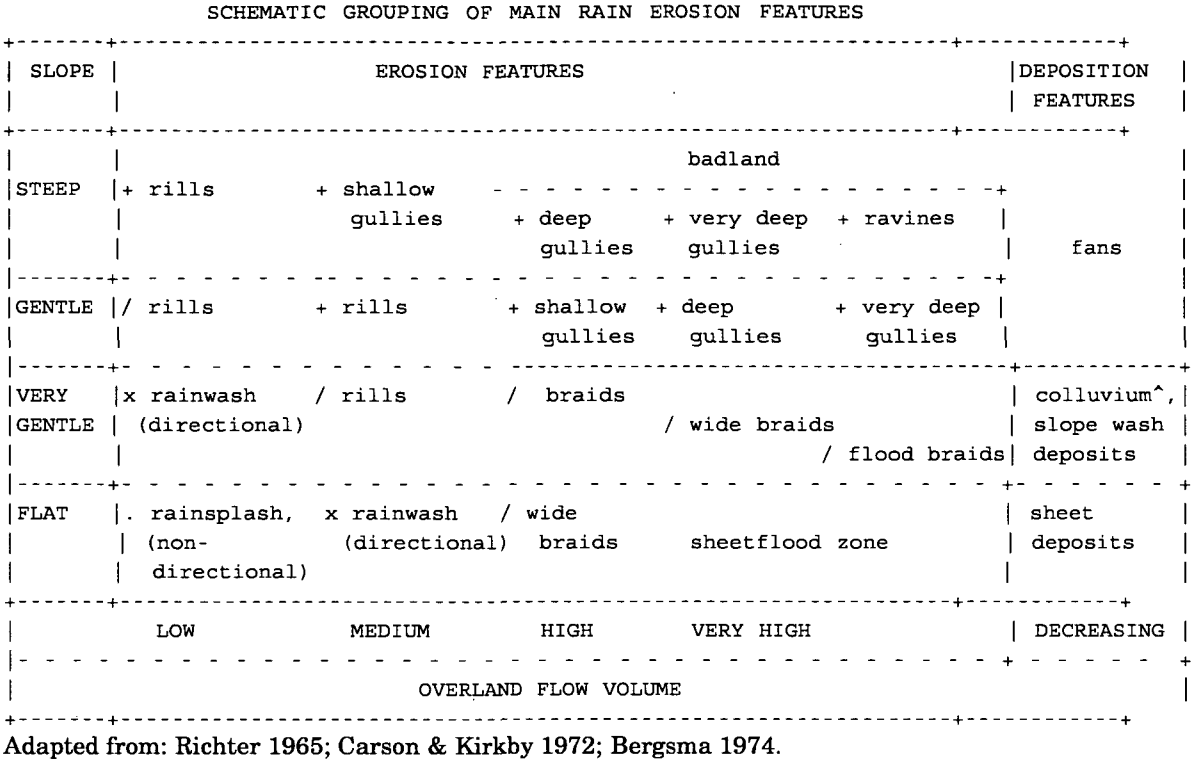
Transport and *deposition* are combined in features:
- *floodbraidwash*
- *sheetflood* zone

Deposition features:
- *colluvium*
- *gully fan*
- *rill fan*



d) The main features of rain erosion

Rain erosion features can be can be grouped in a figure in a general way, according to slope steepness and the amount of *overland flow* :




Adapted from: Richter 1965; Carson & Kirkby 1972; Bergsma 1974.

Legend:
- . = dominantly splash, flow in discontinuous microdepressions
- x = dominantly flow in discontinuous microchannels
- . and x belong to interrill erosion
- / = dominantly flow in continuous but temporary *channels*
- \+ = dominantly flow in permanent channels
- ^ = deposition by gravity and wash.

The processes depend on rainfall, material, position, slope form, *land use* and time. This may sometimes result in regular sequences of features along hillslopes. *Deposition* is mainly determined by slope shape, *basal plant cover* , surface *depression storage* , and *overland flow infiltration*. Deposition is often very local but can be very damaging, as it is receiving material from a large area.

e) The recognition of rain erosion on aerial photographs

The aerial photo-interpretation is an important part of the erosion *mapping* process, a part that is often also of importance for the mapping of rain erosion hazard. General suggestions for airphoto-study in this respect are summarized in the table about recognition of rain erosion and *conservation practices* on aerial photographs.

Regarding the recognition of *rill erosion* the following can be said. On aerial photographs of 1:10 000 - 15 000 only large *rills* could be seen, and most commonly erosion was observed by its *depositional* forms in valley floors. (Evans 1980a:77). The recognition of rills on aerial photographs can be judged from studies using as a reference the mow strip texture and potato rills (Steiner 1951:30). The mowing of grass, by a machine making turns in alternate direction, leaves a recognisable pattern of grass strips, bent in opposite direction, causing different reflection.

The conclusion is that rills can be recognised for 80% on scales larger than 1:5 000 - 1:10 000. On smaller scales recognition is less complete, and it becomes impossible in the range of scales 1:16 000 and 1:22 000. While rills thus cannot be identified generally as single features on scales smaller than 1:20 000, their combined pattern, giving a linear PHOTOTONE texture, may still be used for the recognition of rill erosion up till scales of about 1:30 000, especially when attention is paid to the POSITION and the PATTERN of the occurrence (Bergsma 1989).

RECOGNITION OF RAIN EROSION AND CONSERVATION PRACTICES ON AIRPHOTOS

General table of characteristics at scales 1:10 000 to 1:30 000 (Bergsma 1989).

| | Sheet erosion | Rill erosion | Gully erosion | Deposition |
|---|---|---|---|---|
| GREYTONE grade and texture | diffuse mottle of contrasting greytone; has non directional phototexture/fine mottling | diffuse mottle, of contrasting greytone; has linear phototexture across the contour | abrupt contrasts of tone (shadow of wall, sheet eroded surroundings, bare walls, coarse materials in streambed) | mottles of contrasting greytone, tone often that of eroding uphill areas, non-directional mostly, in gully fans a distributary pattern |
| PATTERN | mottle extends along contour; has natural boundaries, may have historical land use boundaries | mottle extends along contour; often has sides and extensions that run straight, parallel with the slope | linear, often narrow with frequent knicks and branches, it crosses the contour, occurs mainly in a dendritic or parallel pattern | upper boundary abrupt, lower mostly diffuse, but straight and abrupt when area is cut off by throughflow in drainageway or when deposit ends along colluvial field boundary |
| POSITION | - convex summits and slopes<br>- strongest convex parts<br>- shoulder of valley<br>- steep, upper concave slopes in grazing land: near trails and drinking places | as for sheet erosion, on the steeper parts and below sheet eroded land | often on steeper, lower convex, upper concave and in hollow slopes, in drainageways and footslopes, along roads and at field boundaries; in grazing land: also in and below overgrazed places | colluvium mottles extend along contour, gully fan mottles start at gully end and widen lower down in fan shape, may show fingering. |
| STEREODEPTH | -- | -- | depends on stereothreshold of the aerial photographs, width and contrast of features, position of sun, cover of trees. | ditto |
| VEGETATION | poor or absent when active | as for sheet erosion | absent in young gullies, low in incipient and mature gullies | growth often better than uphill where moisture or soil depth is limiting, annual crops may be damaged by depositional cover. |

(CONT.)

| | Contour tillage | Conservation terraces |
|---|---|---|
| GREYTONE grade and texture | linear phototexture closely parallel to contour | often lines of strong tone contrast (shadow of bank or furrow, plant cover, bare soil material in channel) |
| PATTERN | longest field dimension parallel to contour, occurs mostly in contour farming field layout, contourstripcropping and on arable conservation terraces | parallel with contour, or roughly on contour plus buffer strips |
| POSITION | on gently sloping and sloping terrain | in areas of traditional farming also on steep slopes, in mechanised farming mostly on slopes of 4 to 12%, irrigated terraces occur near and below water supply channel |
| STEREODEPTH | -- | terrace riser or bank may show stereo height, depending on airphoto stereo threshold |
| VEGETATION | arable land use | mostly arable, may be in grass, sometimes trees on terrace bank |

NB: The photo-interpretation of rain erosion features and conservation practices needs a field check before final mapping can take place.

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## 4. RILL EROSION as Central Concept

***Related terms:***

braid or braided rill
cross-grading
gully erosion
incision rill
interrill erosion
master rill
micropiracy
rillwash
sheet erosion

**The removal of soil by overland flow running in numerous shallow channels (rills) of a depth up to about 20 cm, being no obstacle to normal tillage operations.**

a) Rill characteristics
b) The concept of rill erosion
c) Rill erosion and interrill erosion
d) Rill erosion and gully erosion
e) Conditions for rill erosion
f) Mapping

a) Rill characteristics

a1) A rill is a shallow linear *rain erosion channel*, not more than 30 cm deep, cut by concentrated *runoff* or formed by collapse after piping, with flow during and immediately after rain, with steep sides when recent, rejuvenated by each (modal) rain and no obstacle to normal tillage operations (Bennett 1955; Richter 1965; Soil Cons. Soc. Am. 1982:136; Houghton & Charman 1986:102).

a2) The upper DEPTH LIMIT of a rill is approximately 30 cm so that the criterion of no obstacle to normal tillage can be kept. Rills affect only the depth of the *plough* layer (Bennett 1955). With simple management levels with animal traction, deep rills may form a management limitation because 30 cm is deeper than most ploughing and quite deep for obliteration with any but large tillage equipment. Rills are to be obliterated by normal tillage operations; this distinguishes them from gullies (Houghton & Charman 1986:102).

a3) Rills as features of a streambed (Picard & High 1973:33-37) have a different origin from rain erosion rills.

a4) Rills typically develop as a result of the action of heavy rainfall on exposed soil surfaces such as recently tilled *land* or construction sites (Houghton & Charman 1986:102; Soil Sci. Soc. Am. 1978), recent *cut and fills* (Soil Cons. Soc. Am. 1982:55) and recent *mass movement* scars.

a5) In other cases rills are reported to appear after long gentle rains or snowmelt. Apparently topsoil saturation plays a role. Subsoil tunnelling may also be a factor in preparation of the surface feature (for instance Gerits a.o. 1987).

a6) Rills not only act as a source of *sediment* themselves (minor role), but also as a way of DISPOSAL OF SEDIMENT originating from the interrill areas (major role) (Wischmeier 1977).

a7) Some rills have a tendency to incise, others have a tendency to widen.
The first type may be called an incision rill. The second type may be called a *braid* (Carson & Kirkby 1972).
The incision rill is a rill that has a tendency to incise deeper and to develop into a *gully*, if not obliterated by tillage or checked otherwise. The term serves to indicate a rill contrasting with a braid or braided rill, which feature gives deposition and transport, but little or no incision.
The incision rill occurs dominantly on hollow slopes and on upper concave slopes where *overland flow* tends to accumulate, explained by the queue effect of Zaslavski & Sinai (1981).

a8) *Braids* (Carson & Kirkby 1972) or BRAIDED RILLS are a type of rill that is many times wider (1-3 m) than deep and in which *deposition* and transport dominate over incision. These develop in conditions of excessive available load, their flow is too low for the *channel* most of the time, erosion of the rill proceeds together with deposition elsewhere, as the flow is loaded to capacity. They occur in gentle relief with a strong supply of *sediment* subject to strong *overland flow*, on moderate and gentle slopes (Richter 1965). Wide braids occur on the gentler relief.
The process of erosion by braids may be called braid*wash*, where braids shift in position over the hillslope with time (Carson & Kirkby 1972). It occurs most frequently in cases of heavy *runoff* and moderate slopes, but also in *drainageways* (Richter 1965).

a9) Very shallow rills have been called PRERILLS (Roels 1984). They have a low storage capacity for water and *sediment*; *erodible* material is plentiful and the flow is very effective in removing material (per unit of

water volume more effective than in *interrill erosion* or rill erosion).
Prerills grow from incision of flow paths created by interrill erosion. By deepening and extending in length, they change into deeper rills. In ploughed *land* the development of rills is faster than in non-arable land, where development is much more gradual. In arable land *plough* furrows may accelerate the erosion process straight to rill erosion (*ploughrill erosion* ). The loose, tilled soil is more easily removed than in case of a more coherent *topsoil* of non-arable conditions, leading to rill formation.
Microrilling is the action of very shallow rills, up to 3 cm deep, as part of the *sheet erosion* process, and often preceding rill erosion.
A distinction between very shallow rills and more developed, deeper rills is suggested here for one of the quantitative differences between sheet erosion or interrill erosion and rill erosion. This agrees with a distinction made by Richter (1965) between Flachenhafte Rillenspulung (*channels* a few cm deep) and Rillenspulung (rill depth within the *plough* layer).

a10) At the lower end of rills *deposition* may occur, as *rill fans* , which may combine into a zone of *colluvium* . A RILL FAN is a small flat cone-shaped depositional area at the foot of a rill; it is most pronounced as single features in grassland. In arable *land* which is tilled parallel to the slope, rill fans often coalesce into a zone of colluvium, where individual fans may later be obliterated by tillage.

b) The concept of rill erosion

b1) Rill erosion often can be evaluated visually when it is serious, but *interrill erosion* is usually so inconspicuous that it must be evaluated experimentally (Meyer 1985:167).

b2) If rills change position over time, their action is described by the term *rillwash* (Rillenspulung, Richter 1965). It indicates erosion by rills on sloping land, in which the rills change position periodically and in that way act on the whole of a hillside (Carson & Kirkby 1972:190). It occurs in cases of moderate *runoff* (Richter 1965).

b3) RILL PATTERNS are mostly parallel or dendritic. Parallel rills are caused by slope control on even slopes, or by tillage control on even slopes in downward or oblique directions. Dendritic patterns are mostly controlled by topography. These rills occur often as single features, and form anew in the same place each year, with a noticeable accumulated effect on the soil profile in that zone. Without tillage they may grow into gullies.
Rills may develop in topographic hollows, in tillage marks, or from random irregularities on the land surface (Meyer 1981:33).

b4) It occurs mainly on recently cultivated soils (Soil Sci. Soc. Am. 1978) and/or recent *cut and fills* (Soil Cons. Soc. Am. 1982:55) and recent mass movement scars.

c) Rill erosion and interrill erosion

c1) Rill erosion is distinct from interrill erosion. In rill erosion deeper *channels* occur, often with vertical walls. Erosion on the interfluves between the rills occurs as sheet erosion and is called interrill erosion.
For rills that have gentle side slopes, inflow will come laterally. For rills that have steep walls, inflow must come from uphill areas of the rill *catchment* . Interrill erosion is largely similar to sheet erosion or *rainwash* . It acts through *splash* and microchannels (of *prerill* formation, less than about 3 cm deep) occurring on the interfluves between rills, and as surface erosion when rills are absent.
Rill erosion causes much more *soil loss/ha* than splash or sheet erosion (Morgan 1979:6).
Rill erosion on arable *land* is always combined with interrill erosion, which provides much of the *sediment* (80% in some experiments) transported by the rills off the field (Young & Wiersma 1973).
In interrill erosion, *detachment* is proportional to *rainfall energy* , and the *transport capacity* is directly related to the amount and velocity of overland flow. In rill erosion (Wischmeier 1977) the detachment is by *shearing* action of flowing water and by *slumping* of undercut sidewalls and small headcuts (Wischmeier 1977:47).

d) Rill erosion and gully erosion

d1) Rill erosion is sometimes a transitional phase to *gully* formation. It may also be a SEMI-PERMANENT STAGE, when *overland flow* volume is limited by gentle rain or permeable soil, or when *overland flow* is distributed evenly over the rills on even slopes or on spur slopes, or when an excess of *erodible* material is available taking all the incisive power and leading to *braid* formation, or when soil properties resist incision or when unstable material (clay) does not allow deep incision through small *mass movements* .
In summary: semi-permanent rill erosion occurs in conditions of:
- limited overland flow
- excess erodible material

- resistance of material to incision

d2) The development from RILL TO *GULLY* takes place through processes of *micropiracy* and *cross grading*, whereby rills develop into *master rills*, turning gullies (Leopold a.o. 1964:411-416).
Micropiracy is the wearing away of a micro*divide* between two rills, resulting in a fusion of the rills. The combined flow develops a larger rill, collecting flow from several rills, as the process of micropiracy is repeated, and this results in the formation of master rills (Leopold a.o. 1964:411-416).
Cross-grading is the formation of some lateral slope *gradient*, across the general slope, by a rill joining with other rills and incising deeper (Leopold a.o. 1964:411-416).

e) Conditions for rill erosion

e1) Conditions governing rill erosion are determined by (Boon & Savat 1981:317):
- quantity of *overland flow*
- slope steepness
- soil texture

Rills cut more easily in loamy sediments than in clay.
These factors are of great importance in deciding on rill erosion hazard, as rill erosion is very effective in causing *soil loss* (Morgan 1979:6).

e2) Great increases in *detachment* rate occur where *slumping* of the rill sides occurs. This process is sensitive to increases in *discharge* and slope steepness (Quansah 1985:421).

e3) Size of experimental plots may often be too small to account for natural rilling (Bryan 1979).

e4) Crust formation is considered necessary for rill erosion on loamy soils (de Ploey 1981:59).

e5) Rill initiation is discussed by Savat & de Ploey (1984:125) and Bryan & Yair (1984:7,8):
- rills most commonly occur on unconsolidated loess or silts
- rills typically form on slopes between 2 and 12 degrees, regardless of climate or regolith. On steeper slopes more incised forms or gullies are typical
- rills can start very close to *divides*. Irregular microtopography may accelerate flow concentration and rill initiation
- permanent shallow or incised rills in *badlands* occur close to divides on shales and sandstones, on slopes of 45 degrees or more, even vertical

e6) Criteria for rill development on loess in Belgium are developed by de Ploey (1983b):
- No permanent rills develop on non-cohesive sandy sediments which are submitted to surficial *liquefaction*
- Incipient rill formation takes place on loamy *topsoils* when the flow is marked by a *Froude number* of the order of 1. For loess-loam Savat concludes "when the surface is smoother and the cohesion is greater, rills can only be produced on steeper slopes"
- An increase of the *washload* concentration with slope length reduces the potential for rill erosion

Rills are often reported to occur on loamy or silty soils, of slope from 2-3 degrees and steeper, independent of the unit *discharge* of *overland flow*. They may start at a very limited distance from the upper boundary of a field.
*Competence* of the flow is a function of slope and Froude number. The critical Froude number for rill development is between 2.0 and 3.0 (de Ploey 1981:149).

e7) In certain conditions of grassland with tussock grasses, the overland flow follows pathways between the grass, partly used by animals. The resulting features show a reticular pattern, and may be called reticular cowpath rills.

f) Mapping

f1) *Mapping* of rilling and rill *deposition* .
On aerial photographs of scales of 1:10 000 to 1:15 000 only large rills could be seen, and most commonly *erosion* was observed by its depositional forms in valley floors. (Evans 1980:77). The recognition of rills on aerial photographs can be judged from studies related to mow strip texture and potato rills (Steiner 1951). The conclusion is that rills can be recognised with 80% reliability, on scales larger than 1:5000 - 1:10 000. On smaller scales recognition is less complete, and it becomes impossible at scales smaller than 1:16.000 to 1:22.000 (Steiner 1951).
While rills thus cannot be identified generally as single features on scales smaller than about 1:20.000, their combined pattern, giving a linear phototexture, may still be used up to scales of about 1:30.000 for the recognition of rill erosion, especially when attention is paid to the position and the pattern of the occurrence. Especially the lower boundary of the zone of rill erosion on a regular slope, has extensions that are characteristic for rill erosion, even on the smaller scales. The extensions have often linear boundaries at

their sides.
General guidelines for recognition have been summerized in a table (Bergsma 1987:33) shown in the central concept of rain erosion features.

f2) Rill erosion is often a part of the natural development of the *erosion* in an area, and as such it will occur in certain positions in the landscape.
It may be part of an *erosion toposequence* (Bergsma 1974).

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## 5. GULLY EROSION as Central Concept

***Related terms:***

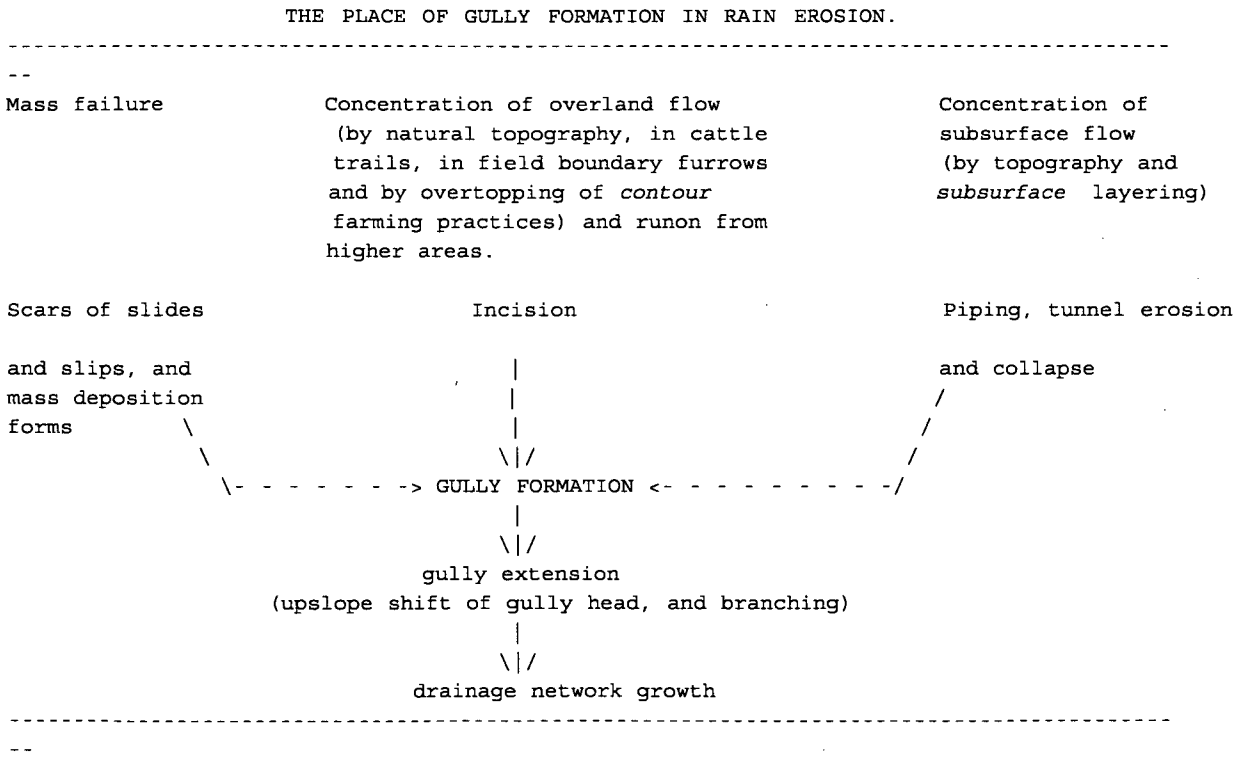
| | |
|---|---|
| ravine | gully erosion |
| arroyo | gully fan |

**The erosion process whereby water concentrates in narrow channels and over short periods removes the soil to considerable depths, ranging from about 20/30 cm to 20 m.**

a) The concept
b) Gully formation
c) Effect on management
d) Mapping
e) Gully as an erosion feature
f) Gully classification
g) Gully control

a) The concept

a1) The place of gully formation in *rain erosion* (modified from Caine & Mool 1982) is schematically shown in the following figure:



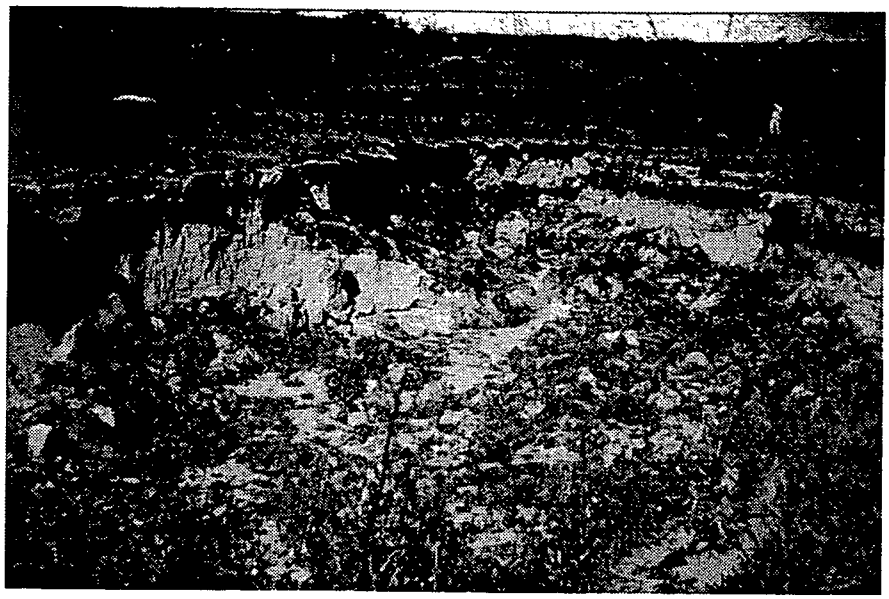

a2) The semi-arid cycle of gully erosion shows periods of incision and periods of aggradation, developing from below through the main gully and its branches (Hadley 1977:77,78).

a3) A GULLY DRAINAGE PATTERN may be dendritic (or branching) or it may be parallel or subparallel. In case of single gullies, the gully course often is linear, rather long, narrow, and of uniform width (Soil Cons. Soc. Am. 1982).

a4) The GULLY HEAD is the upstream end of a gully where *overland flow* from the *catchment* above enters or falls into the gully (Houghton & Charman 1986:64).

b) Gully formation

b1) Gully formation can result from incision by *overland flow* and from *seepage* flow and surface collapse from *piping*.



*Gully head, formally seepage flow (photo E. Bergsma).*



*Gully head, formally incision of overland flow, Merida, Spain (photo E. Bergsma).*



*Gully mouth, in old stage, India (photo E. Bergsma).*

b2) Gully erosion proceeds by a complex of processes whereby the removal of soil is characterised by large incised *channels* in the landscape (Houghton & Charman 1986:49). The gully formation processes may include:
- *scour* by concentrated *runoff*
- *dispersion* in *subsoils* around *seepage* channels, followed by *tunnel* formation, collapse of the overlying soil into the tunnel and surface gully flow (Houghton & Charman 1986:50)
- *headward erosion* of gullies (Houghton & Charman 1986:49)
- gully widening (Houghton & Charman 1986:50)

b3) HEADWARD EROSION is the gully enlargement in an upstream direction due to incision by concentrated *runoff* and the formation of a waterfall and plunge pool leading to *undercutting* and *slumping* of the gully head. This process may be accentuated by the effects of *sheet* and *splash erosion*, and subsurface *seepage* (Houghton & Charman 1986:49,64).
There are two types of uphill erosion of gully heads: by *overland flow* causing plungepool action or by *throughflow*, occurring as *seepage flow* at the foot of the gully head face causing retreat by repeated collapse of the scarp (Imeson & Kwaad 1980). These processes may operate together, in varying degrees.

b4) When gullies are formed by incision of *overland flow*, *RUNON* may play an important part.

b5) In a simple gully system the rate of erosion would increase from the headcut down to some point, beyond which it declines. In other areas most gullies have a more complex growth (Blong 1985:583).

b6) Four STAGES OF GULLY DEVELOPMENT may be recognised:
- the initial stage of *overland flow* concentration
- the incision stage
- the maturing stage, where walls are down wearing (flattening, gully widens)
- the stabilising stage, where vegetation is establishing and soil formation can take place

b7) *GULLY ERODIBILITY* is the sensitivity to *scour* from the concentrated *channel* flow in the (young) gully bed, together with the sensitivity to *splash* and *wash* of the gully walls and shoulders.

b8) The amount of infiltrated water in the gully *watershed* may be increased by good vegetative *cover*, preventing *surface erosion*, but leading to greater hazard from piping and *seepage* in gully heads (Blandford 1981:112).

b9) The load carried by concentrated *runoff* depends on (Meyer 1981:34):
- *sediment* size, shape and density
- flow amount, velocity and *turbulence*
- *channel* cross-section, steepness and *hydraulic roughness*

b10) Gullying caused by surface flow needs at least moderately STEEP slopes of 12-16 degrees, according to a literature review (de Ploey 1983).

b11) Gully erosion near Zaragossa, Spain, was significantly related to (Donker & Damen 1984):
- the distance from the steepest part of the slope to the *divide*.
- the inclination of the steepest part of the slope
- the amount of gravel at the land surface

These factors are expected to be related respectively to the volume of gully flow, its *tractive force* and available *transport capacity*.

c) Effect on management

c1) Though the area actually covered by gullies is small, the effect of gully erosion on land management is often severe, because of the interference with tillage (shallow gullies), the cutting of communications on the farm (deep gullies), the local lowering of the watertable (very deep gullies), damage to the infrastructure of an area such as roads and buildings, and *sedimentation* in ditches, ponds, reservoirs, streams and *waterways*. (McCormack 1981:367).



*Young gully, in a gravelly deposit, Spain (photo E. Bergsma).*

d) Mapping

d1) Mapping of gully erosion is made easier than ground survey by the

use of aerial photographs. Recognition of gully erosion is not difficult on large and medium scales of airphotos. For studying the rate of gully develop-ment large scale airphotos are needed, of scales 1:10 000 or larger (for instance Nakano a.o. 1983:180). For the use of airphotos in mapping gully erosion the following table may be of use (Bergsma 1987):

RECOGNITION OF GULLY EROSION ON AERIAL PHOTOGRAPH
scales 1:10 000 to 1:40 000

| | |
|---|---|
| GREYTONE | (grade, texture) abrupt contrasts of tone (shadow of wall, sheet eroded surroundings,bare walls, coarse materials in channel floor. |
| PATTERN | linear, often narrow with frequent knicks and branches, crossing the *contour* ; occurs mainly in dendritic or parallel patterns. |
| POSITION | often on steeper, lower convex and upper concave and hollow slopes, in *drainage-ways* and footslopes, along roads and at field boundaries. In grazing land: also in and below overgrazed places. |
| STEREODEPTH | depends on stereothreshold of the aerial photographs, width and contrast of feature, position of sun, cover of trees. |
| VEGETATION | absent in young gullies, low in incipient and mature gullies. |

e) Gully as an erosion feature

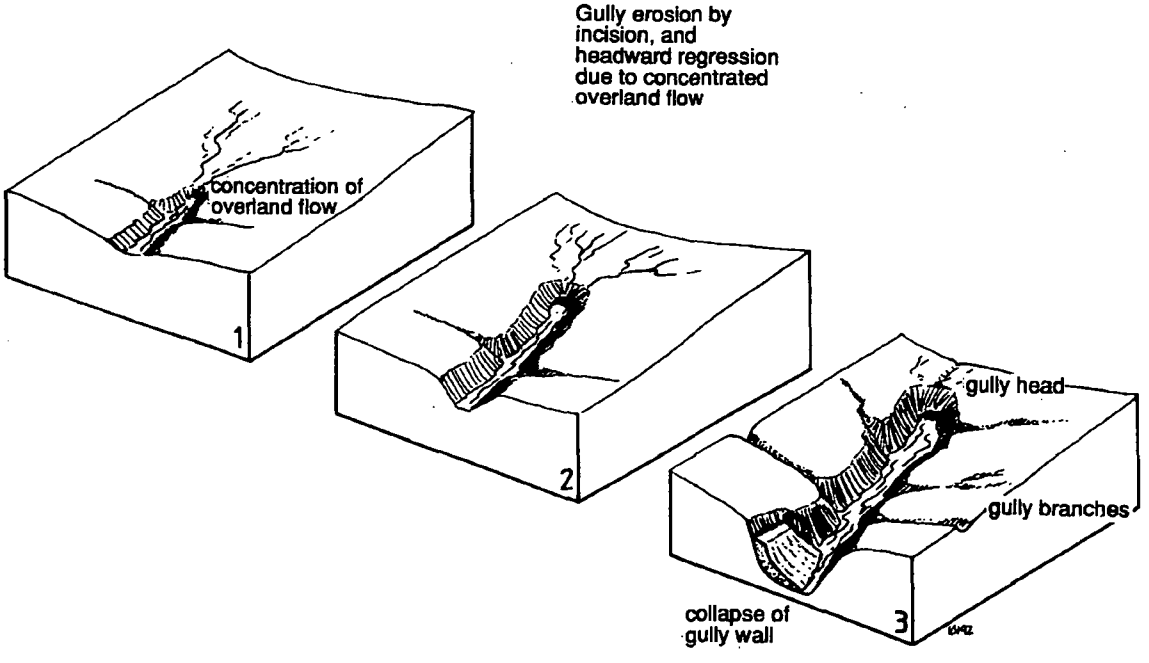
e1) A gully is an incised *channel* or miniature valley cut by concentrated but intermittent flow, usually during and immediately following heavy rain, or during the melting of snow (Soil Sci. Soc. Am. 1978; Soil Cons. Soc. Am. 1982), deep enough to interfere with, and not to be obliterated by normal tillage operations (Soil Sci. Soc. Am. 1978).

e2) Gullies are characterised by moderately to very gently inclined floors and precipitous walls. They form through a complex series of processes dominated by concentrated surface water flow and hence are frequently found in drainage lines. Major flows only occur in gullies during or immediately after periods of heavy rainfall (Charman pers. com. 1986).

e3) There may be continuous flow at the gully bottom as a result of *interflow* . This flow is usually of too low a velocity to cause erosion, but the saturated bottom is much more subject to erosion when high *runoff* rates occur (Moldenhauer pers. com).

e4) The GULLY HEAD is the upstream end of a gully where *runoff* from the *catchment* above enters and often falls into the gully (Houghton & Charman 1986:64).
In case a plungepool is present, *headward erosion* takes place by repeated soil fall from the gully head scarp, otherwise the gully extends headwards by progressive incision.

e6) Gullies vary widely in shape, depending on soil type, landform, and the hydrological regime of the *catchment* . They may be wide in relation to depth or vice-versa, and may be of U or V cross-section



(Houghton & Charman 1986:63).

e7) The distinction between GULLY AND *RILL* is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lesser depth and would be smoothed by ordinary farm tillage (Soil Cons. Soc. Am. 1982).

e8) An ARROYO is a gully, usually with ephemeral flow, and with half a metre to a few metres of unconsolidated *alluvium* forming vertical walls (Soil Cons. Soc. Am. 1982). It often has a size of several metres to tens of metres wide, and some metres deep, like a giant *braid*.

e9) A very deep gully of, for instance, 20 metres depth or more may be called a RAVINE.

e10) A GULLY FAN is the cone-shaped area consisting of deposits from the gully *channel* below its mouth (Charman pers. com. 1986). It occurs where the gully channel becomes less confined, or where the bed *gradient* flattens strongly, or where the gully flow is absorbed by the substratum.

f) Gully classifications

f1) Gullies can be usefully grouped based on one or more of their characteristics.

f2) Gully classification may be according to:

- gully length per unit surface area
- gully depth
- gully cross-section
- gully pattern
- *gradient of channel*
- age or development stage
- drainage area
- hazard of extension
- need for *conservation*
- possibilities for control

f2.1) Gully length per unit surface area.

As gullies are rather obvious features in the field and on airphotos of large to medium scales, gully length has often been used for *mapping*.

The parameter of gully length is especially useful when it has been established that the general *erosion* intensity is well correlated with the occurrence of gullies (for instance Jones and Keech 1966).

The gully density depends on rainfall characteristics, *rainfall acceptance* by the land surface and soil, *soil erodibility*, slope steepness, flow concentrations due to the relief, and *plant cover*.

In view of the damage gullies represent, length classes have often to be combined with depth classes.

One has to be aware that for mapping at different scales, different classes of gully density must be used. Drainage density on small scales will not be shown in such detail as on large scales, and mapping units on small scales include much ungullied *land* together with local areas of high gully density which would be separated on larger scales. Consequently, limits of gully length/area are lower and class intervals of gully length per area on small scale maps are smaller than in larger scale mapping.

f2.2) Gully depth

With increasing depth, gullies represent greater interference with the land management, as well as a somewhat greater loss of land surface.

Depth classes (Schwab a.o. 1966:166-167) may be chosen as follows:

- Shallow gullies, 20 - 30 cm to about 1 metre.
  The gullies interfere with normal tillage operations. On airphoto scales smaller than 1:20 000 (with focal length of 150 mm), they will usually not show stereodepth, as there is a *stereothreshold* greater than 1 metre.
- Deep gullies, about 1 metre to about 5 metres.
  The gullies interfere with normal tillage and, in addition, they start to cut travel paths on the farm for machines, animals and man.
- Very deep gullies, about 5 metres to about 20 metres.
  The gullies in addition may cause excessive drainage for an extensive area around them.
- Ravines, deeper than about 20 metres, associated with steep slopes, may be cut in soft material, more typically in rock.

Other gully depth classifications are:

| shallow | deep | very deep | |
|---|---|---|---|
| < 1 m | 1 - 5 m | > 5 m | (Schwab a.o. 1966:167) |
| < 3 m | 3 - 9 m | > 9 m | (Narayana & Sastry 1985:7) |
| < 1.5 m | 1.5 - 3 m | > 3 m | (Houghton & Charman 1986:49) |

The following classes and definitions may be used:

- shallow gully.
  The gully has a depth less than about one metre. These gullies have the following characteristics:
  a) Occur in cases of heavy *runoff* in concentrated flow and often on steep slopes and in *drainageways* (Richter 1965).
  b) The use of machinery has become difficult and disrupted but travel paths across the fields on the farm are still possible, with some adjustments to crossover points.
  c) Gullies start to show stereodepth on airphoto's with common scales and focal lengths such as 1:20 000 and c = 150 mm, because the gully depth is less than the *stereothreshold* .
- deep gully.
  The gully has a depth greater than about one metre and shallower than about 5 metres. The gullies have the following characteristics:
  a) Occur in cases of heavy runoff in concentrated flow and often on steep slopes and in *drainageways* . The incision may extend into the C-material (Richter 1965).
  b) Not only the use of machinery is hindered, but also travel paths and access across fields on the farm are disrupted.
- very deep gully
  The gully has great depth of more than about 5 metres up to about 10 metres.
  The gullies have the following characteristics:
  a) It includes gullies of greatly damaging dimensions but smaller than *ravines* .
  b) Not only the use of machinery is hindered and communication on the farm is disrupted, but also the groundwater table may be lowered significantly.
- ravines (deeper than about 20 metres)

f2.3) Gully cross-section.
The cross-section is related to the stage of development of the gully, characterised by a different balance between *denudation* and incision, and the stability of the gully wall material. Classes may be:
- U-shape cross-section
- V-shape cross-section
- multi-*gradient* walls, indicating different materials.

f2.4) Gully pattern
Patterns are mostly dendritic or parallel, determined by slope control, tillage control, or rock substratum control.

f2.5) *Gradient of channel.*
The steeper the gradient, the greater the *erosive* capacity of the gully flow, but flow volume is often greater in more gentle gullies.

f2.6) Age or development stage.
The feasibility of gully control is influenced by the stage of gully development, schematically as follows:

| CHARACTERISTIC PROCESS | NAME | CONTROL FEASIBILITY |
|---|---|---|
| scour in surface | incipient gully or rill (incision rill) | high |
| headward erosion, incision | young gully | low |
| widening and flattening | mature gully | moderate |
| stabilisation, new soil formation | old gully | very high |

f2.7) Drainage area.
The greater the drainage area of the gully, the faster it can grow, when runoff occurs.

f2.8) Hazard of extension.

An estimation can be made of the hazard, that is the chance that the gully will show extensive development in the near future and cause damage.

While the classification criteria 1-7 are mostly based on one criterium, gully hazard is based on several criteria, such as (Imeson & Kwaad 1980, Stocking 1980):

- stage of development
- drainage area
- *gradient*
- height of gully head face

f2.9) Need for *conservation*.

The need for conservation depends on the *erosion-hazard* and the suitability of the *land* that is affected, considered for a range of different uses.

f2.10) Possibilities for control.

Control depends on the gully as well as on technical considerations and the means available for *conservation* work, determined by the *land utilisation type*, *farming system*, and outside help.

g) Gully control

g1) It is the execution of measures that prevent the lateral or headward extension of a gully and its branches, and stabilise its course (Houghton & Charman 1986, Das & Shamser Singh 1981:433).

g2) Gully control measures will have three areas of application: the gully *catchment*, the gully walls and the gully bed (Das & Shamser Singh 1981:433, Jiang Deqi a.o. 1981:471).

g3) Gully control measures in gully beds are (Jiang Deqi a.o. 1981:471):

- *drop-structures*, to prevent gully head inflow from causing erosion
- low *channel sills*, to slow down flows
- *gully checkdams* to raise the local base level to prevent further *scouring*, and to trap soil to form new lands for *cultivation*

g4) An important control measure is that of the *GULLY CHECKDAM*. This is a small *dam* constructed in a gully or other small watercourse to decrease the streamflow velocity, minimise channel *scour*, and promote *deposition* of *sediment* (Soil Cons. Soc. Am. 1982:24).

It is often advisable to build a series of checkdams for increased effect and safety in dealing with peakflows (Soil Cons. Soc. Am. 1982:24).

g5) The priority for control will depend on the hazard that the gully will grow, and the suitability and importance of the surrounding *land* and infrastructure. Parameters to predict gully growth can be the gully *catchment* size, height of gully head face, extent of arable *land use* in the catchment (Stocking 1980) and the length of forest roads in the catchment.

Relative priority for control is determined in certain cases by considering gully (stream) order, number of tributaries, stage of development, expected treatment returns for the total gully network, and the potential for vegetation growth which may replace costly mechanical measures, especially in semi-arid and arid regions (Heede 1982).

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## 6. RAIN EROSIVITY as Central Concept

***Equivalent terms:***
rainfall erosivity
erosivity, when context is clear

***Related terms:***

| | |
|---|---|
| rainfall energy | rainfall simulation, rainfall simulator |
| rain interception | rainsplash |

**Potential ability of rain to cause erosion.**

a) The concept
b) The erosivity index R of the Universal Soil Loss Equation (USLE)
c) Approximations of R
d) Indices other than R
e) Erosive showers and overland flow
f) Modifications of R to include runoff effect

a) The concept

a1) The *erosive* potential of a rainstorm and its associated *runoff* is a function of the *rainfall energy*, the maximum prolonged intensity and their interaction (Wischmeier 1977:47).

a2) Rain erosivity varies with the type of shower, characterised by the rain volume per rain intensity class, duration of high intensity rainfall, the variability of the rain intensity and drying spells between showers.

a3) Rain erosivity varies with the square of the terminal velocity of the drops (Wischmeier 1977:47). The terminal drop velocity increases with drop size to a maximum, until it levels off at rain intensities of about 75 mm/h. A common median drop size is 3 mm (Hudson 1981:54).

a4) For flat lands, sloping 1% or less, a correction to the effect of rain is made because surface water ponded during rainfall is deeper (Mutchler & Murphree 1981:322).

a5) Rain erosivity can be expressed by an index. Several indices have been developed. The term rain erosivity index was used in the USLE to describe the influence of the rainfall in *rain erosion* , and so the term was for some time restricted to define the unit of measurement for rain erosivity in that equation. As other indices of rain erosivity developed, the term has now a general meaning.

a6) The RAIN EROSIVITY DISTRIBUTION is the average long term variation of rain erosivity over a certain period. It is usually shown in a cumulative curve for a year period, where the erosivity is usually expressed in the annual index R or annual sum for the Erosivity Index EI of all storms in that year (Wischmeier & Smith 1978; Edwards 1985:477).

a7) *DRIP* may have the same *erosive* power as *throughfalling* rain, it may even have a slightly higher erosivity because of larger drop sizes. Data (Wiersum 1978) show a 20% higher erosivity for drip than for rain.

a8) *Drip* having a fall height of 3 metres or more has 70% or more of the *kinetic energy* of free falling rain (Wischmeier & Smith 1978).

b) The erosivity index R of the Universal Soil Loss Equation (USLE)

b1) R is the annual sum of each shower's product of *rainfall energy* and its maximum 30 minute sustained intensity (Wischmeier 1977:47).

b2) It is calculated from the following data:
* R = sum of EI of rainstorms in a year period, averaged over about 20 years
* EI (or EI30) = storm energy (Eg) x the maximum 30 minute intensity in that storm (I30)
* Eg = storm energy = the sum of the products Eu x rainvolume, in which:
* Eu = the energy per mm rain falling in a certain intensity interval, and
* rainvolume = the volume of rain falling in that storm with an intensity within that intensity interval.

The rain intensity intervals cover all the rain of the storm, the intervals may have a width of 10 or 20 mm/h (half an inch or one inch per hour). Rain falling with an intensity of less than half an inch per hour is discarded, it is assumed to be adsorbed on (dry) surface soil particles.

For Germany, in the area of the Moselle, the limit of discarded rain is changed to 6 mm (Richter & Negendank 1977), for Belgium this volume is set at about 1 mm (Laurant & Bollinne 1976), while in the Netherlands the volume is set at 2.5 mm/h (van Asch & Epema 1983).

b3) For the calculation of R one needs detailed meteorological data of a period of at least 20 years (Wischmeier & Smith 1978). However, one has to be aware of the possibility of periodical fluctuations in rainfall. For instance, rain data over 60 years for the meteo station of Badajoz, Spain, show an 11 year period of annual rainfall about 200 mm above the long period average, and a 24 year period of annual rainfall about 100 mm below the long period average (Inst.Geol.Madrid, undated).

b4) For use on VERY GENTLE SLOPES a correction factor to R is proposed, being 1 for slopes of 1% to 0.9 for slopes of 0.1% when R is about 520 (metric). The factor is 0.7 when R is about 1040 (Mutchler and Murphree Jr. 1985). More accumulation of surface runoff reduces the impact of splash on the land.

b5) A rain erosivity value modified for temperature, Rt, is used for central Italy. Apart from the data needed for R, it includes also the rainfall amount falling in the previous 5 days and the amount of *runoff* (Zanchi and Torri 1980).

b6) Experiments in western Nigeria indicated a rather low correlation coefficient between EI30 and *soil loss* (Lal 1977).

b7) In a discussion of R in India, Singh a.o. (1985) mention that EI30 values gave a correlation (r=0.74) with *soil loss* at Dehradun.
At Coimbatore, the correlation between EI30 and soil loss was high with correlation coefficients r = 0.89 - 0.96 for varying slopes, but at Ootacamund the correlation was low.
It is concluded that until soil loss data from field plots from various countries are sufficient to disprove the reliability of EI30, it continues to be the most reliable estimate of rainfall erosion potential. An iso-erodent map of India is produced (Singh a.o. 1985).

b8) Because the calculation of R puts a high demand on detailed meteo data, several approximations of R have been developed.

c) Approximations of R (Bergsma 1981; El-Swaify a.o. 1982:89)

c1) For certain regions of the USA, R shows a close correlation with a 3 term product:
R = k1 abc + k2, where
a = average annual precipitation,
b = 24 hours maximum precipitation recurring once in two years,
c = one hour maximum precipitation recurring once in two years,
k1 and k2 are constants.
In the USA (Smith & Wischmeier 1962) this approximation has been used in 1700 stations to extrapolate the R values calculated at about 50 stations, to arrive at a national rain erosivity map. The explained variance in R was greater than 90% .
However, the constants are only valid for certain regions, as follows (in metric units: R is expressed in m-ton/ha x cm/h and a,b and c are in cm/h):

| | |
|---|---|
| Subhumid and semiarid western Plains: | R = 0.111 abc + 66 |
| Northeastern states | R = 0.081 abc + 35 |
| Lower Mississippi valley and Gulf coast states | R = 0.095 abc + 47 |

c2) For a wide zone in West Africa, R(metric) = (0.50 +/- 0.05) x Pt where Pt is the average annual rainfall in mm (Roose 1973). The correlation between R and Pt was so good that it is preferred for stations where only data for periods shorter than 5-10 years are available. Roose used this relationship to draw a rainfall erosivity map of West Africa (Roose 1975) including Ivory Coast, Upper Volta, Senegal, Niger, Chad, Cameroon and Madagascar, with the exception of stations near mountain ranges and a belt of 40 km width along the coast.

c3) On Hawaii the best approximation of R (average annual EI30) was by the total annual rainfall (Lo a.o. 1985:391).

c4) The MODIFIED FOURNIER INDEX has been developed by FAO (Arnoldus 1980). It reads:

$$\sum_{i=1}^{i=12} pi^2 / P$$

where i is number of month, p is monthly precipitation in cm, P is average annual precipitation in cm.
This index correlates with R values by an equation of the type:
R = a x index + b, where constants a and b depend on climatic conditions.
Monthly EI values are highly correlated with the monthly $p^2$ /P values for rains in Belgium, Brazil and the Mediterranean area, but regional coefficients vary greatly between regions (Gabriels &Pauwels 1980).

| Area | Number of stations | Values of constants a | b | Linear correlation coefficients |
|---|---|---|---|---|

| | | | |
|---|---|---|---|
| USA, general | 164 | 4.17 - 152 | 0.89 |
| Eastern USA | 102 | 6.86 - 420 | 0.89 |
| Western USA | 47 | 0.66 - 3 | 0.83 |
| West Africa | 14 | 5.44 - 416 | 0.83 |

When, for a certain zone, measured R values are available in two stations, the constants can be calculated and extrapolation can be done on the basis of the Modified Fournier Index for stations having limited meteo data, but occurring in the same climatic region.
The index has been used by FAO to compile an erosivity map of the Mediterranean area.

c5) In southern Germany the total summer rainfall correlated well with R (Rogler & Schwertmann 1981).

c6) As an approximation of R for Java, Indonesia, Bols developed an index (Wiersum 1978) on the basis of daily rain. From daily rain volumes one can easily derive the monthly rainfall and the number of raindays per month. Data were used from 15 stations and 2850 showers, later again 47 stations and 38 years of rainfall record. The equations are:
EI30 daily = 2.467 P square/(0.0727 R + 0.725) and
EI30 monthly = 6.119 P (to the power 1.11) N (to the power -0.474) Pmax (to the power 0.526)
In the formulas P is daily or monthly rainfall in cm, N is the amount of raindays and Pmax is the maximum 24 hours rainfall per month. The correlation with EI has an r-squared of 0.995.

d) Indices other than R

d1) The *kinetic energy* of all rain falling with an intensity above 1 inch per hour, KE>1, was developed for southern Africa. It appears to be more appropriate than EI30 for tropical and subtropical rainfall (Hudson 1981).

d2) The storm rainfall times the maximum rain intensity sustained during 7.5 minutes, AIm, was developed for Nigeria (Lal 1977). Good results were also obtained with this index in Trinidad (Gumbs a.o. 1985).

d3) Monthly erosivity prediction for Zambia can be based on the average monthly rainfall amount, average monthly number of days with at least 0.1 cm of rain, and the average maximum daily rainfall of each month (Lenvain a.o. 1988).

d4) The amount of *erosive* rain, near Delhi, India, being rain with intensities above 0.1 mm/minute (6 mm/h) is well correlated with *soil loss* in a curvilinear relationship. Intensity of erosive rain had a linear relationship with soil loss. (Tamhane a.o. 1959).

d5) An index for rain erosivity was proposed by Onchev (1985:425). It assumes that *erosive* rain is that which has more volume than 9.5 mm and an intensity higher than 0.180 mm/min. The index works better than any other for the conditions investigated in Bulgaria.

e) Erosive showers and overland flow (Bergsma 1981)

e1) *Erosive* showers have an effect that is modified by the production of *overland flow*. Kowal & Kassam (1977) describe observations at Samaru, Nigeria. Like Hudson (1981) who developed his index on the basis of a RAIN INTENSITY THRESHOLD for *erosion* , they found a RAIN VOLUME THRESHOLD for erosion. Above 20 mm of rain in an intensive shower, *overland flow* occurs. It appeared that rain volumes were correlated with peak intensities of the showers, i.e. the maximum intensity sustained during 5 minutes.
For example, a shower of 20 mm has a peak intensity of 88 mm per hour. This agrees very much with the index developed by Lal, which includes the sustained peak intensity during 7.5 minutes of the rainstorm (Lal 1977).

e2) Joshua (1977) pointed out that in Sri Lanka *erosion* on reddish brown earths is serious at rain intensities between 0.5 and 1.0 inch per hour (and higher) because the soils have a basic *infiltration rate* of 0.5 inch per hour. Similarly, erosion on red-yellow podsolics occurs only at rain intensities above 1 inch per hour, their basic infiltration rate being 1 to 2 inches per hour. In contrast, erosion on highly permeable red yellow latosols occurs only when vegetation is removed and *surface sealing* takes place. Then erosion is high, in agreement with a high *erodibility factor K* . Otherwise the basic infiltration rate of 15 inches per hour prevents all *overland flow* and largely prevents erosion.

e3) Thus for certain soils the concept of rain erosivity can be refined by taking a threshold rain intensity or a threshold rain volume into account.
This would not apply when *land use* frequently exposes the soil to *splash* inducing the *sealing* of the soil surface. The EI-T index adjustment used in Ife, Nigeria for example, takes initial *rainfall acceptance* through adsorption and *ponding* into account and subtracts a corresponding amount of kinetic energy, called T (Wilkinson 1975).
On the other hand, from the point of view of a systematic approach, it may be better to account for basic infiltration-rate and sealing by modifying the *soil erodibility factor* . This has been done to some extent in the K factor nomogram by specifying six *permeability* classes.

e4) Emphasizing the water deficit in the soil at the beginning of the rainshower leads to characterising *erosive* rains by the rain volume falling in the first 20 minutes. The water deficit can be quantified, for example, by the time (in hours) since the last rain. This approach, used by Vuillaume (1969) working in the Sahel, is similar to the conclusion of Johnston a.o. (1980), working in Ireland, that Horton *overland flow* characterises the later stages of rainstorms but *rain storage capacity* sometimes determines the *overland flow* occurrence in the early stages. This also agrees with the relationship of overland flow occurrence to differences in drainage conditions of soil profiles, depth of relatively impermeable *subsoil* , slope steepness, and *permeability* of the upper profile. This relationship was used by Farquharson a.o. (1978) in *mapping* winter *rain acceptance* potential in England.

e5) When *rain energy* correlates with rain amount, then rain amount is a good index. This is the case for heavy tropical rainshowers where total annual rainfall or storm rainfall are used. When, however, rain energy and rain amount show a strong independent variation, indices stressing both energy and amount are better as appears to be the case in the USA (Bergsma 1981).

e6) For areas with gentle rainfall, *detachment* may limit *erosion* , and indices stressing *rain energy* will be more promising.
Rain intensity is not only of importance for detachment, but also for building up of *overland flow* . The amount of *overland flow* , and especially its intensity (cubic cm passing per cm per sec) affects the occurrence of *rills* as distinct from *interrill erosion*, which is of great influence on the amount of *soil loss* . This may be one important cause of dissatisfaction among researchers in using indices to predict soil loss (Bergsma 1981).

f) Modifications of R to include runoff effect

f1) In the MUSLE, the Modified Universal Soil Loss Equation, a modified R value is used to include the effect of *overland flow* on surface *erosion* (Laflen a.o. 1985:286). The erosivity factor R becomes:

$R_w = 27.06\ A^{0.12}\ Q^{0.56}\ q_p^{0.56}$, where A = *watershed* area in ha
Q = volume of runoff in mm
$q_p$ = peak flow rate in mm/hr

The equation was derived using watershed *sediment yield* ; hence the erosivity factor expresses the effect of the *sediment delivery ratio* .
The MUSLE does not include a rainfall variable, even though it is well recognised that *rainfall energy* is important in *soil erosion* .
It does not predict *soil loss* without *runoff* . If runoff is high relative to rainfall erosivity, as might be the case for high *antecedent moisture* conditions and/or for relatively impermeable soils with little waterholding capacity, the MUSLE soil loss prediction would exceed that of the Onstad Foster modification of R, and that of the USLE.
In the MUSLE the *sediment* production is related to the size of the watershed. The positive linear relation which is found would be unusual, but the lower Q and q values result in the MUSLE equation having lower sediment rates with larger *catchments* .

f2) Another modification of R was made by Onstad & Foster (1975):

$R = 0.5\ R + 3.42\ Q\ q_p^{0.33}$ , where R = the usual USLE rainfall erosivity factor in SI units
Q = volume of runoff in mm
$q_p$ = peak flow rate in mm/hr

If there is no *runoff* the equation predicts a *soil loss* equal to half that of the USLE.
If runoff is high relative to rainfall erosivity, as might be the case for high *antecedent moisture* conditions and/or for relatively impermeable soils with little waterholding capacity, the predicted *sediment* by the Onstad Foster model would exceed that of the USLE.

f3) Williams (1975) developed a model with an energy term that is only associated with *runoff*. The energy term of the USLE is only associated with rainfall. The Williams model predicts small events very accurately, while the USLE predicts small storms very poorly. For the large storms, the opposite is true. This suggests that runoff characteristics are the major influence on *sediment yields* for small storms, and rainfall characteristics are the major factor for the large storms. In general, a model that contains an energy term and a runoff term is superior to one containing only a rainfall or a runoff factor (Onstad a.o. 1975).

## TABLE OF R VALUES

R values are listed for various countries, giving the area of investigation, the reference and the method of determination (after Bergsma 1981, El-Swaify a.o. 1982).

| Country | Area/site | R-value (metric) | Method of determination | Reference |
|---|---|---|---|---|
| Argentina | Corrientes | 574 | F | Klingebiel 1972 |
| Belgium | general | 50-200 | A | Bolline undated |
| | Brussels | 60-70 | A | ,, |
| | Uccle | (40)/65 | A/Acor | Laurant & Bolline 1976 |
| Brazil | Belem | 1494 | F | Klingebiel 1972 |
| | Campinas, Sao Paulo | 690 | A? | Lombardi Neto 1977 |
| Cameroon | Dschong | 625 | E | Roose 1975 |
| | Douala | 2000 | A? | Roose 1977 |
| Chad | Deli | 550 | E | Roose 1975 |
| France | middle part | 60-340 | - | Masson 1971 |
| | north: Artois | 50 | A | Pihan 1978 |
| Germany | Munchen | 82 | A# | Rogler & Schwertmann,1981. |
| | Nurnberg | 46 | A# | ,, |
| | Augsburg | 79 | A# | ,, |
| | Weiszenburg | 49 | A# | ,, |
| Guinea | Conakry | 2000 | A? | Roose 1977 |
| India | erosivity map (CSWCRTI 1977) | | A? | El-Swaify a.o. 1982 |
| | general | 120-3000 | A | Singh a.o. 1985 |
| | Bombay | 1130 | F | Klingebiel 1972 |
| | Mangalore, W.India | 1457 | A? | CSWCRTI 1977 |
| Indonesia | | | | |
| Java + Madoera, erosivity map | | | A(Bols) | El-Swaify a.o. 1982 |
| West Java | Citarum basin | 150-400 | A | Wiersum & Ambar 1980 |
| Central Java | Banjarnegara | 382 | A(Bols) | van der Linden 1980 |
| Central Java | Karangkobar | 392 | A(Bols) | ,, |
| Iraq | general | 0-700 | H | Hussein 1986 |
| Ivory Coast | general | 500-1400 | E | Roose 1973 |
| | Abidjan | 1260 | E | Roose 1975 |
| | Bouake | 520 | E | Roose & Bertrand 1972 |
| | Divo | 840 | E | Roose 1975 |
| Jordan | Janin | 154 | F | Klingebiel 1972 |
| | Amman* | 125 | B | Projectgroep 1973 |
| Luxemburg | northern part | 20-30 | B | Hof 1975 |
| Madagascar | Befandriana | 1375 | D | CTFT 1971 |
| | Taheza | 500 | D | Goujon 1968 |
| | Manankazo | 883 | D | ,, |
| | Ampamaherana | 613 | D | ,, |
| | Nanokely | 633 | D | ,, |
| Mexico | Ciudad Lerdo | 42 | F | Klingebiel 1972 |
| Morocco | general | 50-300 | - | Kalman 1967 |
| | Fes | 84 | - | ,, |
| | Melenes | 100 | - | ,, |
| Netherlands | de Bilt* | 72 | B | Bergsma 1980 |
| | de Bilt | 66 | Ac | van Asch & Epema 1983 |
| Niger | Allokoto | 250 | E | Roose 1975 |
| | Ngumi | 113 | F | Klingebiel 1972 |
| Nigeria | Kano | 437 | F | ,, |
| Senegal | Bambey | 325 | E | Roose 1975 |
| | Sifa | 655 | E | ,, |

| Country | Area/site | R-value (metric) | Method of determination | Reference |
|---|---|---|---|---|
| Spain | Merida | 90 | B | ITC 1975 |
| | Malaga | 138 | F | Klingebiel 1972 |
| | Antequera (Malaga) | 60 | B* | ITC 1985 |
| Taiwan | general | 430-3000 | A | Huang 1979 |
| Thailand | Loei | 9634 | A | Marston a.o. 1985:637 |
| Trinidad | northern mountains | 263 | A | Gumbs a.o. 1985 |
| Tunesia | general | 60-300 | - | Masson 1971 |
| | central* | 235 | A | Projectgroep 1973 |
| Turkey | general | 10-400 | A | Guçer 1972 |
| United States | general | 90-1130 | A/B | Wischmeier 1962 |
| | Birmingham (Alabama) | 614 | A | Wischmeier & Smith 1978 |
| | des Moines (Iowa) | 236 | A | ,, |
| | S.Louisiana | 600 | A | ,, |
| | Hawaii, Oahu | map | G | Lo a.o. 1985 |
| | Laupahoehoe | 740 | A? | El-Swaify & Cooley 1980 |
| | Hilo | 780 | A? | El-Swaify (unpubl.) |
| Upper Volta/ | general | 200-650 | E | Roose a.o. 1974 |
| Burkina Faso | Bobo Dioulasso | (553) 575 | (C)E | Roose 1975 |
| | Dori | (261) 270 | (C)E | ,, |
| | Ouagadougou | (466) 440 | (C)E | ,, |
| Zambia | general | 259-1157 | A (Bols) | Lenvain a.o. 1988 |
| Zimbabwe | general | 375 | A | Ellwell 1978 |

Legend of table:

Method A : based on Wischmeier's EI (rain energy x I30) (Wischmeier & Smith 1978)
Method B : based on (Pt) x (2year 24 hour Pmax) x (2 year 1 hour Pmax) (Smith & Wischmeier a.o. 1962, and Ateshian 1974)
Method C : based on I 6 hours (USWB 1963 and Ateshian 1974)
Method D : based on P storm x I 30 (Delwaulle 1973)
Method E : based on adjusted Ps x I 30 (Roose 1973, Roose 1975)
Method F : based on normal monthly precipitation and rain days (Klingebiel,1972)
Method G : based on average annual rainfall amount (Roose 1975, Lo a.o. 1985)
Acor : method A corrected: no exclusion of rain with I less than 12.5mm/h.
Ac : method A corrected: exclusion of rain with I < 2.5 mm/h
A# : method A corrected: exclusion of rain with I < 10 mm/h, or volume < 10 mm.
() : method which is not preferred
* : based on approximate data only
A(Bols) : method A approximation according to the Bols index (Wiersum 1978)
? : probable data
Method H : based on the FAO index (Arnoldus 1980)

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## 7. RELIEF EFFECT as Central Concept

***Equivalent terms:*** topographic factor of erosion, relief susceptibility to erosion

***Related terms:*** erosion slope length
slope aspect = slope exposition

**The influence of topography on rain erosion, including the effect of steepness, slope form, length of uninterrupted non-depositional overland flow, and slope exposition.**

a) The concept
b) Slope steepness
c) Steep slopes
d) Slope length
e) Slope form
f) Slope position
g) Slope aspect or exposition
h) Relief effect on rainfall
i) Parameters of relief effect on rain erosion
j) Mapping relief for erosion hazard

a) The concept
The effect is part of the relatively permanent *erosion hazard*. It may be called also the relief *susceptibility* to erosion.

b) Slope steepness

b1) Steeper slopes show less *infiltration* and more *runoff* (Toy 1977:10). One reason is that infiltration decreases significantly with increasing slope, due to the reduction in the time available for rainfall to infiltrate (Sharma a.o. 1983).

b2) For example, data from India show the increase of *erosion* with slope steepness (Narayana & Sastry 1985:5):

| slope % | soil loss t/ha/yr | runoff % |
|---|---|---|
| 0.5 | 3.0 | 34 |
| 1.0 | 9.4 | 42 |
| 3.0 | 13.6 | 51 |

b3) It remains however difficult to compare degrees of steepness without introducing soil differences (Lal 1981).

b4) The influence of slope angle between 3 and 30 degrees, for 8 Canadian soils, showed frequently strong variation, to be explained by microscale variation in soil surface characteristics. Complex interrelationships exist between rain drop size, soil properties (*texture, aggregate* size distribution and stability) and microtopography. They determine *splash entrainment* and affect *wash* entrainment (Bryan 1979).

b5) *Detachment* by *splash* and by *overland flow* were studied by Quansah (1985: 413,414) for slopes of 14 - 35 percent for different *soil textures.*

b6) Length and steepness equations in the USLE need corrections for very gentle slopes (Mutchler & Murphree jr. 1985:525) which are eroded slightly less.
There is more *surface ponding* and slower, deeper, *overland flow* which protect the surface against the impact of rain.

b7) A convex upward relation between steepness and *sediment field* from hillslopes in Arizona, USA, had a vertex at 12 degrees slope. This was explained by the occurrence of stone *cover,* and stone size which increases on steeper slopes. The stone cover becomes a dominant influence in slowing overland flow and reducing the overland flow volume on slopes steeper than 12 degrees. Such situations can be expected where substrata and climate produce such stony slopes (Abrahams & Parsons 1991).

c) Steep slopes

c1) The exponential curve for 3-24% *gradients* is significantly flattened on steeper slopes (Hurni 1981:192). Hurni (El-Swaify a.o. 1985:764) modified the LS factor of the USLE for steep slopes in Ethiopia, L being correlated with the root of the length in metres, S being correlated as:

| slope steepness | 10 | 20 | 30 | 40 | 50 | 60 | 70 % |
|---|---|---|---|---|---|---|---|
| relative S value | 1 | 3.1 | 4.6 | 5.2 | 5.75 | 6.35 | 6.9 |

c2) Research (Bergsma 1986:90) found that between a steepness of 25% and 40% a similar increase in *surface rain erosion* occurs as between 16% and 25%. For 40% - 60% slope steepness erosion increases by half this amount, and above 60% up to about 120% erosion is roughly constant. For still steeper slopes the influence of rain erosion is expected to decline, because steep slopes catch less rain that falls vertically. However, the influence of *mass movement* may increase on these slopes.

c3) *Gully erosion* increased abruptly for slopes above 34 degrees in a study for the east central part of the South Island of New Zealand (Cuff 1985:106).

d) Slope length

d1) The erosion slope length is the length of uninterrupted *overland flow*, from the beginning of flow to where *deposition* starts, or flow enters into well defined *channels*, (Wischmeier & Smith 1978).

d2) Slope length has an effect that interacts with rainfall intensity.
Data in Baver (1963:439) show that longer slopes have less erosion when rainfall and *infiltration* are about in balance, but longer slopes have more erosion per surface area when rainfall is in clear excess over infiltration (Toy 1977:10, Baver 1963:439).
This may perhaps explain why Lal (1981) calls the effect of slope length ambiguous, in addition to his explanation of differences in time of concentration for different lengths of slope.
The influence of slope length on *soil loss* varies strongly depending on the presence or absence of *rill erosion*. The *interrill erosion* rate may be the same in such cases (Meyer a.o. 1976).

d3) The length and steepness relationships are not independent of soil, *plant cover* , steepness and length. Natural *runoff* plot data have not been adequate to define these factor interactions. Analytical studies indicate that the slope length exponent may be related to the ratio of *rill* and *interrill erosion* (Foster a.o. 1977, Moldenhauer & Foster 1981:23).

e) Slope form

e1) One of the earlier studies about slope shape is by Young and Mutchler (1969). Their conclusions are that *erosion* at a certain steepness depends on the slope shape immediately above the point of observation. On concave slopes most erosion takes place on the upper one third, on convex and straight slopes most erosion takes place about 3/4 down the slope.

e2) The slope form is to be taken into account (Lal 1981), as it will determine the erosion slope length by its influence on *deposition*. However, not all concave slopes are depositional. The accumulation of *overland flow* and soil moisture in concave downslope positions (Zaslavski 1981:9) may lead to *surface erosion* such as *rilling* and even *gullying* in the upper part of concave slopes.
Gullying may continue in a lower concave slope as far as a drainage way, but *incision rills* will change into *braids* at the transition from convex/straight to concave slope form (Young & Mutchler 1969).

e3) The LATERAL SLOPE FORM determines the convergence and divergence of flow lines for *overland flow* and *interflow*. The effect is demonstrated by data from Schumm a.o. (1974:71,72), showing nose slope topography giving relatively low *sediment yields*, even slopes giving intermediate sediment yields, and hollow slopes giving relatively high sediment yields. Steeper and hollow slopes produced the greatest quantities of *sediment*. Nose slopes gave less sediment because of divergent flow lines.

f) Slope position

f1) In certain positions a mapping unit or site receives *overland flow* from higher adjacent sites or mapping units. This *overland flow* comes in addition to the amount that is locally generated, and enters a mapping unit from higher areas, and is called *runon*.

g) Slope aspect or exposition

g1) Slope exposition is the direction of slope (Stamp & Clark 1979:195).

g2) Slope exposition often has a secondary effect, not easy to distinguish. In certain cases, the *erosion* types which had any noticeable relationship with slope exposition were *gully erosion*, and mass movements of

*slip* and scree *creep*. There were probably effects from a greater *exposure* to south-western storms, from a difference in temperature regime (specifically the means, extremes and frost-heave), from rainfall effectiveness on north-western faces, and consequently an effect on the soil and vegetation (Cuff 1985:103).

g3) Slope exposition induced differences in topoclimate in Dakota, USA (Churchill 1982) which are summarised in the following table:

| Characteristic | N-facing slopes | S-facing slopes |
|---|---|---|
| drainage density | high | low |
| fluvial erosion | higher | lower |
| mass movement features, slope failures | high magnitude, low frequency | frequent, small movements |
| moisture regime | wetter,less variable | drier, more frequent and intense wetting and drying |
| weathering activity | thick regolith, higher antecedent moisture levels, unconsolidated material is more erodible | almost no regolith<br>rocky, stony and gravelly, less erodible |

g4) In the case of the central Appalachians the following patterns were found (Derbyshire a.o. 1979:101): Differences between opposite slopes in Central Appalachians

| Characteristic | NW or SW facing slopes | NE or SE facing slopes |
|---|---|---|
| angle | gentle | steep |
| moistness | dry | wet |
| surface mantle of stones | coarse | fine |
| predominant vegetation | Yellow pine forest | Oak forest |
| density of cover | dense with many shrubs | open with few shrubs |
| drainage density | high | low |
| postulated most important process | slope wash and channel erosion | creep |

h) Relief effect on rainfall

h1) Relief influence on rainfall is called the orographic effect, when pronounced relief differences such as mountains influence the rainfall distribution over an area.

h2) The orographic rain has been related to (Spreen 1947):
- elevation
- elevation differences within an 8 km range around the site
- *exposure*, which is the sum of the sectors in degrees around the site lacking barriers to wind of 300 metres or higher, within a radius of about 30 km.
- orientation, direction of the greatest exposure, to be compared to the direction of the dominant rainbearing winds in the area.

i) Parameters of relief effect on rain erosion

i1) The relief factor of the *USLE*, including the steepness and the erosion slope length, is probably the most universally applicable of all its factors. Research on these factors is probably not a high priority for slope lengths between 10 and 100 metres and for steepness between 3 and 25% (Moldenhauer & Foster 1981:23).

i2) The LS FACTOR of the USLE has been generalised for the relief steepness classes used in soil survey by the USDA, which are used in many other countries as well (Soil Survey Staff 1951; Bergsma 1985:432-436).

i3) In the area of North Thailand the LS FACTOR for steep slopes has been limited to values below 20 (Harper & El-Swaify 1988:82; Harper 1989:535).

j) Mapping relief for erosion hazard

j1) For mapping *rain erosion hazard*, the relief steepness classes of soil survey have been correlated with erosion hazard in a general way (Bergsma 1985).

| Steepness classes of Soil Survey Manual (Soil Survey Staff 1953) | | Steepness classes of erosion hazard (Wischmeier & Smith 1978; Bergsma 1985) | | |
|---|---|---|---|---|
| Name | % steepness | Name | % steepness | increase in hazard |
| level to nearly level | 0 - 1/3 | nearly level | 0-2 | |
| undulating | 1/3 - 5/8 | gently undulating | 2-4 | 2 x |
| | | strongly undulating | 4-6 | 2 x |
| rolling | 5/8 -10/16 | gently rolling | 6-10 | 2 x |
| | | strongly rolling | 10-16 | 2 x |
| hilly | 10/16-20/30 | hilly | 16-25 | 2 x |
| steep | 20/30-40/60 | eep | 25-40 | 2 x |
| very steep | 40/60 + | very steep | 40-60 | 1.4 x |
| | | extremely steep | 60-120 | -- |

The slope steepness classes for hazard evaluation are not intended for creating mapping units. They are meant for describing the *erosion hazard* in mapping units that had been created already on the basis of geomorphological or physiographic differences, such as used in soil mapping.

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## 8. SOIL ERODIBILITY as Central Concept

***Equivalent term:***
erodibility, when context is clear

***Related terms:***
- to erodibility:
  interrill erodibility
  rill erodibility,
  gully erodibility
- to components of erodibility:
  aggregate stability,
  antecedent soil moisture
  compaction
  depression storage = surface storage
  erodibility classes
  liquefaction
  macropores
  overland flow
  rainfall acceptance
  shear (rill and gully erosion)
  slaking
  soil aggregate
  soil aggregate stability
  soil detachability
  soil dispersion
  soil sealing
  soil structural stability
  soil structure
  surface gravel
  surface sealing
  surface storage
- to erodibility indices
  USLE K-value

**The influence of the soil profile (apart from that of relief) on the soil erosion process, determined by the availability of material for erosion and the generation of overland flow volume from rain.**

a) The concept of soil erodibility
a1) the concept
a2) topsoil and subsoil
a3) a soil as relief and profile
a4) interactions with rainfall
a5) overland flow production and erosive power
a6) interrill and rill erosion
a7) change with time

b) Components of soil erodibility
b1) main components: flow and material
b2) soil characteristics
b3) texture
b4) surface gravel
b5) binding agents
b6) sealing
b7) antecedent-moisture
b8) flat land
b9) forest

c) Extrapolation/mapping
c1) density of observations
c2) benchmark soils
c3) variability in space
c4) soil classification

d) Indices of soil erodibility
d1) dominant factors
d2) parameter for soil behaviour

e) The soil erodibility index K of the USLE
e1) the concepts
e2) accuracy

e3) a lumped parameter
e4) an independent variable
e5) antecedent moisture and surface roughness
e6) measurement
e7) the nomograph

f) Other indices of soil erodibility

g) Tests of soil erodibility
g1) a combination of tests
g2) modal situation
g3) flow and material
g4) tests of components of soil erodibility

h) Soil erodibility classes
h1) the concept
h2) examples of classes

**APPENDIX A**: Table of measured K-values

**APPENDIX B**: Brief description of some simple tests related to soil erodibility

a) The concept of soil erodibility

a1) The concept of soil erodibility has to do with *overland flow production* as well as *detachment* of soil material. The rainfall supplies the water, but the soil profile determines how much overland flow is generated from a rain. The volume of overland flow, together with the detachment of soil material, determine the erodibility of the soil profile.
The potential *erosive* power of the overland flow will depend on the relief, the actual erosive power depends also on *plant-cover* and *cultivation/conservation practices.*
Soil erodibility may vary with the season and management.

a2) Soil erodibility usually refers to the *TOPSOIL,* except in construction sites. Where the land surface carries a soil, the name soil erodibility is proper and relates to a loss of the soil resource for agriculture. The term is also used for unaltered, *friable* materials, like *subsoil* clays, if they are, or are likely to be, subjected to the forces of raindrops or *overland-flow.*

a3) Soil erodibility for *rain erosion* indicates a group of influences on the *erosion* process, which are dependent on SOIL PROFILE PROPERTIES. The influence of the relief is by steepness, form and length. The soil surveyor's concept of "a soil" is a three dimensional part of the landscape (Soil Survey Staff 1951) and is thus subdivided into the relief and the soil profile (Wischmeier 1977:46), but the immediate surroundings of a site do receive consideration as part of the landscape. For instance, its position in the flow line pattern for surface flow and *subsurface flow,* as these influence the *rainfall acceptance* of the soil profile.

a4) INTERACTIONS of erodibility with rainfall character, relief and *land use* may give rise to strong secondary effects (Morgan 1979:21). Part of these effects may be included in soil erodibility by accurately describing the soil moisture regime. *Rainfall storage* in the soil profile, *subsurface flow,* and water loss by drainage and *evapotranspiration* play a large role in *overland flow* production by the soil. The use of separate *erosivity* and soil erodibility *factors* should not divert attention from existing strong interactions between the two (de Boodt 1981:534).

a5) Erodibility includes the generation of *overland flow.* The *erosive* power of that amount of overland flow largely depends on the relief in case of bare *land* (and is then part of the *erosion susceptibility).* Under *plant cover* the erosive power of the overland flow depends much on the *ground cover* density or *basal cover* (and is part of the erosion hazard).

a6) A distinction may be made between INTERRILL AND RILL ERODIBILITY (Meyer 1981:40; Moldenhauer & Foster 1981:22; de Ploey 1981:150). This distinction could be related to the factors that determine the occurrence of *rill erosion* according to Boon & Savat (1981): steepness, *soil texture* and volume of *overland flow.* Rill erosion hazard depends on soil erodibility and relief for its potential, while the actual rill erosion hazard is, of course, also strongly dependent on the *plant cover* and farmer's practices. For the incision of a *rill, shear* will also play a role (Bryan 1977:70).

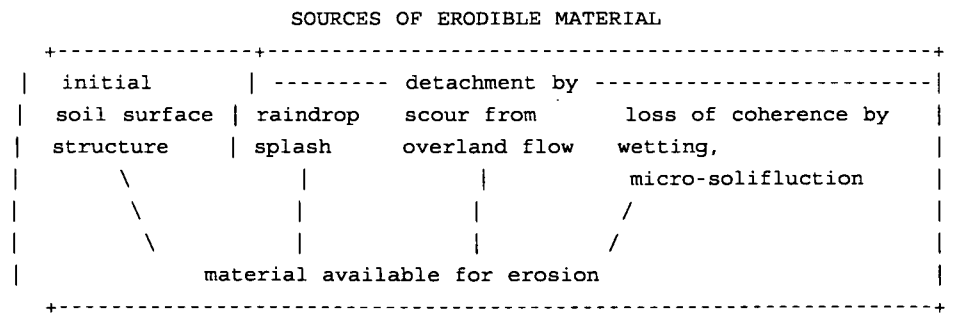
a7) Erodibility may CHANGE OVER TIME. During a single rain erodibility may decrease (de Ploey 1981:143,149) by:
- selective *erosion* and the development of a pavement of coarse material
- diminishing *roughness* and progressive *crusting*

Meyer (1985:169) cautions that the basic erodibility of a soil may decline considerably through the cropping season. This is probably due to fine root formation, and changes in the physical and chemical properties that affect the soil's sensitivity to *erosion* by *raindrop impact*, such as organic matter content for instance. The so-called *residual effect* (Wischmeier & Smith 1978) of the preceding crops will linger for some time and gradually wear off, just as does the influence of forest after the land is put into agricultural use (Dissmeyer & Foster 1981). Another study of the seasonal effects on soil erodibility was carried out by Kirby & Mehuys (1987) for Canadian soils, and showed that there is a great influence of freezing and thawing.
The possibility that soil erodibility may change over the years is stressed by Lal for tropical soils. In a 6-year period after reclamation, it first increases and then gradually decreases to a low value (Lal 1976). The explanation is a decrease in *aggregate stability* and *infiltration* after reclamation, and later a gradual accumulation of more stable material at the land surface.
For certain locations, formulas have been developed to express soil erodibility for half month periods during the year (Mutchler & Murphree jr. 1985:525).
In order to take the effect of soil tillage on soil erodibility into account, a useful concept is "the time since last tillage" (van Doren a.o. 1984).

b) Individual components of soil erodibility

b1) The influence of the soil profile on *rain erosion* has two main aspects:
- PRODUCTION OF *OVERLAND FLOW*. This includes *surface storage* and *infiltration*.
- AVAILABILITY OF *ERODIBLE* (transportable) MATERIAL.

The stability of the *soil structure* against *shear* forces from *splash* and *scour* is often called the DETACHABILITY.
"Erodible material" may consist of primary mineral particles, fragments (parts of *aggregates*) or small aggregates. It has the following sources:




In many situations rainfall is the main cause for *detachment*, while *runoff* is the main agent for transport. One of the first publications on the role of rainfall and runoff in detachment and transport was by Meyer & Wischmeier (1969).

b2) Many of the soil properties influencing soil erodibility are listed below according to their most direct effect on the availability of erodible material or production of *overland flow*.

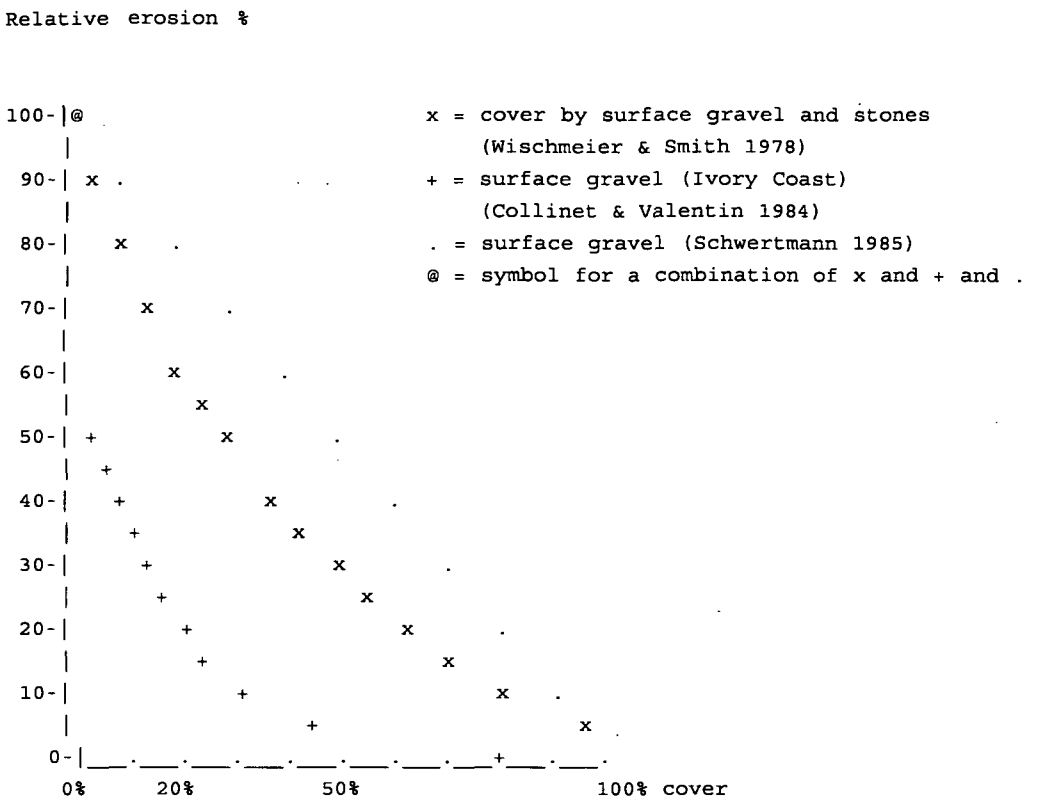
ASPECTS OF SOIL ERODIBILITY

| Soil Erodibility | |
|---|---|
| Erodible material | Overland flow production (volume) + |
| Soil texture | Surface depression storage ++ |
| Soil surface structure<br>- strength (of expression)<br>- size | Surface sealing<br>Infiltration (during the rain and immediately after mainly through macropores) |
| Soil surface structural stability (against splash forces: soil detachability) and against wetting (slaking, dispersion, liquefaction) | Profile storage<br>- adsorption on dry soil (for instance Onchev 1985:425)<br>- macroporosity<br>- permeable depth/ depth of easy infiltration/ hydraulic depth/ in which the macropores (Troeh 1980) or non-capillary porosity plays the main role. Compaction may interfere with permeable depth<br>- antecedent soil moisture content or drainage condition, related to internal as well as external factors such as slope configuration runon and subsurface flow (Zaslavski 1981; Ward 1975) |
| and factors such as exchangeable sodium percentage (ESP) and content of electrolytes in runoff | |

+ = here the volume of overland flow is considered while the erosive capacity of the overland flow depends on other hazard factors such as topography (especially slope form, steepness, length of erosion slope) and (basal) plant cover.
++ = an interaction with the soil management

b3) From several studies the role of textural fractions in soil erodibility is clarified (Romkens 1985:458; Poesen & Savat 1981:32). The very fine sand and silt can best be considered in combination.

b4) A soil characteristic strongly influencing soil erodibility and which is sometimes forgotten is the amount of area covered by *SURFACE GRAVEL*.
The effect is strong and can be rated in the same way as that of *plant cover* (Wischmeier & Smith 1978; USDA SCS 1973). One of the graphs below is taken from Wischmeier & Smith (1978), it shows a strongly concave form. In other areas the relation is not the same, in tropical areas it is even more concave (Collinet & Valentin 1984), in the temperate zone (southern Germany) the curve is linear (Schwertmann 1986).




The influence of *surface gravel* is also studied by Romkens (1985:449). He argues that the effect of stones or rocks on *soil loss* is best considered in the C factor of the USLE. Stones act as surface *mulch* by protecting the soil surface from *raindrop impact* and by affecting *surface runoff* velocity. Also, stone *cover* density or percentage varies from site to site of otherwise identical soils.
Stone cover density may be larger at the surface than below it because of frost heaving, *rillwash* by rainfall, or management. Furthermore, stones are normally excluded in the analysis of soil material even though they, like subsurface residue, which is also acounted for in the C factor, affect *infiltration*.
Another view is that surface gravel and stones can better be included in the K factor, or soil erodibility, because they are a permanent characteristic of a soil, and residue material and plant effects are not. The gravel affects the *erosion susceptibility*, while plant material affects the actual *erosion hazard*. Surface gravel is part of the soil, and is described as such in good soil descriptions, for instance by gravelly phases.

b5) In soils poor in organic matter, other binding agents may have a dominant influence on *soil structure stability* (Romkens 1985:458).

b6) *SOIL SEALING* is not always evidence of a high erodibility. Surface crusts are smooth, and the low *hydraulic roughness* does not contribute to turbulent, *erosive* flow. *Splashed* and fine material may be incorporated in the crust, resisting transport in that way, till the crust is broken up, which takes time (de Ploey 1981:149, Morgan & Morgan 1981:332).

b7) *ANTECEDENT MOISTURE* has a strong effect on *rainwash* erosion, as it influences soil structural stability (Luk 1985). Rates of *wash* may vary 4-5 times with the range of moisture variation. *Shear strength* is reduced by an increase in soil moisture. A parameter in assessing this effect can be the liquid limit. Antecedent moisture also influences the actual *storage-capacity* of rain in the soil profile.
As *macropores* dominate *infiltration* and storage of rain, their volume and stability could be of more importance than soil antecedent moisture content, as they empty rapidly (24 hours) and so mostly would be available, except in poorly drained soils.
An appreciable amount of rain can be adsorbed on dry clayey soil depending on the amount of the finer fractions.
Antecedent moisture may be generalised for a site by describing the drainage condition or the soil moisture regime. The moisture state is also influenced by the inflow of *runon* and *subsurface flow*.

b8) On FLAT *LAND*, sloping between 0 and 4%, erodibility is relatively higher than calculated following the rules of the USLE for sloping land, because flat lands have generally higher average moisture conditions (Mutchler & Murphree 1981:322; Mutchler & Murphree jr. 1985).

b9) Under FOREST special conditions play a role in soil erodibility. A quantitative discussion is given by Dissmeyer & Foster (1985:480). The typical forest effects on soil erodibility are:
- Soil *reconsolidation*. In general cropland reconsolidates and becomes less *erodible*, with time after tillage, while forest land does not.
- High organic matter content. In a forest organic matter may accumulate and reach high percentages, giving a lower erodibility
- Residual binding effect. *Erosion* is influenced by prior *land use*. After reclamation of forest, the effect of *soil structure*, fine roots and organic matter reduce erodibility for some years.
- The on-site *depression storage*. In a forest this includes stump holes, *berms* turned up by tractor treads, dips created by bulldozers, *debris* on the surface, and voids between *clods*. *Overland flow* production is influenced by natural microtopography from tree fall and root growth, and from management.
- *Colluviation-steps*. Behind debris soil accumulates until no more soil can be stored. The occurrence of these steps reduces the slope steepness. The more area covered by steps, and the steeper the slope, the greater the reduction in erodibility.

c) Extrapolation/mapping

c1) The density of observations is of importance for determining the soil erodibility of a mapping unit. Mapping of soil erodibility must deal with the variation with distance. The erodibility may show variation going from "one soil" to "another", and an amount of variation within an area covered by "one soil". The problem is of course closely connected with that of the scale of soil survey and its accuracy. Soil classification considers the top*soil texture* on a very low level, only used for very detailed surveys (Soil Survey Staff 1988).

c2) The establishment of soil erodibility factors for BENCHMARK SOILS greatly facilitates estimating K-values for soils with similar characteristics.
Unfortunately, the published literature provides only a limited number of direct measurements from natural *runoff* plots in fallow condition. Moreover, most data represent single replications of plots with steepness varying from 5 to 19 % and observation periods of 3 to 10 years. Adjustment for steepness and the relatively brief storm record may have yielded inaccurate estimates of K-values (Romkens 1985:450).

c3) Variation in soil erodibility, and an approach to studying the variability, is illustrated by Rogowski a.o. (1985). Use is made of a variogram, showing the variance of increments of a variable that is partly random, and partly continuous, as is soil erodibility. In a bounded case, like a mapping unit, the variogram reaches a plateau value, called "sill", within a distance known as the "range". The range gives information on the extent of the zone of influence (Rogowski a.o. 1985:151-155).
In the study area, the variogram of soil erodibility showed a range of 400 metres for a sampling grid of 100x100 metres, with a sill value of 0.14 (in the dimension of the K-value). For larger sampling grids (1000x1500 metres), the variogram showed a sill value of 0.18 and a range of about 2500 metres (Rogowski a.o. 1985:151-155).
These values will depend largely on the physiographic character of the area over which the grids have been superimposed. Applying the method explained above should probably give most useful information when applied for individual physiographic mapping units. These are mapping units, often used for soil survey, determined by relief, geology, landscape forming processes, vegetation and/or *land use*, mostly in combination.

c4) The SOIL CLASSIFICATION in Soil Taxonomy at Soil Subgroup level does not describe a soil sufficiently to correlate soil classification with soil erodibility. The Soil Family level of soil classification is a better level of detail, but as soil surface *texture* is generalised for a Soil Family, it may be necessary to describe soils on the level of Soil Series, or even Soil Types, to find a correlation with soil erodibility (Romkens 1985:451) in the table of K values below.
The characterisation of soils in relation to erodibility in a way that is practical for extrapolation of measured data to other soils, and for mapping soil erodibility, is an important question that still needs to be answered by research. Romkens a.o. (1989) suggest that the parameter of surface texture goes a long way, but still needs backing up by other soil characteristics.
Soil mapping units rarely consist of one soil, more often they contain an "association of soils", often they are a "soil complex" (Soil Survey Staff 1951).

Data of K-values of soils of different countries and belonging to different orders of the Soil Taxonomy classification system (Soil Survey Staff 1988) are given in El-Swaify a.o. (1982:92-94). The values are:

| Order | Range of K-values |
|---|---|
| Alfisols and Aridisols | 0.69 - 0.14 |
| Oxisols | 0.22 - 0.01 |
| Inceptisols | 0.55 - 0.02 |
| Mollisols and Vertisols | 0.67 - 0.05 |
| Ultisols | 0.36 - 0.00 |

It appears that a wide range of K-values is found within the Soil Orders and large overlaps occur. Oxisols are relatively resistant to erosion, and a tendency to resistance is seen for the Ultisols, and a tendency to erodibility is observed for the Alfisols and Aridisols. A discussion of these data is given with comments on subsoil erodibility, the use of the nomogram for tropical soils being limited by texture determination and the role of sesquioxides.
Variability of erodibility and limited accuracy of K determination by soil loss measurement exists partly because parameters for relief and rain *erosivity* may not be very accurate. Lal (1981a:176) stresses that the applicability of the soil erodibility nomograph is questionable for many soils.

d) Indices of soil erodibility

d1) The accuracy of a soil K-value is primarily related to the variation in annual precipitation or *antecedent conditions* at a location (Romkens 1985:452,453).

d2) An INDEX of soil erodibility is a numerical value, indicating the degree of influence of the soil profile on the *erosion process*. Indices are derived from soil profile data or they are based on results of testing the reaction of the soil to some treatment in the field or in the lab. Indices of soil erodibility mostly refer to the processes of surface or *laminar-erosion* (Bryan 1977:58).
Until more fundamental insight is obtained, a pragmatic way of evaluating soil erodibility can be the use of tests of soil behaviour, without necessarily relating the results to particular soil characteristics (Bergsma 1986).
One can conclude that a specific soil parameter capable of predicting soil erodibility across a wide range of soils will be difficult to identify.
Regionalisation, or a grouping of soils according to soil classification, may offer more potential (Romkens 1985:459).

e) The soil erodibility index K of the USLE

e1) The factor K is defined as the amount of *erosion* per unit of rainfall erosion index measured from or adjusted to unit plot dimensions and conditions (Romkens 1985:447).
The rainfall erosion index unit (EI30) or the erosion potential index for a specific storm is the product of the total *rainfall energy* of the storm times its maximum 30-min intensity (Wischmeier & Smith 1978).
The unit plot is defined as a 22.1 metre length of uniform 9 percent slope in continuously clean-tilled *fallow*. Thus, for the standard soil loss plot, having the factors of slope length L, steepness S, plant cover C, and practices P at unity, the soil erodibility factor K can be calculated from measured soil loss A as K = A/R. The K factor has the dimension of t.ha.h/ha.MJ.mm (Mutchler & Murphree jr. 1985).

e2) The accuracy of a soils K-value is primarily related to the variation in annual precipitation or *antecedent conditions* at a location. Variation of the calculated K per plot varies over the years in some relation to the annual rainfall factor or EI value (Romkens 1985:453).

e3) The K-value will represent the soil erodibility only approximately. Implicit in the definition is the representation of K as an integrated soil response to several *erosion* and hydrological processes. K, then, is a simplistic constant or lumped parameter; it cannot be equated with the process-specific constant "soil erodibility". While soil erodibility represents soil response to a specific *erosive* force or mechanism - such as *shear* forces in surface flow, impact of raindrops, or *scouring* by flow in headcuts - K lumps all these factors together (Romkens 1985:447).

e4) The K factor of the USLE is supposed to be a measure of the soil's ability to withstand rain impact, independent of topography or management (since they are also *factors* in the equation). Actually this is not a single-valued function because certain things can affect it that are not considered in the equation, for example season of the year, long term management effects, or intensity of *cultivation*, etc. (Moldenhauer pers. com.).

One of the situations where the application of the K factor as the soil erodibility index is difficult, is when the soil is pulverised by plough, disc, harrow, etc. For a period of time these operations and the pulverised condition override soil material characteristics as determinants of erodibility (van Doren a.o. 1984).
In the USLE this effect is implicit, not explicit, and really not well taken into account. The concept of "time since last tillage" used by van Doren a.o. (1984) gives an approach that can be further developed, especially as methods of no-till or reduced tillage receive more attention (Moldenhauer pers. com.). The same concept is also used for one of the adaptations of the USLE for agroforestry conditions by Dissmeyer & Foster (1981).

e5) Variability in K-value measurement can be somewhat reduced by estimating the effect of variation in *antecedent soil* water and *soil surface roughness* . This could be done by using predictions of *ponding* time and *surface retention*. For a nonconsolidating, non*sealing*, homogeneous soil, ponding time can be described as a function of rainfall rate, total rainfall, initial soil water content, and soil hydraulic properties. *Surface storage* may be approximated by measurements of the distribution of surface elevations (Romkens 1985:459).

e6) Accurate K-estimates can best be obtained from DIRECT MEASUREMENTS on natural *runoff plots* if a sufficiently long observation period is used and unit plot conditions are met. Good estimates may be obtained from *rainfall simulator* studies, provided storm weighting reflects the frequency pattern for the location and unit plot requirements are met. Indirect estimates, based on the nomograph or other predictive relationships of soil properties, need to be carefully considered in relation to the type of soils for which these relationships were derived. In the absence of a suitable prediction model, substantial errors in K-values may be made (Romkens 1985:459).

e7) As *soil loss* data are not always available, K-values have been approximated by using soil analytical data and the SOIL ERODIBILITY NOMOGRAPH. The development of the nomograph resulted from studies of the relationship between the K factor and soil properties (Wischmeier & Mannering 1969), such as % silt, organic matter, *aggregation*. Very sandy or very clayey soils can present problems in use of the nomograph (Houghton & Charman 1986).
Use of the nomograph is possible for soils where erodibility is dominantly determined by the factors used in the nomograph. For other soils such as very loamy, *sealing* loess soils and the soils which derive their structural stability from sesquioxides, other methds have to be used (Roth a.o. 1974).
The nomograph is based on five soil parameters:
- the sand minus the very fine sand in the *topsoil*
- the silt plus the very fine sand in the topsoil
- the organic matter content of the topsoil

When extreme the next two parameters are used also:
- the *permeability* (drainage) class of the *soil profile*
- the *soil structure* of the topsoil

It is advised (USDA 1973) that for the use of the nomograph attention should be paid to *SURFACE GRAVEL* and the CLAY MINERALOGY. For Hawaiian soils the clay mineralogy appeared to be significant (Romkens 1985:458).
Studies to test the accuracy of the nomograph showed that nomograph predictions appreciably underestimated K-values of well *aggregated* soils. The underestimates are believed to be due to the mass removal of detached surface aggregates (Romkens 1985:458).

e8) In the prediction of K-values for tropical soils several conclusions were made (Dangler a.o. 1987):
- Soil parent material must be considered when developing K factor values statistically from experimental soil parameters in the tropics.
- Poorly aggregated volcanic ash soils yield better correlated K-values than well-aggregated residual soils.
- The soil parameters necessary to develop K factor values also differ depending on the parent material.
- Use of easily determined soil parameters only, did not seem to reduce the reliability of prediction. This is an obvious advantage to laboratories with limited facilities.

Which soil parameters were of most power to predict soil erodibility ?

| | |
|---|---|
| all soils | particle size fraction <250 mu<br>% suspended silt+clay |
| residual soils | infiltration rate mm/h<br>extractable silica from solution |
| volcanic ash soils | (% silt + very fine sand) :<br>(% silt + very fine sand + sand coarser than 100 mu)<br>particle size fraction <250 mu<br>mineralogical class<br>mean-weight diameter of aggregates |

e9) Generally results of various studies of *soil texture* in relation to soil erodibility seem to suggest that the M term "([silt + very fine sand] x [silt + sand])" best predicts K-values in poorly structured soils and that different parameters relating to aggregation characteristics might be more suitable for aggregated soils. Unfortunately, not much quantitative information is available that relates these characteristics to *erosion* processes (Romkens 1985:459). In Hawaiian soils a texture parameter of particles larger than 250 mu was found to predict K-values well (r=0.90) (Romkens 1985:459).

e10) To describe K-values accurately in terms of a few measurable soil characteristics is difficult, if not impossible. The physical, chemical and mineralogical constituents are many. Their variability is great and their structural interactions are many and varied. Several *erosion* mechanisms may be present simultaneously (Romkens 1985:452). El-Swaify a.o. (1982:99) report on such efforts in East Africa. Rank correlation coefficients above 0.9 for relationships between a soil characteristic and K-values or measured *soil loss* were very few:

| Author & year | Area | Soils | Kind of rain | Field /Lab | Soil property | Rank cor. coeff. of K <->loss |
|---|---|---|---|---|---|---|
| El-Swaify & Dangler 1976 | Hawaii | 5 soil orders, mainly clay & clayloam textures | simulated | lab | percentage aggregates size > 250 mu | 0.903 |
| Ngatunga a.o. 1984 | Tanzania | Rhodic Ferralsol | natural | field | water stable aggr | 0.98 |
| | | | | | clay content | 0.91 |
| | | | | | gravel content | 0.93 |
| | | | | | *dispersion ratio* | 0.98 |
| | | | | | erosion ratio | 0.95 |

f) Other indices of soil erodibility

Parameters included in indices of soil erodibility have been for instance:
*surface ponding, clod* size distribution and *bulk density* (Ellwell 1981:290). Or, in another case, the *time to ponding* or the *sorptivity* has been found to be correlated at 85-90% with 5 factors: bulk density, liquid limit, de Ploey's *sealing* index C5-10 and results of the drop test of *aggregate stability*, while the *antecedent moisture* explained another 4% of the variation for two areas in Northern Morocco (Imeson pers. com. 1982). Other tests such as *wet sieving* are discussed by Bryan (1976, 1981) and others (Ambar & Wiersum 1980, El Swaify & Dangler 1976, Luk 1977, Vleeschauwer, Lal & de Boodt 1978, Ngatunga, Lal & Uriyo 1984).

Verhaegen (1984) used Atterberg limits, the C5-10 sealing index, organic matter, *texture*, cohesion, *permeability, water* content at saturation and aggregate stability to predict soil erodibility of loams and sandy loams in Belgium.

For tropical soils such efforts are discussed in El-Swaify a.o. (1982:95-99).

g) Tests of soil erodibility

g1) For the evaluation of erodibility perhaps several tests are needed in order to obtain a complete picture of all the important aspects of the erodibility a soil. The evaluation of such test results will depend on the spectrum of results, indicating which aspects are dominating the erodibility in a particular soil. The dominant aspect may be the *soil sealing*, the *soil structure* and the structural stability, the *storage capacity* for rainfall, etc.. Lal (1981b) also stresses that *erosion* may not be related to a single index, but to a number of indices in combination.

g2) For different types of rainshowers, for different soil surface conditions of tillage or *antecedent mois-ture*, different soil properties may become critical. A generalisation is perhaps allowed for the modal situation. But could *erosion* not be originating dominantly from non-modal conditions? This is a key question for erosion prediction. For Australia it is concluded that large losses are infrequent but contribute most to the total losses (Edwards 1985:478). This is the same for the USA (Moldenhauer pers. com.).

g3) Erodibility is determined by the availability of *erodible material* and the production of *overland flow* by the soil profile. The erodible material depends on the present soil surface *structure*, the resistance to *splash detachment* and the resistance to *scour detachment*, the soil's *shear strength*. The production of overland flow depends on such factors as the *sealing sensitivity*, macroporosity and its stability, the depth of relatively permeable *topsoil*, etc. (Bergsma 1985).

g4) Simple field tests related to *splash detachment*, *overland flow* production and *scour* resistance may be considered. Conclusions may be drawn for interrill erosion and for rill erosion from these simple fields tests (Bergsma 1985). Together with some laboratory tests the simple field tests are tabled:

TESTS OF ASPECTS OF SOIL ERODIBILITY
(a short description of the test and references are given in Appendix B)

| Test | Aspects of erodibility involved in tests | | | | | | |
|---|---|---|---|---|---|---|---|
| | Available erodible material | | Overland flow production | | | | Rill erodibility |
| | Soil surface structure | Structural stability | Sealing | Infiltration | Profile drainage /storage | Surface retention storage | Shear strength |
| **Simple field tests** | | | | | | | |
| Profile description | +" | @ | @ | @ | + | + | - |
| Crumb test | - | + | @ | - | - | - | - |
| Field pinhole test | - | @ | - | - | - | - | @ |
| Manipulation test | - | + | - | - | - | - | - |
| Rainfall acceptance test | - | + | + | + | - | - | - |
| Soil loss test | @ | @ | @ | @ | - | - | - |
| Shear vane test | - | - | - | - | - | - | + |
| **Simple lab tests** | | | | | | | |
| drop test | - | + | @ | - | - | - | - |
| wet sieving | - | + | @ | - | - | - | - |
| C5-10 | - | @ | + | - | - | - | - |
| K factor | - | @ | @ | @ | - | - | - |
| **Less simple lab determinations** | | | | | | | |
| dispersion ratio | - | + | @ | - | - | - | @ |
| erosion ratio | - | + | @ | @ | - | @ | - |
| heat of wetting | - | @ | - | - | - | - | - |
| silica/sesquioxide ratio | - | + | @ | @ | - | - | @ |

Legend: + = direct evidence
@ = inferred evidence
- = little evidence
" = includes record of surface gravel and drainage condition

h) Soil erodibility classes

h1) Classes of soil erodibility are ranges in the degree of erodibility, used for classification and mapping.

h2) Some examples of quantified ranges of values are given below.

1) Classes of K-values (Pauwels a.o. 1980:195)

| | |
|---|---|
| Very High | > 0.45 |
| High | 0.35 - 0.45 |
| Moderate | 0.25 - 0.35 |
| Low - Very Low | < 0.2 |

2) In another system (Bergsma 1985) the values of the classes differ by a factor of 2. If for a survey of surface *rain erosion hazard,* one succeeds in expressing the other erosion hazard *factors* of a mapping unit also in classes differing by a factor 2 in their effect on *soil loss,* one has a common basis for expressing the erosion factors which describe the mapping units and which are of a very different character.

When 5 classes are used

| Class name | "Equivalent K" class limits | "Equivalent K" central value | Step rating |
|---|---|---|---|
| | 0.7 | | |
| Very High | | 0.52 | -1 |
| | 0.35 | | |
| High | | 0.25 | -2 |
| | 0.17 | | |
| Medium | | 0.12 | -3 |
| | 0.08 | | |
| Low | | 0.06 | -4 |
| | 0.04 | | |
| Very Low | | | -5 |

When 3 classes are used

| Class name | "Equivalent K" class limits | "Equivalent K" central value | Step rating |
|---|---|---|---|
| | 0.7 | | |
| High | | 0.52 | -1 |
| | 0.25 | | |
| Medium | | 0.12 | -3 |
| | 0.06 | | |
| Low | | 0.03 | -5 |

APPENDIX A

TABLE OF MEASURED K-VALUES

The table contains a world overview of measured K-values, per country in alphabetical order, giving investigator, reference, soils and measured K-values. In rare cases K-values calculated from the nomograph are presented also.

---BELGIUM ----------

Four soils of the Loamy Low Plateau have K-values between 0.4 and 0.53 (Pauwels a.o. 1980)

Research station of Sauveniere (Gembloux), a loess derived siltloam, Orthic Hapludalf (Bolline 1985:207):
K (nomogram) = 0.62
K from 6 years soil loss measurement = 0.53
Corrections may be made for the threshold of rain volume that is used (12,5 mm and 1 mm), and for the types of rotations. For several reasons the K Wischmeier seems applicable for the region.

---ETHIOPIA----------

| Location | Climatic region | slope % | average rainfall mm/yr | erosivity index R (metric) | soil erodibility | crop |
|---|---|---|---|---|---|---|
| Simen, Northern Ethiopia | Tropical high mountain area | 60 | 1500 | 600 | - 0.02 (average K of Andosol soil surfaces) | Barley |

(Hurni 1981:192)

--- HAWAII ----------

| Local soil name | Soil Taxonomy name | dry soil | wet soil |
|---|---|---|---|
| - Molokai silty clay loam | Clayey, kaolinitic, isohyperthermic family of Typic Torrox | 0.09 | 0.22 |
| - Molokai silty clay loam | Clayey, kaolinitic, isohyperthermic family of Typic Torrox | 0.19 | 0.27 |
| - Waipahu silty clay | Very fine, kaolinitic, isohyperthermic family of Vertic Ustropepts | 0.03 | 0.41 |
| - Wahiawa silty clay | Clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox | 0.09 | 0.20 |
| - Lualualei clay | Very fine, montmorillonitic, isothermic family of Typic Chromusterts | 0.26 | 0.31 |
| - Waikane silty clay | Clayey, kaolinitic, isohyperthermic family of Humoxic Tropohumults | 0.02 | 0.14 |
| - Kukaiau silty clay loam | Thixotropic isothermic family of Hydric Dystrandepts | 0.12 | 0.22 |
| - Hilo silty clay loam | Thixotropic, isohyperthermic family of Ustollic Camborthids | 0.08 | 0.07 |
| - Kawaihae, very rocky very fine sandy loam | Medial, isohyperthermic family of Ustollic Camborthids | 0.36 | 0.34 |
| - Naalehu, extremely stony silty clay loam, thin variant | Medial isohyperthermic family of Typic Eutrandepts | 0.15 | 0.26 |
| - Pakini, very fine sandy loam | Medial isohyperthermic family of Entic Eutrandepts | 0.60 | 0.51 |

(El Swaify & Dangler 1976)

--- INDIA

| Location | Soil Type | Average K | Number of years |
|---|---|---|---|
| Agra | Loamy Sand, alluvial | 0.07 | 7 |
| Dehra Dun | Dhulkot silt loam | 0.15 | 7 |
| Hyderabad | Red chalka sandy loam | 0.08 | 4 |
| Kharagpur | Soils from lateritic rock | 0.04 | 4 |
| Kota | Kota clay loam (black soil) | 0.11 | 13 |
| Ootacamund | Deep lateritic | 0.04 | 6 |
| Rehmankhera | Loam, alluvial | 0.17 | 10 |
| Vasad | Sandy loam, alluvial | 0.06 | 3 |

(Singh a.o. 1985:500)

--- IVORY COAST

| Location | Climatic region | slope % | average rainfall mm/yr | erosivity index R (metric) | soil and K-value | crop |
|---|---|---|---|---|---|---|
| Abidjan, Ivory Coast | Tropical rain forest | 4, 7, and 20 | 2100 | 1200 | Ferrallitic 0.05 - 0.15 | Pineapple |

(Valentin & Roose 1981:239)

--- KENYA Machakos

| Depth cm | org.C % | pH water | CEC meq/100 gr soil | clay minerals | dry unit weight | soil erodibility |
|---|---|---|---|---|---|---|
| 0-15 | 0.99 | 6.0 | 13 | kaolinite illite | 12.2kN/m3 | Ferral-chromic Luvisol 0.52 |
| 0-16 | 2.43 | 6.4 | 34 | Kaolinite illite | (5.6kN/m3) 8-10kN/m3 | Humic Nitosol 0.05 |

(Barber a.o. 1981:222-223)

--- MALAYSIA Sarawak

Red Yellow Podsolic soil, Merit family, brownish yellow to yellowish brown heavy loam to clays, with increasing clay content with depth, slope 25 degrees: K = 0.1 . For other Red Yellow Podsolic soils, on which pepper is regularly grown: K = 0.15 - 0.2. (Hatch 1981:259)

--- THAILAND

Most K factor values published in North Thailand have been calculated from Wischmeier and Smith's K nomograph. The few reliable bare-plot K data as measured results were consistently lower than the nomograph values by a factor 0.73. For one location the factor was 0.50. Therefore the nomograph-calculated K values were multiplied with these factors (Harper & El-Swaify 1988:82)

--- USA

Reasonable estimates of K-values have been computed according to soil loss per total EI for the duration of the experiment except for Loring and Lexington soil series, where the average annual value is given.
Values are those after adjustment for topography and cropping management.
Storms of less than 1.27cm were excluded. This amount of rain was the average rain captured by infiltration and *surface-storage* before unoff began on fallow plots. It may have to be modified for different physiographic areas, soil type, soil manipulation, and seasonal values of K factors (Romkens 1985:450,451).
Soils are ordered according to increasing K-value of the cropped state.

## APPENDIX A SOIL ERODIBILITY

| Location | Soil Type | Soil Subgroup in Soil Taxonomy | Practice | K |
|---|---|---|---|---|
| Arnot, New York | Bath SiL | Typic Fragiochrept | cropped | 0.02 |
| ,, | ,, | ,, | fallow | 0.05 |
| Beemerville, New Jersey | Albia gravelly L | Aeric Fragioqualf | cropped | 0.03 |
| Marlboro, New Jersey | Freehold LS | Typic Hapludult | cropped | 0.08 |
| Tifton, Georgia | Tifton LS | Plinthic Paleudult | cropped | 0.10 |
| Geneva, New York | Ontario L | Glossoboric Hapludalf | fallow | 0.27 |
| Marcellus, New York | Honeoye SiL | Glossoboric Hapludalf | cropped | 0.18 |
| ,, | ,, | ,, | fallow | 0.28 |
| Guthrie, Oklahoma | Zaneis fSL | Udic Argiustoll | cropped | 0.22 |
| Watkinsville, Georgia | Cecil SL | Typic Hapludult | cropped | 0.23 |
| Clemson, South Carolina | ,, | ,, | cropped | 0.25 |
| ,, | ,, | ,, | fallow | 0.28 |
| Tyler, Texas | Boswell fSL | Vertic Paleudalf | cropped | 0.25 |
| Watkinsville, Georgia | Cecil CL | Typic Hapludult | cropped | 0.26 |
| McCredie, Missouri | Mexico SiL | Udollic Albaqualf | cropped | 0.28 |
| Temple, Texas | Austin C | Typic Haplustoll | cropped | 0.29 |
| Hays, Kansas | Mansic CL | Aridic Calciustoll | cropped | 0.32 |
| Castana, Iowa | Ida SiL | Typic Udorthent | cropped | 0.33 |
| Clarinda, Iowa | Marshall SiL | Typic Hapludoll | cropped | 0.33 |
| Watkinsville, Georgia | Cecil SCL | Typic Hapludult | cropped | 0.33 |
| LaCrosse, Wisconsin | Fayette SiL | Typic Hapludalf | cropped | 0.37 |
| ,, | ,, | ,, | fallow | 0.38 |
| Blacksburg, Virginia | Lodi L | Typic Hapludult | cropped | 0.39 |
| Holly Springs, Mississippi | Lexington SiCl | Typic Paleudalf | fallow | 0.44 |
| ,, | Loring SiCL | Typic Fragiudalf | fallow | 0.49 |
| Bethany, Missouri | Shelby L | Typic Argiudoll | cropped | 0.41 |
| ,, | ,, | ,, | fallow | 0.53 |
| Zanesville, Ohio | Keene SiL | Aquultic Hapludalf | cropped | 0.48 |
| Geneva, New York | Dunkirk SiL | Glossoboric Hapludalf | fallow | 0.69 |

Notation: S=sand, Si=silt, L=loam, C=clay, f=fine.

Observed values of the annual soil erodibility factors and rainfall factors at several locations in the USA (Romkens 1985:453).

| | Barnes Loam (Morris, Minnesota) | | | | Ida Silt Loam (Castana, Iowa) | | | Loring Silt Loam (Holly springs/ Mississippi) | | trend in Minnesota |
|---|---|---|---|---|---|---|---|---|---|---|
| Plot | 1 | 2 | 3 | R | 1 | 2 | R | 1 | R | plots |
| 1961 | | | | | 0.30 | 0.27 | 425 | | | |
| 1962 | 0.56 | 0.52 | 0.62 | 541 | 0.50 | 0.50 | 357 | | | 0.57 |
| 1963 | 0.04 | 0.04 | 0.04 | 94 | 0.35 | 0.39 | 486 | 0.54 | 677 | 0.04- |
| 1964 | 0.61 | 0.49 | 0.56 | 241 | 0.22 | 0.31 | 415 | 0.63 | 701 | 0.55+ |
| 1965 | 0.19 | 0.23 | 0.18 | 135 | 0.31 | 0.34 | 361 | 1.06 | 507 | 0.20- |
| 1966 | 0.13 | 0.17 | 0.04 | 111 | 0.03 | 0.01 | 125 | 0.53 | 793 | 0.11- |
| 1967 | 0.04 | 0.04 | 0.10 | 75 | 0.10 | 0.19 | 262 | 0.57 | 538 | 0.06- |
| 1968 | 0.06 | 0.05 | 0.05 | 62 | 0.25 | 0.26 | 350 | 0.56 | 970 | 0.05- |
| 1969 | 0.13 | 0.08 | 0.05 | 83 | 0.37 | 0.37 | 324 | | | 0.09+ |
| 1970 | 0.40 | 0.37 | 0.26 | 61 | 0.14 | 0.16 | 153 | | | 0.34+ |
| 1971 | 0.30 | 0.16 | 0.16 | 132 | | | | | | 0.21- |
| Ave. | 0.25 | 0.22 | 0.22 | 158 | 0.26 | 0.28 | 326 | 0.65 | 697 | - = decreasing |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| St.dev | 0.21 | 0.18 | 0.22 | 144 | 0.14 | 0.14 | 116 | 0.09 | 76 |
| Coef. of var. | 0.84 | 0.82 | 1.00 | 0.91 | 0.54 | 0.50 | 0.36 | 0.14 | 0.11 |

+ = increasing

The variation of K over the years may be related to the rainfall pattern, and *antecedent moisture* (Romkens 1985:452).

--- WEST AFRICA ---

- Adiopodoume: Low base-saturated ferrallitic on argillic-sandy K = 0.10
- Agonkamey: Medium base-saturated ferrallitic /argillic-sandy K = 0.10
- Bouake: Eroded, reworked, ferrallitic on granite K = 0.12
- Korhogo: Impoverished, reworked, ferrallitic on granite K = 0.02
- Gampela: Tropical ferruginous on lateritic pan at 20 cm K = 0.25
- Saria: Tropical ferruginous on lateritic pan at 50 cm K = 0.25
- Sefa: Leached tropical ferruginous with stains and concretions K = 0.25

(Roose 1976:60-74)

---

ferralitic soils

| | |
|---|---|
| - from tertiary sands | K = 0.05 - 0.10 |
| - from granite | K = 0.10 - 0.15 |
| - from schist | K = 0.15 - 0.20 |
| - gravelly | K = 0.01 - 0.03 |
| ferruginous tropical soil from granite, | |
| - after clearing old fallow | K = 0.03 - 0.15 |
| - 3 to 4 years of cultivation | K = 0.20 - 0.30 |

(Roose 1980:158-159)

--- WEST AFRICA ---

| Location | FAO soil classification | Texture | % Coarse fragments | Erodibility-Factor K Measured | Computed |
|---|---|---|---|---|---|
| Hyper arid climate | | | | | |
| | Dystric Regosol | cobbly CL | 79 | 0.04 | 0.55 |
| Agadez | Dystric Fluvisol | S | 5 | 0.300 | 0.28 |
| | ,, ,, | C | 0 | 0.695 | 0.41 |
| Arid climate | | | | | |
| Oursi | Arenosol | S | 0 | 0.063 | 0.20 |
| | Xerosol | C | 4 | 0.291 | 0.63 |
| | Ferric Luvisol | S | 5 | 0.102 | 0.39 |
| Semi-arid climate | | | | | |
| Galmi | Ferric Luvisol | S | 1 | 0.070 | 0.20 |
| | Xerosol | SL | 8 | 0.060 | 0.18 |
| | Vertic Cambisol | SCL | 0 | 0.100 | 0.43 |
| Pouni | Ferric Luvisol | SCL | 48 | 0.004 | 0.18 |
| | ,, ,, | SCL | 70 | 0.001 | 0.08 |
| Batanga | Vertic Cambisol | SC | 4 | 0.050 | 0.16 |
| Sub humid climate | | | | | |
| Loumbila | Gleyic Luvisol | S | 12 | 0.017 | 0.24 |
| Humid climate | | | | | |
| Tingrela | Helvic Acrisol | SL | 53 | 0.013 | 0.17 |
| | Plinthic Acrisol | SL | 27 | 0.104 | 0.27 |
| | Ochric Gleysol | SiL | 0 | 0.455 | 0.43 |
| Tieningboue | Helvic Acrisol | LS | 60 | 0.054 | 0.23 |
| | Plinthic Acrisol | LS | 36 | 0.019 | 0.22 |
| | Helvic Acrisol | SL | 2 | 0.035 | 0.40 |

## APPENDIX A SOIL ERODIBILITY

| | | | | | |
|---|---|---|---|---|---|
| Sakassou | Helvic Acrisol | SL | 15 | 0.008 | 0.12 |
| Hyper humid climate | ---------- | ---------- | ---------- | ---------- | ---------- |
| Tai | Rhodic Acrisol | SC | 40 | 0.001 | 0.02 |
| | Helvic Acrisol | SCL | 1 | 0.006 | 0.10 |

Symbols: S=sand; LS=loamy sand; SL=sandy loam; SiL=siltloam; SCL=sandy clayloam; SC=sandy clay; C=clay.

(Collinet & Valentin 1958)

APPENDIX B

BRIEF DESCRIPTION OF SOME SIMPLE TESTS RELATED TO SOIL ERODIBILITY

- *crumb* test
- pinhole test
- manipulation test
- rainfall acceptance test
- soil loss test (microplot)
- shear vane test
- drop test
- wet sieving
- C5-10 sealing index
- the soil erodibility factor K
- dispersion ratio
- erosion ratio
- silica/sesquioxide ratio

CRUMB TEST - RATING OF THE BEHAVIOUR OF A CRUMB THAT IS SUBMERGED IN WATER.
(Loveday & Pyle 1973; Greenland a.o. 1975; Jungerius 1982)
The test is considered to give an indication of the sensitivity to sealing by wetting of the dry soil, and to give a measure of the structural stability of the dry soil against sudden wetting.
The test is performed by submersion of small, air-dry, soil *clods* or aggregates, the reaction of the clods after 5 - 10 min (and after 20 hours) of immersion is rated following slaking (loss of form) by wetting, swelling, or air explosion, and *dispersion* of clay. Four classes are used.

PINHOLE TEST - A FIELD MODIFICATION
RATING THE EFFECT OF FLOW OF WATER THROUGH A SOIL BALL (Sherard a.o. 1976).
The test is performed on a moulded ball of soil, at sticky point. Water conducted through a 1 mm hole is collected in a transparent plastic beaker.
Colouring of the water by dispersive clay in suspension and the amount of erosion of the hole in the soil ball is rated. Four classes are used.
N.B. The pinhole test was originally designed to recognise dispersive clays for engineering of water holding dams. The test, as described by Sherard a.o. (1976) is performed in the laboratory and is a sophisticated technique.

MANIPULATION TEST - A RATING OF SOIL COHERENCE.
(Charter 1949; Bont & van der Poel 1979).
The test consists of manipulating a 2 cm soil cube, at plastic limit, into the most complex form possible out of a series of seven defined forms.
Ranking for erodibility is usually low for sands, higher for sealing loamy sands and sandy loams, high for very silty loams, lower for clayloams and low for clays.
The manipulation test was originally developed as a simple means for determining soil texture in the field, for the conditions in Ghana.

RAINFALL ACCEPTANCE TEST - FIXED VOLUME INFILTRATION TIME, UNDER SPLASH, AVOIDING PONDING (Bergsma 1986).
The test measures the time needed for the infiltration (without strong ponding) of 24 mm artificial rain.
A prewetting run is done and a series of runs follows at intervals of 2 minutes, to obtain an impression of the reduction in infiltration caused by the splash and wetting.

SOIL LOSS TEST - SEDIMENT ERODED FROM A SMALL AREA OF CERTAIN STEEPNESS BY A CERTAIN RAINFALL (Bergsma 1986).
The amount of sediment eroded from a small area, without *plant cover,* with known steepness (made by scraping if necessary) is recorded after a prewetting run without soil loss. A mini-rainfall simulator is used.

RILLING TEST - A SIMPLE FIELD TEST TO EVALUATE THE SENSITIVITY OF THE SOIL SURFACE TO SCOURING BY CONCENTRATED FLOW.
The shear strength of the soil is indicated by the pinhole, shear vane and rilling tests.
On the wet soil surface (for instance after performing the soil loss test, when the soil surface is still wet and kept protected against evaporation), sloping 9 % and of a size of 30 x 30 cm, two plastic rulers of 30 cm length are inserted into the topsoil by their tapered side (or about 1 cm deep). The spacing of the rulers is 4 cm. Their downslope end touches a sediment collecting tray. The placing of the rulers is planned so that the test can be repeated four times on the area.

At the upper end of the rulers, a plastic cube of 6 cm side, open at the upper side, is placed. It has a slit in one of the slides facing downslope. This side should be touching the upslope ends of both rulers.
The cup, containing 600 cc, is emptied rapidly into the cube and water will pour through the slit and run between the rulers down the test plot, as an imitation rill flow. The first run is used to wash the surface free of loose surface aggregates , and the collecting tray is not used but a small piece of stiff plastic is put at the lower end of the plot, to protect the end of the test plot against the flow.
Then the collector tray is placed below the test plot, at the end of the rulers. The second run is made and the sediment is collected on the tray. This procedure is repeated four times on the surface of the test plot. The sediment produced by all (four) rills together is collected on the tray, the overland flow is decanted. The total sediment is transfered to a box for transport to the field base to be measured. Results are expressed as gram sediment per artificial rill.

SHEAR VANE TEST - A TEST OF THE SOIL'S SHEAR STRENGTH
Maximum torsion force exerted by the soil on symmetrical intersecting blades, inserted 1 cm deep into the topsoil surface, is recorded.
Observations may be done on a saturated surface to eliminate the influence of the antecedent moisture content.
Observations are repeated for instance ten times (Bergsma 1986).

DROP TEST - A TEST OF THE SOIL'S STRUCTURAL STABILITY
(Bergsma & Valenzuela 1981)
The reaction of selected soil surface structural elements to falling waterdrops of known dimension and energy is recorded. Results are expressed as the number of drops that are needed to have the soil aggregate (of for instance 5mm diameter) break up to fragments of less than 3 mm diameter, passing through a sieve.
Drop size is often 5 mm, fall height 1 metre. Selection of aggregates, transport and storage, frequency of drop fall are critical for results.

WET SIEVING - A TEST OF THE STRUCTURAL STABILITY AGAINST WETTING
It is a standard treatment of wetting soil and in some procedures it includes moving the submerged soil fragments in a set of sieves through the water. Splash is absent, wetting is the main agent of change in soil structure, and there is some minor scour.
Results are discussed by Bryan (1976, 1981).

C5-10 SEALING INDEX.
It is a sealing index developed by de Ploey (1981), used also as an index of soil erodibility of Belgian loams (Verhaegen 1984).
It is the difference in moisture content between the point of 5 strokes and 10 strokes in the determination of the liquid limit by using the Casagrande apparatus. Soils with a C5-10 above 3 are relatively stable against sealing, those with values 2.5 and less are relatively sensitive to sealing.
Verhaegen (1984) used the C5-10 sealing index as one of the indices to obtain a picture of the soil erodibility of loams and sandy loams in Belgium.

THE SOIL ERODIBILITY FACTOR K - A FACTOR IN THE UNIVERSAL SOIL LOSS EQUATION
It is defined as the amount of erosion per unit of rainfall erosion index (EI) measured from or adjusted to unit plot dimensions and conditions (Romkens 1985:447). A discussion of the index is given by Romkens (1985), and Romkens a.o. (1989).
As soil loss data are not always available, K-values have been approximated by using soil analytical data and the soil erodibility nomograph (Wischmeier & Smith 1978). Use of the nomograph is possible for soils where the erodibility is dominantly determined by the factors used in the nomograph. For other soils such as very loamy, sealing loess soils and the soils which derive their structural stability from sesquioxides, other ways have to be followed. (Roth a.o. 1974).
The nomograph is based on three to five soil parameters:
- the sand minus the very fine sand in the topsoil
- the silt plus the very fine sand in the topsoil
- the organic matter content of the topsoil

When extreme the next two parameters are also used :
- the *permeability* (drainage) class of the soil profile
- the *soil structure* of the topsoil

It is advised (USDA 1973) that for the use of the nomograph attention should be paid also to surface gravel and the clay mineralogy. For Hawaiian soils the clay mineralogy appeared to be significant (Romkens 1985:458).

DISPERSION RATIO
The ratio of silt and clay remaining in suspension after limited shaking and settling, following a specific procedure, to the total silt plus clay as determined by mechanical analysis.

EROSION RATIO
It is the quotient of the dispersion ratio over the ratio of colloid-to-moisture equivalent. Thus it reflects both erosional characteristics and the ability of the soil to absorb water.

SILICA/SESQUIOXIDE RATIO - used in an index together with soil texture (Roth a.o. 1974).

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## 9. SOIL COVER as Central Concept

***Related terms:***
not included in list of terms:
crop cover (focus on arable crops)
ground cover (focus on low cover of the soil)
land use cover (focus on human land use: arable, grazing)
plant cover (focus on vegetative cover, planted or natural)
vegetative cover (focus on plant cover plus *residues)* included in list of terms:
basal cover (cover by plant stems just above soil surface)
canopy (cover by plant/tree crowns)
cover crop
cover factor (C)
crop residue (crop remnants)
folial cover (cover by leaves on plants/trees)
mulch (cover by material on the ground)
soil surface cover = surface cover = ground cover

**There are definitions stressing vegetative aspects (A), stressing protection by cultivated plants plants against *erosion* (B) and others stressing cover of the soil surface by any material (C).**

A) Vegetation cover or natural plant cover, from the ecological viewpoint:
**All plants of all sizes and species found on an area, irrespective of whether they have forage or other value.**
B) Crop cover or cultivated plant cover, from the conservation viewpoint:
**The combined aerial and basal parts of plants, covering a proportion of the ground surface over a given area against the impact of rain.**
C) Ground cover/ surface cover/ soil cover, from the conservation viewpoint:
**A vegetative layer of grasses and/or other low growing plants or plant residues providing protection to the soil against erosive agents.**

***Descriptive aspects***
The descriptive aspects have been subdivided according to the three concepts of the definitions: A, B, and C. Under B and C a subdivision is made in aspects related to the importance of the type of soil cover, and the quantification of its effect.

A a) Natural vegetation in the humid tropics, especially the evergreen forest, has a tremendous effect on soil formation. Even on very steep slopes and under highly *erosive* rainfall *soil losses* are minimal, and very deep soils are found (Bennema & de Meester 1981:83).

B Importance of the crop and plant cover
a) The term "aerial cover" is somewhat misleading relative to airphoto coverage, so the term *folial cover* is used as distinct from basal cover, or *canopy* cover may be more precise.
b) Of all hazard *factors,* cover and cover management for *conservation* are the most important influences on the *rain erosion hazard.*
c) Cover is very effective against *rain erosion,* and small amounts have a more than proportional effect (Wischmeier & Smith 1978; Shaxson 1981:389-390).
d) Proper agronomic methods, including planting time, applied to single or intercropped plant stands, may shorten the period in which *erosive* rainfall can cause significant damage to the soil (Shaxson 1981:390).
e) Cover crops are those that are especially planted for the cover they provide during a season, during a *growth stage* of other crops, or for permanent protection.
f) Vegetation protects soil against *surface erosion* in various ways (Wiersum 1985:79):
- *interception* decreases the volume of rain water reaching the soil surface. It also alters the spatial distribution of rainfall through *stemflow* and concentrated *drip* points.
- interception breaks the erosive power of the falling rain. However, when the fall height for drip is great enough, and the drop size is large, the erosive power of the drip may exceed that of the original rain.
- Surface vegetation and *litter* protect the soil against the force of *splash* and *overland flow.* It protects surface pores, sustaining surface *infiltration.*

- Decomposition of vegetative litter increases the humus content of the *topsoil*, creating optimal conditions for water *permeability* and increasing *aggregate stability*.

g) The distribution of ground cover and bare soil differs between cropland and forest. In cropland, groundcover and bare soil are nearly uniformly distributed, while in forest they are randomly distributed. There the bare patches are almost always surrounded by *litter*. At about 30% of bare soil, bare patches connect to *erosion* pathways, and the litter effect decreases strongly (Dissmeyer & Foster 1985:483).

h) In a tree vegetation the presence of a direct soil cover is the single most important vegetation factor protecting the soil. The sustained presence of *LITTER* is ensured by the litter production capacity of the tree canopies.
This litter decomposes gradually, resulting in increased humus in forest soils and decreased *erodibility*. The vegetation effect on erodibility takes much longer to develop than the effect of producing a protective layer on the soil surface (Wiersum 1985:85).

i) *DRIP* from leaves lower than about 3 metres above the ground becomes less *erosive* than rain, and *interception* by these leaves becomes more effective, and drip energy is negligible (about 25 %). At greater heights, drip energy becomes substantial, also because of the greater drop sizes it contains.
At about 2 m drip energy becomes about half that of *throughfalling* rain (Wischmeier & Smith 1978).

j) Good cover is entirely consistent with good economics (Stocking 1981:383).
In the matter of crop cover, the concern of the farmer, the agronomist, and the conservationist may coincide. For the agronomist a better bulk of leaves and *litter* is often correlated with a better yield, for the conservationist more leaves often coincide with better protection against *raindrop impact*, and for the farmer a better crop and less *erosion* are a favourable result of his management (Shaxson 1981:391).

Quantification of crop and plant cover

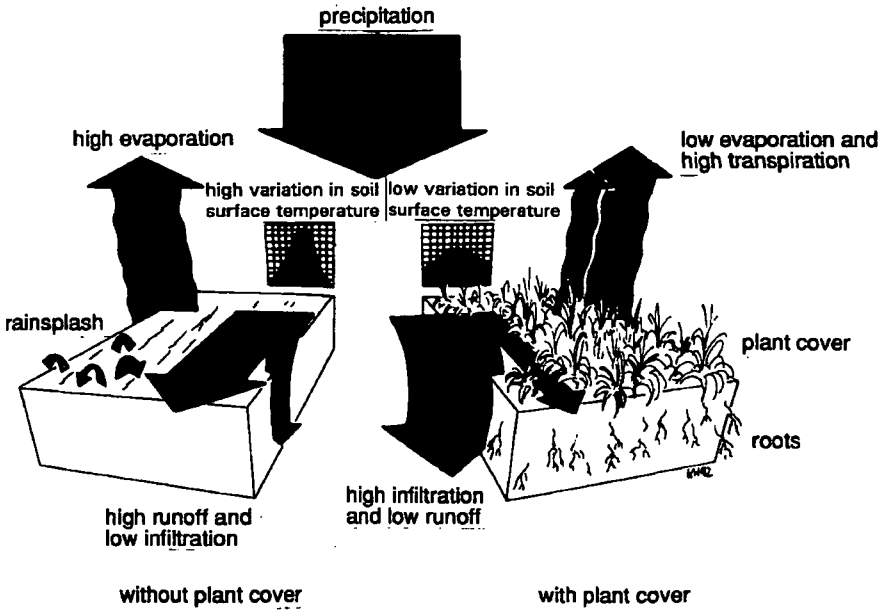
k) It may be expressed as a percentage of the area (Houghton & Charman 1986:33), determined by the vertical projection of the cover on the ground surface (Soil Cons. Soc. Am. 1982:6).

l) In row crops the row spacing is a dominant part of the cover effect (Meyer 1981:40).

m) Cover density can be affected by interrow and intrarow spacing in row crops.
Certain dimensions are optimal for reducing *soil loss* and producing a smooth *hydrograph*, for the same plant number per hectare (Bhardwaj a.o. 1985:644-648).

n) Subfactors of C, the cover factor in the USLE, are: prior *land use*, crop-*canopy*, residue cover and *surface roughness* (Laflen a.o. 1985:287).
A canopy subfactor is recognised for the plant cover effect on *erosion*, not only for forest but also for lower plants. It depends on the height and the density of the canopy (Dissmeyer & Foster 1985:484).

The importance of soil cover



o) The subfactor of RESIDUAL EFFECT (of plant cover) is the effect on *erodibility* by cultivated plants or natural vegetation growing in recent years before observation time. It is strongly dependent on the type of vegetation and the previous management of residues. Forest and *perennial* pasture are well known for a strong residual effect (Wischmeier & Smith 1978:20).

p) In Thailand it was found that in managing forest *land,* especially areas designed for *watershed* protection, the specific crown cover required for minimizing *surface runoff* and *soil erosion* should be at least 70 % and be kept in combinaton with minimum bare soil openings. This is because crown density and *litter* production go together, having also a residual long term effect on organic matter content and *infiltration* (Ruangpanit 1985:471).

q) In a forest some soil cover may also be provided by a fine rootmat. It even acts for several years after the trees have been removed. Values of this subfactor of C go down to 0.2 (Dissmeyer & Foster:483-484).

C Importance of soil cover

a) A good ground cover is an essential part of the majority of soil *conservation* programs (Houghton & Charman 1986:63,82).

b) The plant cover close to the surface is the *basal cover,* in contrast to the *canopy* or *folial cover.*

c) The effect of stones and rocks on *erosion* is best considered to be part of the C factor of the USLE. Stones act as surface *mulch* by protecting the soil surface from *raindrop impact* and by affecting *surface runoff* velocity (Romkens 1985:449).The surface coarse textural fraction is however a much more permanent feature than plant cover and vegetal mulch, and therefore could belong to the influence of the soil profile (USDA SCS 1973; Wischmeier & Smith 1978).

d) It is probably wise to use the cover factor only for material covering the soil surface, and to describe the effect of tillage by the P-factor. The tillage direction is already included, and different ways of preparing the *land,* such as in ridges or in beds, would be included in the P-factor also.

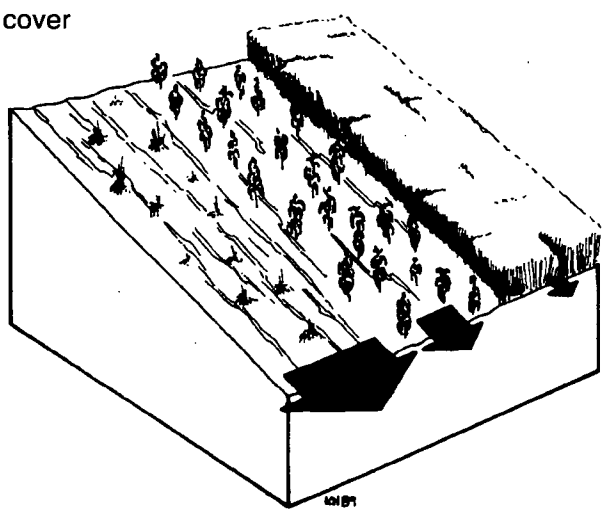
e) The cover factor is the C-factor in the USLE, or similar parameter in *erosion models.* The effect is rated in Wischmeier & Smith (1978:19). The relation given there between relative *erosion* and *cover* is strongly parabolic. This means that small amounts of cover have a relatively big effect, a 25 % cover would give a 50 % reduction in erosion.
However, a general guideline for New South Wales in Australia is that a percentage ground cover of 75 or more is needed to give adequate protection against *soil erosion* (Houghton & Charman 1986:63).

f) One has to be aware of situations such as freshly prepared soil for *seedbeds* or improved drainage of the *topsoil,* where the *soil loss* due to land surface preparation may be twice the soil loss from flat tilled plots. In these cases the value of the C-factor (or P-factor) would be greater than one (Mutchler & Murphree 1981:323).

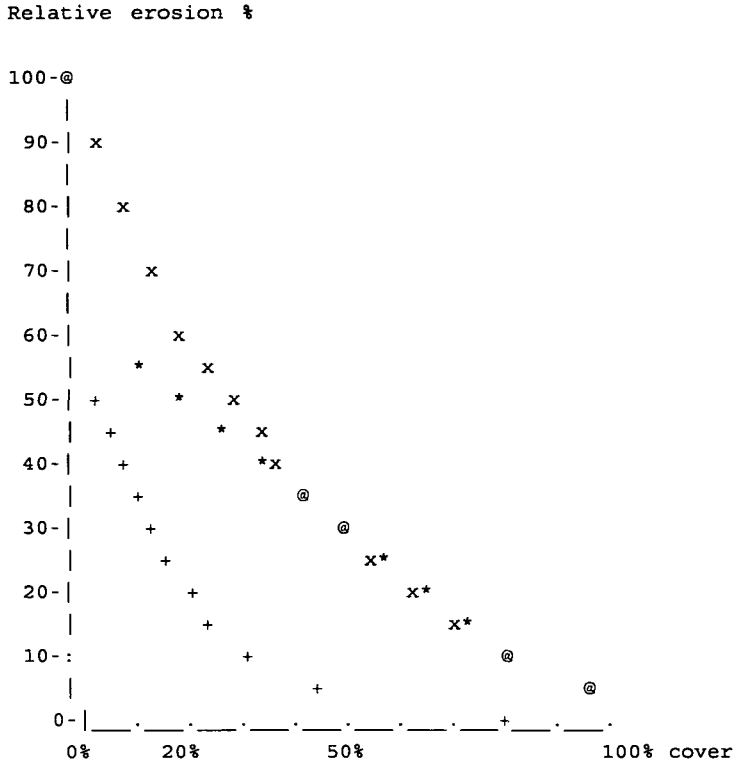
Quantification of soil cover

g) C values may be more useful when presented as a range of possible values for a given cover condition and hydrologic soil group, because tillage, time and crop conditions appear to affect the C-factor (Cooley & Williams 1985:521). For example, crop cover has a greater reducing effect on *erosion* for soils with low *infiltration* and high *runoff* potential than on the more porous soils with higher *infiltration rates.*

Overland flow and plant cover



## h) RELATIVE EROSION and GROUND COVER PERCENTAGE




x = cover of surface gravel and stones (Wischmeier & Smith 1978)
\+ = surface gravel (Ivory Coast, Collinet & Valentin 1984)
* = corn data (Bavaria, Germany, Schwertmann 1986)
@ = symbol for a combination of +, x and .

APPENDIX

MEASURED C-VALUES

**The values should not be copied and used in other areas without considering the particular growing conditions for the reported experimental fields.**

| Plants and management conditions | | C-values |
|---|---|---|
| Bare soil | | 1.00 |
| Dense forest or crop in thickly straw covered field | | 0.001 |
| Savanna or prairie in good condition | | 0.01 |
| Overgrazed savanna or prairie | | 0.1 |
| Cover plants of slow development (in plantation) | first year | 0.3 - 0.8 |
| | second year | 0.01 - 0.1 |
| Cover plants of fast development (in plantation) | (first year) | 0.01 - 0.1 |
| Maize, sorghum, millet (depending on yield) | | 0.4 - 0.9 |
| Rice, intensive cultivation, from second cycle | | 0.1 - 0.2 |
| Cotton, tobacco (second cycle) | | 0.5 - 0.7 |
| Groundnuts (depending on planting date and yield) | | 0.4 - 0.8 |
| Cassava or yam (first year) (depending on planting date) | | 0.2 - 0.8 |
| Palmtree, coffee, cocoa, with cover plants | | 0.1 - 0.3 |
| Pineapple on contour | - burned residue | 0.2 - 0.3 |
| | - buried residue | 0.1 - 0.3 |
| | - surface residue | 0.01 |
| Pineapple and tied ridging (slope 7%) | | 0.1 |

(Roose 1975)

| | |
|---|---|
| Forest duff | 0.001 |
| Pastures,humid region or irrigated | 0.001 |
| Range or poor pasture | 0.05 - 0.10 |
| Grass/legume hay land | 0.05 |
| Lucerne | 0.10 |
| Orchards, vineyards, with cover crops | 0.20 |
| Wheat, fallow, stubble, not burned | 0.60 |
| Wheat, fallow, stubble, burned | 0.75 |
| Orchards, vinyards, clean tilled | 0.90 |
| Row crops after fallow | 1.00 |

(Penman 1963:27)

| Crop | Stage description | Duration | Soil Loss Ratio |
|---|---|---|---|
| Yam | 1. Land preparation to planting | 2 mo | 0.7 - 0.6 |
| | 2. Planting to closing | 4-5 mo | 0.6 - 0.5 |
| | 3. Closing to full cover | 2-3 mo | 0.5 - 0.4 |
| | 4. Full cover to harvest | 4-5 mo | 0.4 - 0.2 |
| | 5. Harvest to land preparation | 2-3 yr | 0.2 - 0.1 |
| Vegetables | 1. Land preparation to planting | 1 mo | 0.7 - 0.6 |
| | 2-3. Planting to full growth | 3 mo | 0.6 - 0.4 |
| | 4. Closing to full cover | 1 mo | 0.4 - 0.1 |
| | 5. Full cover to harvest | 1-3 mo | 0.2 - 0.1 |

## APPENDIX SOIL COVER

| | | | |
|---|---|---|---|
| Pigeon peas | 1. Land preparation to planting | | |
| | a) Minimum tillage | 2 wk | 0.4 - 0.3 |
| | b) Complete ploughing | 1 mo | 0.8 - 0.7 |
| | 2. Planting to 2-3 months | | |
| | a) Minimum tillage | 1-2 mo | 0.3 - 0.2 |
| | b) Complete ploughing | 2-3 mo | 0.7 - 0.6 |
| | 3. 2-3 months to harvest | | |
| | a) Minimum tillage | 1-2 mo | 0.2 |
| | b) Complete ploughing | 2-3 mo | |
| | 4. Harvest to land preparation | 1-6 mo | 0.2 |
| Coffee, sun-grown | | | |
| | 1. Land preparation to planting | 1 mo | 0.4 - 0.3 |
| | 2. Planting to 2 months | 2 mo | 0.3 - 0.1 |
| | 3. 2 months to first harvest | 21 mo | 0.1 - 0.05 |
| | 4. First to second harvest | 12 mo | 0.05 |
| Coffee, shade-grown | | | |
| | 1. Land preparation (hoeing, shade control) | 1-2 mo | 0.3 - 0.2 |
| | 2. Planting to 2 months | 2 mo | 0.2 - 0.1 |
| | 3. 2 months to first harvest | 21 mo | 0.1 - 0.05 |
| | 4. First to second harvest | 12 mo | 0.05 |
| Pastures, non-irrigated. | | | |
| | 1. Land preparation to planting | | |
| | a) Minimum tillage | 1 wk | 0.4 - 0.3 |
| | b) Ploughing and sprigging | 2 mo | 0.7 - 0.6 |
| | c) Furrowing and sprigging | 1 wk | 0.5 - 0.4 |
| | 2. Planting to closing | | |
| | a) Minimum tillage | 2 mo | 0.4 - 0.2 |
| | b) Ploughing and sprigging | 2 mo | 0.6 - 0.2 |
| | 3. Closing to grazing or cutting | 2 mo | 0.2 - 0.05 |
| | 4. Grazing or cutting to full cover, irrigated | 1-2 mo | 0.05- 0.01 |
| Pastures, irrigated. | | | |
| | 1. Land preparation to planting | 2-4 wk | 0.8 - 0.7 |
| | 2. Planting to closing | 2-3 mo | 0.7 - 0.2 |
| | 3. Closing to begin first grazing | 2-3 mo | 0.2 - 0.05 |
| | 4. Begin-end of first grazing | 2-4 wk | 0.05- 0.01 |
| Plantains | 1. Brushing, ploughing to planting | 1 mo | 0.7 - 0.6 |
| | 2. Planting to establishment | 5-6 mo | 0.6 - 0.3 |
| | 3. Establishment to first harvest | 7-8 mo | 0.3 - 0.2 |
| | 4. First harvest to finish harvest | 2 mo | 0.2 - 0.1 |
| | 5. Establishment to second harvest | 7 mo | 0.1 - 0.05 |
| | 6. Second harvets to finish harvest | 2 mo | 0.05 |
| | 7. Finish harvest to rebrushing and ploughing | 2-3 yr | 0.05 |

(El-Swaify a.o.1982:109,110, table 48)

| Type of cover | Soil loss ratio |
|---|---|
| Natural herbaceous cover | |
| - Sahel, Oursi | 0.01 |
| - Savannah, Sakassou | 0.002 |
| - Scanty cover, Oursi | 0.47 |
| Galmi | 0.45 |

| | | |
|---|---|---|
| After burning Sakassou | 0.16 | |
| After traditional land clearing of tropical rainforest, Tai | 0.01 | |
| Mulching | | |
| - millet straw, Loumbila | 0.00 | |
| Pouni, Ferric Luvisol, SCL, | 0.17 | @ |
| Batanga, Vertic Cambisol, SC, | 0.38 | @ |
| - sugar cane residues, Marabadiassa, Ochric Ferralsol, sandy loam | 0.013 | @ |
| - gauze | 0.049 | |
| - pineapple, Adiopodoume, Ochric Ferralsol, loamy sand | 0.0001 | @ |

(Collinet & Valentin 1958, with some additions indicated by @ from: Collinet & Valentin 1984:451-461)

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Crop management factor C for various vegetation covers and locations in India.

| Crop | Kota | Vasad | Kharagpur | Agra | Hyderabad | Rehmankhera |
|---|---|---|---|---|---|---|
| Green gram, Phaseolus aureus | 0.39 | 0.47 | - | - | - | 0.45 |
| Black gram Phaseolus mungo | 0.54 | - | - | - | - | - |
| Ground nut Arachis hypogea | 0.41 | 0.38 | - | - | - | - |
| Ground nut + red gram Cajanus cajan | - | - | - | - | - | 0.42 |
| Soybean, Glycine max. | 0.42 | - | - | - | - | - |
| Cowpea, Vigna sinensis | 0.39 | 0.32 | 0.17 | - | - | - |
| Guar, Cyamopsis psoraioides | 0.59 | - | - | 0.42 | - | - |
| Guar - red gram | - | - | - | - | - | 0.35 |
| Maize, Zea mais | 0.50 | - | 0.35 | - | - | - |
| Jowar, Andropogon sorghum | 0.62 | - | - | - | 0.64 | - |
| Jowar + red gram | 0.33 | - | - | - | - | 0.28 |
| Red gram | - | - | 0.38 | - | - | - |
| Jowar + red gram | - | - | - | - | 0.32 | - |
| Paddy, Oriza sativa | - | - | 0.28 | - | - | - |
| Bajra, Pennisetum typhoides | - | - | - | 0.61 | 0.40 | - |
| Castor, Ricinis communis | - | - | - | - | 0.79 | - |
| Til, Sesamum indicum | - | - | - | 0.51 | - | 0.39 |
| Natural cover | 0.14 | - | - | - | - | - |
| Cynodon dactylon | 0.22 | - | 0.04 | - | - | - |
| Dichanthium annulatum | 0.01 | - | - | 0.13 | - | - |

(Singh a.o.1985:503)

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Range of values of crop cover and management factor C, for pineapple and sugercane fields in Hawaii.

| Crop | Hydrologic Soil Group | Range of C factor values (tillage and time since tillage) Bare soil | Limited cover | Partial cover | Complete cover |
|---|---|---|---|---|---|
| Sugarcane | A | 0.04-0.13 | 0.03- 0.12 | 0.02 - 0.11 | 0.01 - 0.10 |
| Sugarcane or Pineapple | B | 0.10-0.30 | 0.08- 0.26 | 0.06 - 0.23 | 0.04 - 0.20 |
| Pineapple | C | 0.24-0.55 | 0.21- 0.45 | 0.18 - 0.35 | 0.15 - 0.25 |

(Cooley & Williams 1985:515)

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## APPENDIX SOIL COVER

Ethiopia

- barley, sorghum, maize, lentil and peas,
  - . residue left on the fields 0.53
  - . no residue left on the field 0.42
- lentil, peas, maize, sorghum,
  - . no residue left 0.35
  - . residue left on or in the field 0.24
- barley with high residue cover,
  *controlled grazing* for low productivity areas
  - . 40% vegetative cover 0.09
  - . 80% cover or more 0.013-0.00

(Rosenzweig D.: Using the USLE method as a tool for land use classification: the Ethiopian case,
Harerge Highlands; summary of paper circulated at the VI ISCO conference, Sydney, 1992)

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Ruanda

| Crop | C-value | Crop | C-value |
|---|---|---|---|
| Coffee | 0.02 (ground cover) | Manioc/cocoyam | 0.20 |
| Banana | 0.04 | Pyrethrum | 0.20 |
| Banana/beans | 0.1 | Sorghum/sweet potato | 0.20 |
| Harvested field | 0.10 | Peanut/beans | 0.21 |
| Manioc/banana | 0.10 | Potato/maize | 0.21 |
| Not cultivated | 0.10 (weeds) | Manioc/beans | 0.22 |
| Pasture | 0.10 | Manioc/sweet potato | 0.22 |
| Soy beans/banana | 0.11 | Potato | 0.22 |
| Beans/banana | 0.12 | Sweet potato | 0.23 |
| Banana/cocoyam | 0.13 | Eleusine | 0.25 |
| Banana/sorghum | 0.14 | Maize/sweet potato | 0.25 |
| Sweet potato/beans | 0.14 | Manioc | 0.26 |
| Maize/banana | 0.15 | Beans/maize | 0.30 |
| Peas | 0.15 | Maize/beans | 0.30 |
| Sweet potato/banana | 0.15 | Maize/peas | 0.31 |
| Sorghum/cocoyam | 0.17 | Sorghum/manioc | 0.31 |
| Sorghum/banana | 0.18 | Maize/tobacco | 0.32 |
| Cocoyam/banana | 0.19 | Cocoyam | 0.35 |
| Beans | 0.19 | Maize | 0.35 |
| Beans/manioc | 0.20 | Sorghum/maize | 0.53 |
| Beans/peanut | 0.20 | Manioc/quinine | 0.38 |
| Beans/peas | 0.20 | Sorghum | 0.40 |
| Beans/potato | 0.20 | Tobacco | 0.45 |
| Beans/sweet potato | 0.20 | | |

(Lewis 1988: Crop values of C)

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## 10. SOIL CONSERVATION as Central Concept

***Related terms***:
land degradation
soil loss tolerance
yield sensitivity to erosion
vulnerability of productivity

**The use of *land*, within the limits of economic practicability, according to its capabilities and the need to keep it permanently productive.**

a) The term
b) The concept
c) Conservation planning
d) Practices

a) The term

a1) It is a whole program of connected studies, investigations, projects, methods and techniques for remedying, preventing or reducing *soil degradation* in a particular locality or under defined circumstances (Gibbons, pers. com. 1988).

a2) "Soil Conservation" as a term may not be the most appropriate name. An alternative is "conservation farming" which changes the emphasis from *conservation* to farming (Hudson 1988a:3).

a3) The term soil conservation should be de-emphasised or dropped altogether. It holds too many negative connotations in developing countries. In Malawi, a term such as "*land husbandry*" is more acceptable and brings out the integrated farm approach to conservation (Stocking 1985:756).

b) The concept

b1) Soil conservation is part of conservation of the *land:* the protection, improvement and use of *natural resources* according to principles that will assure their highest economic or social benefits for man and his environment now and into the future (Soil. Cons. Soc. Am. 1982:32).

b2) *Soil degradation* is one of the major problems confronting agriculture throughout the world. Deforestation, intense *cultivation* of vulnerable *land, overgrazing,* and poor soil and water management all reduce the productive capacity of soils and pose constraints to increased food, feed, and fuel production (El-Ashry 1988:ix).

b3) The soil conservation objective has been for many years to reduce *soil loss* to a level that will permit a high level of *soil productivity* economically and indefinitely (Wischmeier & Smith 1978).

b4) It aims to maintain or improve the productive capacity of *land,* normally expressed in terms of sustainable crop or pasture yields (Houghton & Charman 1986).

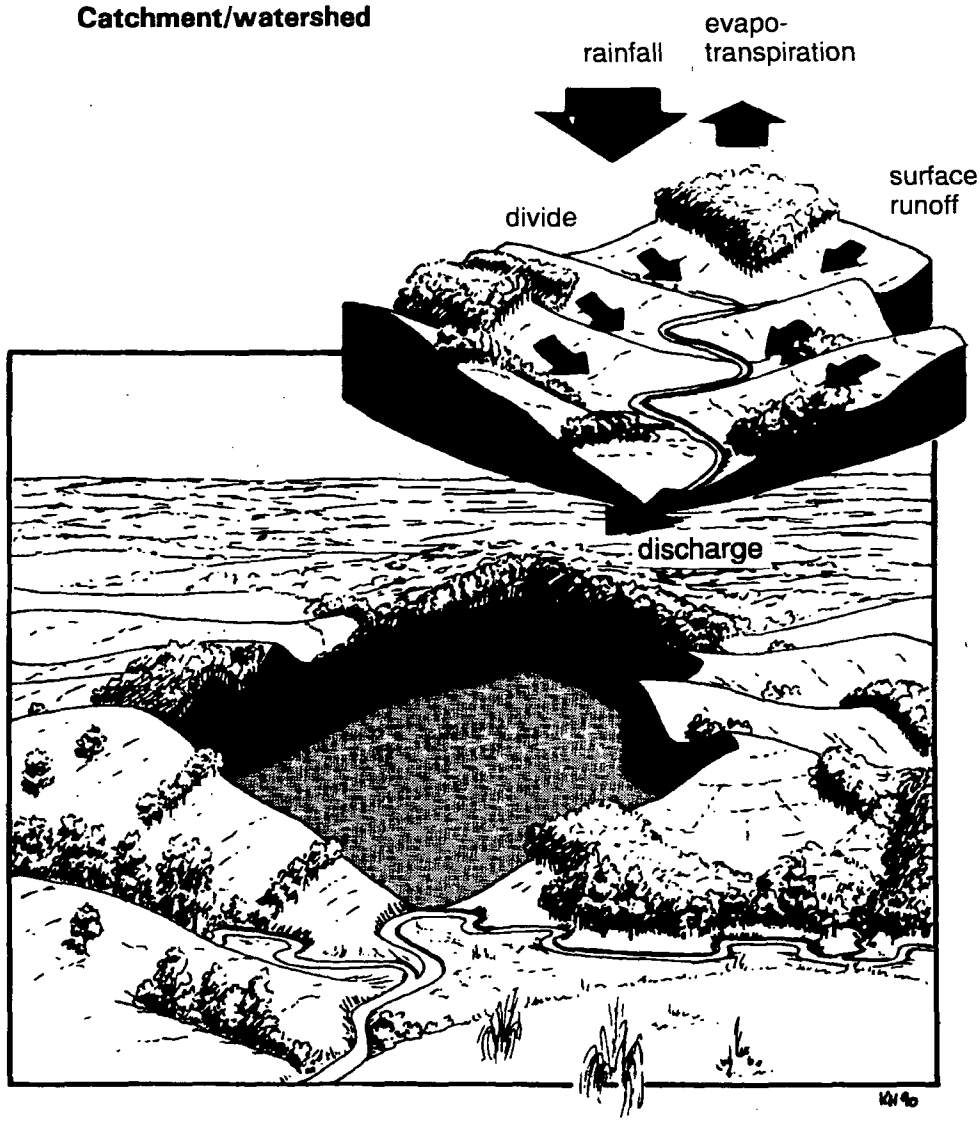
b5) It is aiming to assist farmers in situations of a high *vulnerability of productivity to erosion.*

b6) The decline in *productivity* due to *erosion* is often not very apparent.
- attention is focussed on the amount of *soil loss.* This is however only a very general indication of the need for conservation.
- the process of productivity decline is often slow, and therefore the effects are not striking, except over a long period.
- when a low level of productivity has been reached, as in the most vulnerable parts of the world is often the case, the hazard for a further decline is low.
- technology can obscure the effect of erosion on yields. *Inputs* of fertiliser, new varieties obtained by plant breeding, improved cropping systems and tillage may more than compensate for the effect of erosion.
- erosion-induced loss in productivity goes by other names. Drought for example may not be the same as a lack of rainfall, it may be a name to indicate a lack of available water in the soil at the time of plant growth. Part of the lack of moisture in the soil may be due to erosion of the water-holding *topsoil.* Other names are poor farming, infertile soils. These names may result from a wrong analysis of the causes of lower productivity. In that case they even may divert attention from the real cause of food shortage (Stocking & Peake 1987).

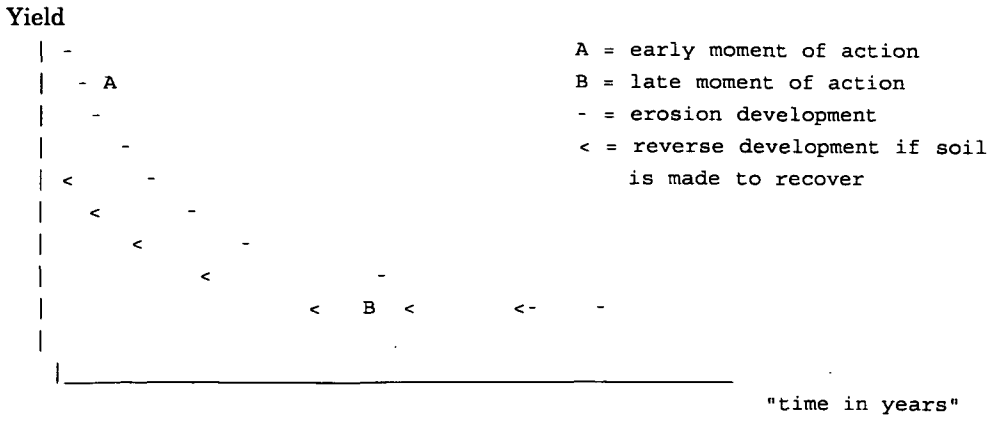
b7) Two criteria for soil conservation are proposed, one pedological and the other social (Flach & Hytry 1987:4-7):
The pedological criterion is maintaining the quality of the surface soil.

The social criterion is considering the onsite and offsite cost of *erosion* in relation to the cost of erosion prevention and the price the society is willing to pay to protect the soil resource for future generations. For the quality of the surface soil, the organic matter content can be a useful parameter. However, undesirable properties of subsoil *horizons* may have to be taken into account.
The cost of erosion may be found in the increasing cost of fertiliser to compensate for loss of *productivity*. Rooting limitations may become more severe, and cost of soil improvement may be considered.
Offsite costs of erosion are related to the sensitivity of streams, lakes or reservoirs to suspended soil particles and pollutants.

b8) There is a great need for more research into the relationships between *erosion* and *productivity*, and the impact of these relationships on the soil, on farming practices, on the cost of production and the cost of erosion (Stocking & Peake 1987). The TREND OF PRODUCTIVITY DECLINE will change with time, the curve is steep when the fertile *topsoil* is lost, and much less steep when *subsoil* or substratum is lost by erosion.
When productivity is raised by conservation practices that stop erosion and cause new soil to form, the same curve will not apply. Restoration of productivity will not take place to levels that existed before, only a lower level can be reached, with much effort.



Stocking & Peake (1987) show in this way that prevention is cheaper than curing the effect of erosion and trying to recover productivity after it has been lost.




Implications (Stocking & Peake 1987):

1) The *erosion yield* relationship is generally exponential in form. If a deep *topsoil erodes,* the upper part of the curve may be flat to gently convex before it steepens to the pronounced concave shape.

2) Concentrate soil conservation resources at point A, potentially there is the greatest impact on "saved yield".

3) At point B a minimal impact on yield is obtained by even a large saving of soil, at a cost of a large amount of input.

4) Working on the principle of point A means helping those areas which already have substantial farming advantages. This may be unacceptable as a policy.

5) A severe loss in yield will occur when an area with little prior *erosion* is allowed to become *eroded.*

6) There is little additional loss in yield for an area that is already at the quasi-level state of low *productivity.*

7) Investing conservation resources in areas that are already severely degraded will result in a very small positive impact on yield, against a substantial input. When further *erosion* would be tolerated, no input is used, and the further loss in yield is almost negligible.

8) Investing conservation resources in areas that have suffered only minor *erosion* will result in a greater proportional protection of yield than is recovered by the same input after having allowed the *land* to become seriously eroded.

b9) The feeling that *land* is plentiful and *soil erosion* is not a serious problem has changed rapidly into a greater awareness of *soil degradation* and interest in soil conservation. There are a number of reasons for this change in attitude (Sanders 1988a):

- soil erosion and other forms of *land degradation* are now so far advanced in many countries that their effects are obvious even to a casual, untrained observer.
- many of the large *dams* that have been built in the 1960's and 1970's are silting up much more quickly than expected because of the high rates of soil erosion in the *catchment* areas.
- the effects of drought in Africa over the last decade are now being closely linked with *soil degradation.*
- the worldwide interest and publicity given to environmental matters over the last 10 - 20 years are now having their effect, and the public at-large is now much more aware and interested in the protection of the environment than ever before.

Turning this interest into effective programs is not an easy task however (Sanders 1988a:54-55).

Three FAO projects with an important soil conservation element are discussed with comments on what can be learned from them. They are located in Jordan, Ethiopia and Lesotho (Sanders 1988a:56-60).

b10) The prime OBJECTIVE OF SOIL CONSERVATION (Stocking 1985:753) is to provide for the permanent maintenance of the soil's productive potential. Secondly, to provide a good, and, one hopes, improving living standard for people.

Three criteria may be adopted for final choice:

- EFFICIENCY: Does the approach conserve soil, not necessarily in the most efficient manner, but at least in meeting an interim objective of saving soil and maintaining fertility ?
- ACCEPTANCE: Is the approach broadly capable of being integrated into farming systems, and is it acceptable sociopolitically, culturally, and technologically ?
- COST: Are extra resources needed ? Are they cost-effective ?

b11) In the USLE the factor combination CP determines the effectivenss of a soil *erosion control* measure. It could be expressed as:
R x LS x K x CP (total soil loss) / R x LS x K (the product of certain *factors).*
In situations when the CP cannot be made sufficiently low, practices have to be considered that will modify the LS effect, such as *bunds* and *furrows* (Hurni 1981:188).

b12) "The time has come for all concerned, be it in research, institutions of higher learning or agricultural extension, to shift the emphasis from structures alone to a combination of biological/cultural and appropriate physical measures. The role of physical and biological measures should be complementary in nature. More consideration should be given to the effectiveness of *contour* planting, grass strips, trash lines, *ridging, strip cropping* and *intercropping* in soil conservation, particularly in fields where ground slopes are gentle and undulating coupled with fairly *erosion resistant soils.*
We have embarked on field studies to investigate the economic, social and technical implications of soil conservation activities at community level."
(Odongo Omamo, Minister for Agriculture and Livestock Development, Kenya, 1989:2).

c) Recommendations and planning

c1) *Soil loss tolerance* may be used as an indicator for the need of soil conservation. There are however several complications: the *soil loss* is not always a good indicator of land damage, and therefore is sometimes abandoned as a criterion for planning.
On the other hand soil loss may be low on the uphill areas, but the accumulated effect off-site may be damaging.

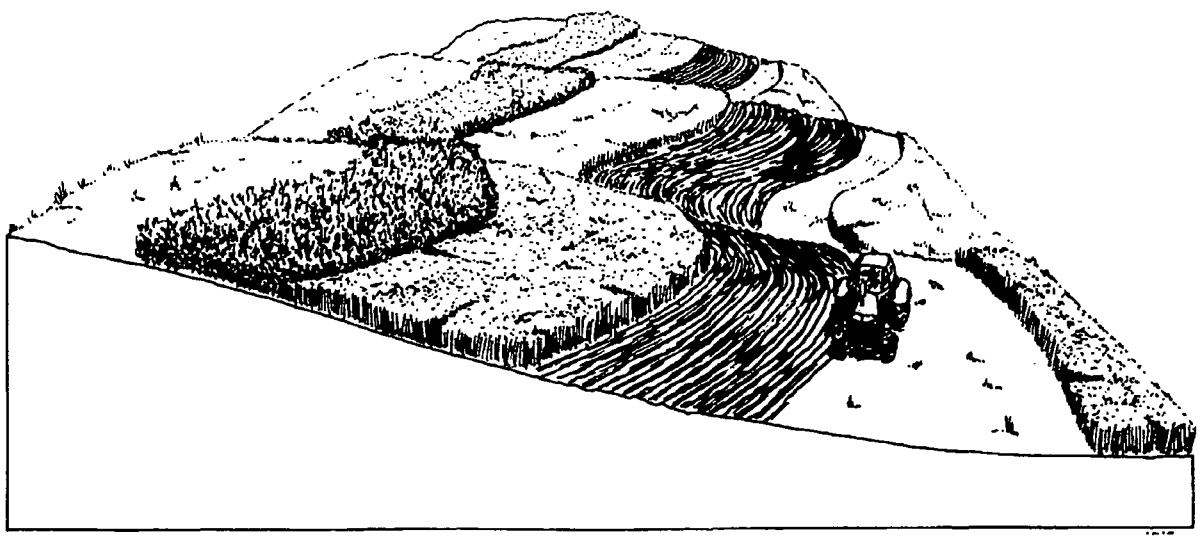
c2) Soil conservation is especially useful for conditions with soils of a high *yield sensitivity to erosion.*

c3) *Vulnerability of productivity to erosion* gives a correction on the ranking of hazard above *tolerance* as a basis for a soil's priority for *conservation.*
Soils with shallow layers/horizons that affect growth negatively, will have a high vulnerability, and therefore qualify for high priority of *conservation input.*

c4) Recommendations have a better chance of being adopted if they are seen to assist rather than hinder the overall aims of the land user. Four examples are given (Shaxson 1985:670):

1. Tea estate owners in Malawi readily adopted the layout of tea fields on the *contour,* along with interrow microcatchments, strip *mulching,* and roads aligned along crests and shallow gradients on a catchment pattern, when it was shown that the cost of production per kilogram of tea could be cut by a significant amount. Cost reductions resulted from less maintenance on roads and *contour banks* and reduced costs of repairing erosion damage, compared with traditional square layouts.
2. Tobacco farmers in central African countries adopted a closer-than- essential spacing of graded terraces in contour planted fields because the arrangement allowed more effective and precise management of the crop at all stages. But it also provided added erosion protection in a cropping system that otherwise brings about serious soil degradation.

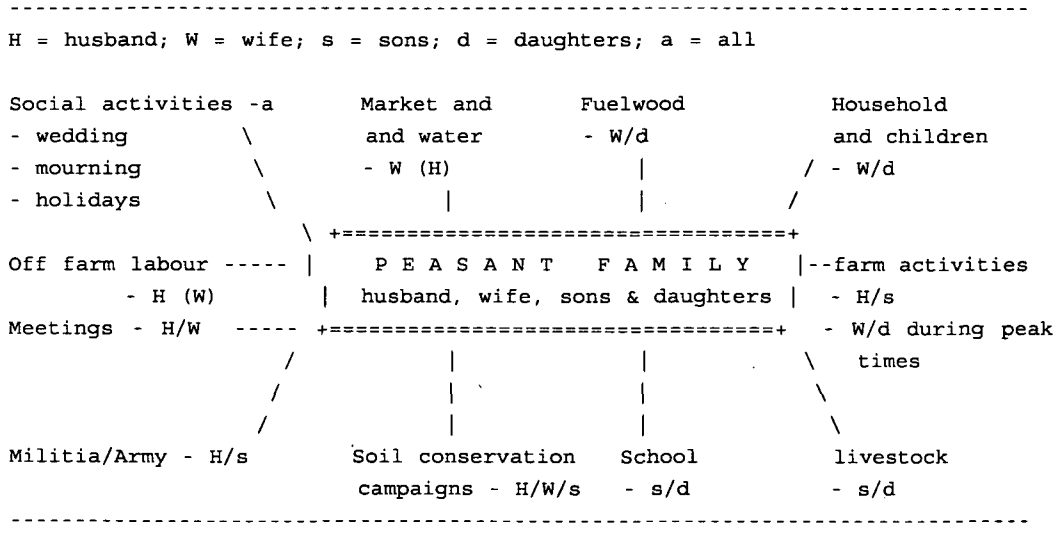
Contour strip cropping



3. Direct planting of soya and wheat has been adopted by many farmers in southern Brazil because such a system allowed more flexibility in planting dates. The conventional system requires time-consuming cultivations that often delay planting beyond optimum dates. Farmers also noticed marked reduction in erosion.
4. Small farmers in central India enthusiastically adopted recommendations for more productive cropping practices, based on using improved seed, optimising planting dates, and fertilisers. Extension agents were delighted with the response to their efforts, farmers were pleased with better production, and conservationists were gratified at the reduced *erosion* that followed the significant increases in crop canopy and *rainfall energy interception*.

c5) The attitude of the adviser, who may be the extension officer, the professor, the official, the expert, is as important as that of the land user (Bergsma 1987:1200; 1989).
The understanding of the local conditions, the constraints of the farmer, his outlook on life, are all important. An example of the many relationships between farmer's activities and the plant and land management and the attention given to conservation, is shown in a scheme developed for Ethiopian conditions of small scale farming (Herweg 1992:410):

GENERALISED LABOUR AND ACTIVITY DIVISION ON A SMALL ETHIOPIAN FARM




c6) Discussing the *erosion productivity conservation* systems in Ethiopia, it is important to note that the greatest resources at hand are the Ethiopian peasants themselves, whose workforce will have to be utilised through better motivation. A deep dedicaton towards natural resource conservation and development can be observed at all levels, and deserves support from assisting agencies (Hurni 1987: 654-674).

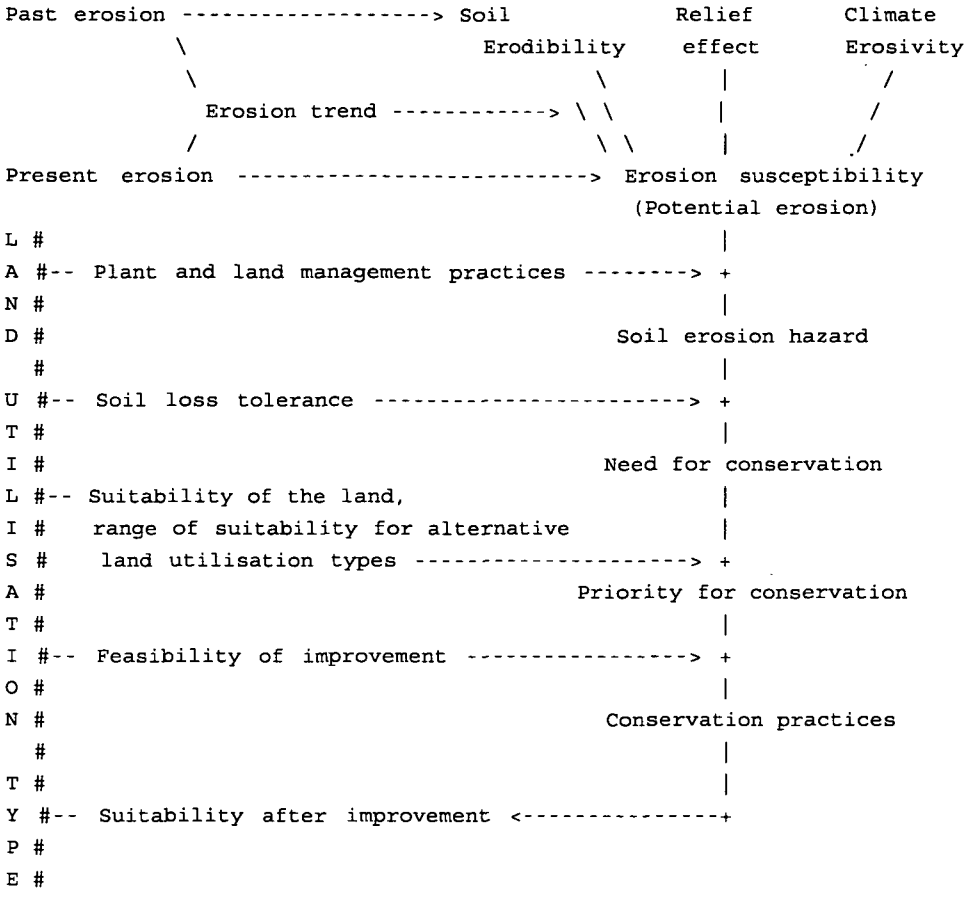
c7) Proposals that are most effective and most readily acceptable in controlling *erosion* are those that are:
1. site specific, to take account of the unique combinations of physical characteristics of each individual property, and
2. person-specific, to take account of the unique complex of wishes, resources, and abilities of each individual farmer (Shaxson 1985:671).

c8) General order of steps from erosion surveys to conservation planning.
(modified from Bergsma 1989).

## STEPS IN CONSERVATION PLANNING

*ATTENTION:*

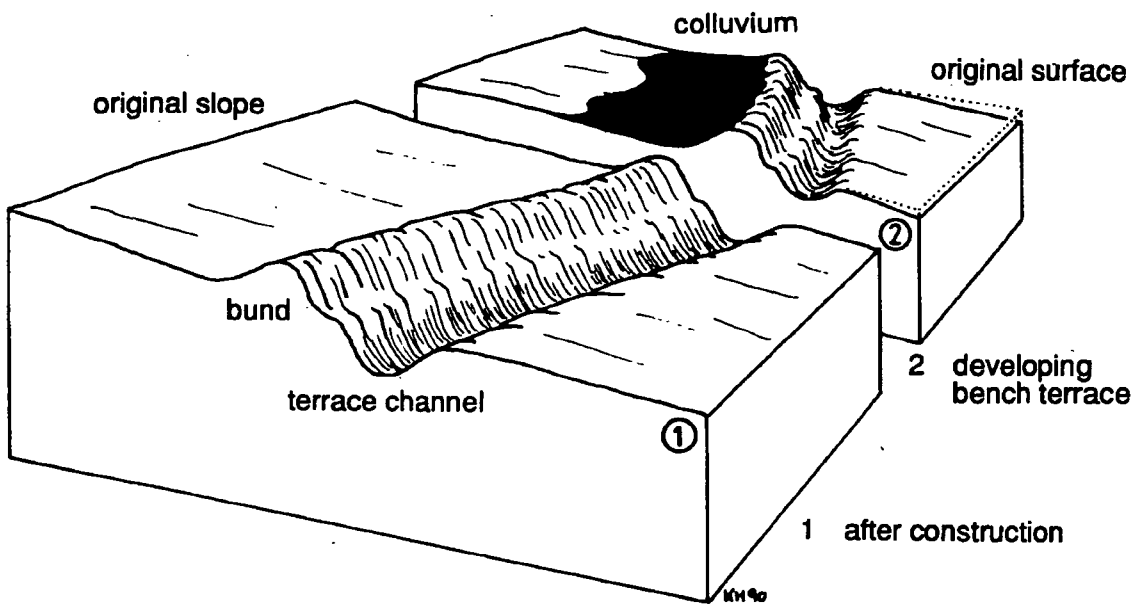
*What is the farmers need ? Is it electricity? Is it new roads ?*
*Or is it soil conservation ?*
*What is his aim, optimising production ? minimising risk ?*
*securing perhaps an amount of leisure ?*




c9) There seems to be no one factor that can be singled out as the key to successful soil conservation program. Success generally can be attributed to a combination of factors that have led land users to adopt and then continue conservation practices. Among these factors are the following (Sanders 1988 a: 60-62):

- the adoption of conservation practices appears to depend at least as much on socioeconomic factors as on physical effectiveness of the practices.
- farmers and other land users need to be involved from the start in planning conservation schemes. This involvement must be genuine, including full explanations of what is possible, consultations, and negotiations of agreements.
- farmers will only adopt and continue conservation methods if they can see some direct benefit in doing so for themselves and their families in the short-term. These benefits are most likely to be in the form of increased yields, higher incomes, or the reduced need for some input, such as labor. Farmers in the Kitui area of Kenya are now terracing fields at their own expense and without the need for much encouragement by the government. The *terraces* effectively prevent *soil erosion,* but they also lead to yield increases on the order of 40 to 90 percent.
  Appeals to land users to adopt conservation programs for such reasons as national interest, the protection of downstream *dams,* or the need to save soil for future generations are not likely to have lasting effects.
- land tenure systems also influence whether land users will accept conservation practices. Farmers see no point in investing in conservation works on *land* to which they have no assured long-term rights or control. Many farmers in the Machakos district of Kenya have been building *terraces* on their fields in recent years - at the same time that they are being granted legal title to the land. On the other hand it is

Fanya Juu




understandable that farmers in Lesotho have shown little interest in leaving protective *crop residues* on their fields when they know that anyone can bring animals to graze them once the grain has been harvested.

- the conservation practices and techniques advocated must be practical and appropriate to local conditions. In Kenya, the *fanya juu terrace,* a modified form of *contour terracing,* has been developed to suit local conditions. The conservation practices advocated must be within the technical capabilities of field staff and farmers to apply. Therefore, systems that require complex engineering designs and layouts are not practical in circumstances where large areas must be treated and where field staff are few and their training limited. - implementing soil conservation programs can be expensive in time and labor. A combination of incentives, subsidies, and disincentives are required to induce land users to take up soil conservation on the necessary scale. In recent years, food aid has been extensively used in a number of developing countries to encourage farmers to install physical *erosion control* structures. However, the use of incentives or subsidies must be carefully thought out, planned, and implemented, or the inducements may become counterproductive. Farmers can easily become dependent upon subsidies or refuse to do even maintenance work if they are not paid.
- experience indicates that conservation can only be achieved if governments are committed to seeing through long-term programs. Short-term project approaches have met with little success. It has only been through long-term programs, supported by the necessary legislation, staff, finances, and facilities, that worthwhile achievements in conservation have been made (Sanders 1988a:61).

c10) The strategy for soil conservation is discussed by Hauck, with its underlying principles, times for action at the national level, types of local initiative and FAO's activities (Hauck 1985:724).

c11) The program of soil conservation has consecutive stages, each involving the cooperation of two or more of three groups of people, viz. the land-managers, the extension workers and the investigators/researchers (Gibbons 1988; Perrens & Trustrum 1984).

c12) Some important stages of the program are (Gibbons 1988):

c12.1) Problem identification: In terms of current rate of change in severity and extent of defined types of *soil degradation,* preferably expressed quantitatively, and put in relation to land type and to land capability assessment. For example: a soil loss of x ton/ha/yr on y ha, or x % of y ha is affected each year by z grades of salinity.

c12.2) PROBLEM ANALYSIS. Three common substages are:

a) process study for determining the basic causes for the *degradation*

b) site investigations for determining the local manifestation and status of those processes, in relation to land type and land capability

c) determination of which factors and their correlations are locally most important for contributing to the *degradation,* so as to identify the chief requirements and kinds of action for an effective solution.

c12.3) STRATEGY, PLANNING and EXECUTION of works:

a) The strategy is a particular combination and sequence of practices to achieve a solution. Different strategies are often possible, with different effectiveness and *benefit/cost ratios.*

b) It is important to estimate the short term and long term economic feasibility of each strategy, because the strategy cannot be applied by the land manager unless it is economically feasible in the short term and should not be financed by the community unless it is economically beneficial in the long term.

c) Not all conservation practices are economically beneficial in the long term although many are. Still fewer practices are economically beneficial in the short term, although some may be so. The aim is to determine and select those which are so.

d) The economic benefits of particular practices and strategies vary according to circumstances of application and it is unwise to make general predictions about their economic consequences.

c12.4) REVIEW and MAINTENANCE:

a) The strategic works planning and works execution aspects should be considered also from the point of view of review and maintenance. Strategy and planning may be adequate, but the program may yet be ineffective because the works have not been executed properly.

b) The degree of success of measures of soil conservation, or their effectiveness, may be estimated, such as by the degree of *cover* that is established. This is most easily done, but it is less reliable information.

c) The effectiveness may also be measured in the field, by the change in the degree of *soil degradation,* for instance the lower *soil loss* in tons/ha/yr after the measures have been taken. These data are more difficult to obtain, but they are more reliable information.

c13) Direct feedback from the experiences of technicians, during program implementation, to research allows better practical guidelines to improve soil conservation (Hurni 1989:15).
Classification for recommended conservation measures can benefit from agro-ecological principles. Agro-climatic zones may be recognised based on crops, traditional conservation, soils, and natural vegetation. Conservation measures are then recommended according to *land use,* steepness, *soil texture,* local context, soil depth, and degree of *degradation* (Hurni 1989:18).
For a given ecological situation, options for conservation are proposed for the development agent, who is requested to discuss these options with the land users concerned. It should be only with their agreement that a certain conservation activity is selected and implemented. The approach is a mix of top-down and bottom-up. Guidelines for development agents can include drawings to describe practices (Hurni 1989:16-18).

c14) Planning for grazing in dry areas needs special considerations (Barrow 1989). We must realise, and at present we do not, the value of existing land management strategies as a basis for long-term development. Otherwise existing development initiatives in such dry areas will only exacerbate the problem and cause an increased level of *soil erosion,* hardship and famine-relief dependency. The traditional value of trees and the roles that they play and people's ownership rights to them must not only be realised but respected. The traditional knowledge base should be used as a building block to development, and not seen as a hindrance as is often the case. For instance, flexibility and mobility of livestock grazing and herding must be recognised as the priority. Security of tenure should be increased, based on existing grazing patterns, which incorporate both wet and dry-season grazing areas, combined with substantial areas of reserved grazing (Barrow:1989:481-482).
The people should be helped to analyse their own problems and find their own solutions. Solutions brought or imposed from outside are less likely to be implemented (Barrow:1989:485).
Improvements can be made, for instance in the browse regime, by plantings, particularly in the existing settled areas, to ensure both a browse and fuel supply for the people associated with the settlements (Barrow 1989:481,482).

c15) Planning soil conservation requires in most instances a community or COOPERATIVE ACTION. The size of the farmstead most often does not allow the individual farmer to have an impact on the process of *land-degradation.*

This must be undertaken on a *watershed* basis, as a concerted action where all efforts reinforce and complement each other. Also some *erosion* and flood control measures may be within the reach of the individual farmer, but on larger undertakings the support of government is called for. At all times farmers should be closely involved in the planning and execution of field programs (Dudal 1981:10).

c16) Soil conservation structures have to be selected on the basis of their feasibility, effectiveness and rentability. *Cultivation systems* have to be profitable and sustainable.

c17) "It is in the SOCIAL AND ECONOMIC ENVIRONMENT that the reasons for the failure of soil conservation schemes all too often lie" (Morgan 1981a)

c18) The costs of avoiding loss of *soil productivity* by reducing *erosion* must be compared to the cost of productivity compensating technologies (Crosson 1985:235).

c19) Guidelines for soil conservation planning in Ethiopia are demonstrated by Hurni (1988:43).
There are three steps:
- choice of agro-climatic zone
- planning on a selected slope. Option packages of practices depend on *soil texture* , steepness, maintenance
required, input required, farmers preference
- execution of the selected package of practices.

c20) The land user will be convinced about soil conservation practices if these will minimise risks, increase income or make yields more reliable, and/or reduce *inputs* of money or labor (Sanders 1988b:277).

c21) The need for flexibility in a project is important. It was suggested that any project should frequently and regularly review its own progress and then change and adapt its program as it proceeds. Such a procedure implies a built-in system of monitoring and evaluation (Sanders 1988b:278).

c22) Questions to farmers should be carefully phrased to avoid bias in the answer. Questions used in a survey of farmers understanding of *erosion* processes and their attitude towards conservation in North Thailand provide an example (Harper & El-Swaify 1988:84).
Questions were used such as: where did you learn about soil erosion ?
Answers include:
- direct observation
- from neighbours
- from TV or radio
- project or government
- other source

c23) Soil conservation planning in conditions of sourthern Mali takes the following considerations into account (Hallam & van Campen 1987):

a) - fields often have a form not suitable for *contour farming.* Yet the boundaries have to be respected.
- *bunds* that were used in some projects often lead to breakthrough and subsequent severe *erosion.*
- the need for permanent maintenance has to be low.
In view of these conditions vegetated strips are recommended, and they will become stronger over the years, while bunds become weaker.

b) In the planning of conservation, emphasis is given to the relationship between parts of the slope, independent landscape units do not exist.

c) In planning conservation together with the villagers, not one practice but several options are presented, so that the farmers can make a choice according to their current priorities and capabilities.

d) To get all farmers involved in the learning process, the plans have to be discussed in general meetings of the village association. They decide on the priorities for the village.

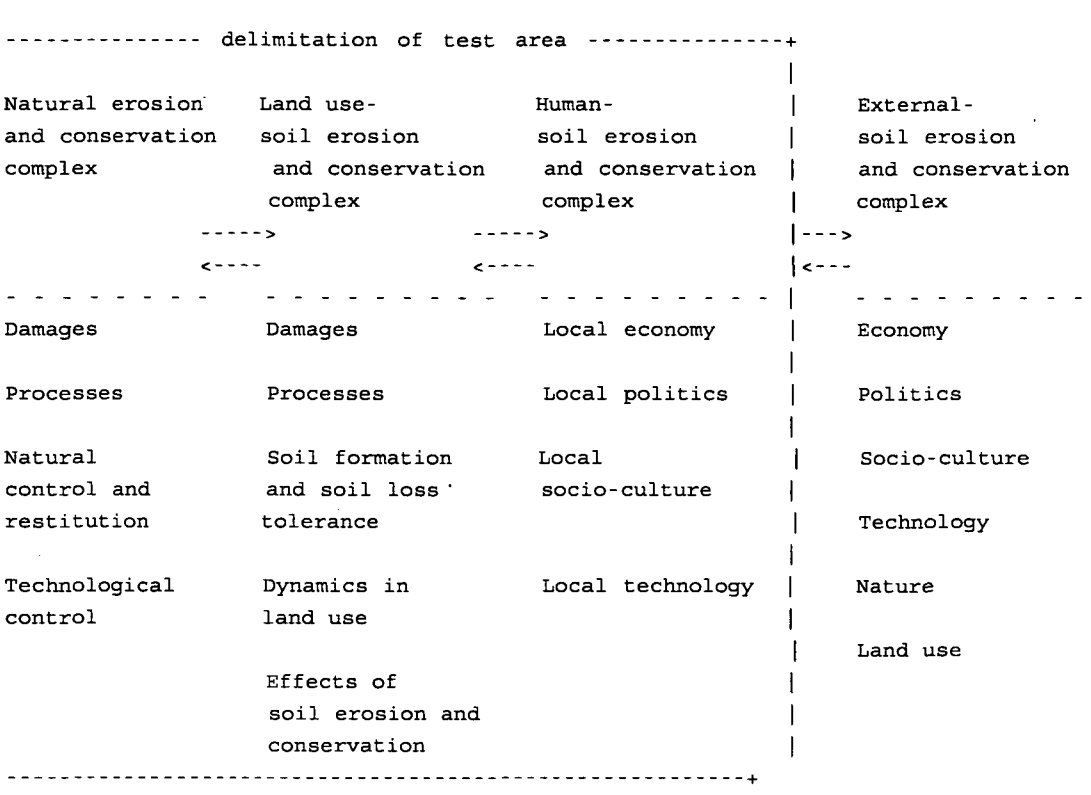
e) The plan is a multi-year program so that the discussion and explanation in the village will continue over the years.

f) To avoid that *soil degradation* and *soil erosion* are considered only as *runoff* problems, which would have nothing to do with the *farming system* as a whole, a strong cooperation between farmers, researchers of farming systems and extension services has to be maintained.

d) Practices

d1) Practices are related to the natural conditions of the area. The *ecosystem* for conditions of Ethiopia (Hurni 1989:11) can be represented as:

AN ECOSYSTEM FRAMEWORK OF SOIL CONSERVATION




d2) *Soil surface roughness*, vegetation and water storage volume in the upper soil are components of the *soil erosion* system that have very great influence and are most easily controlled by man (Thornes 1981:267).

d3) The effectiveness of a measure of *erosion control* is judged by the ratio of *soil losses* from a cultivated to a *bare fallow* plot, see for instance Ngatunga et al.(1984).
Another example is Chisci (1981:170), where he shows the most critical conditions, and compares this *erosion susceptibility* with a reference of erosion under forage as a control. He then shows the effect of several tillage practices in relation to *erosion susceptibility* and forage sod control.

d4) Agricultural benefits or on-site benefits are (Wiggins 1981:402):
- the prevention of falling yields per hectare which would otherwise result from the loss of *topsoil*
- an initial rise in yields consequent on implementing the works such as the use of *mulch*, owing to less fertiliser being washed out, increased soil moisture and improved *soil structure*
- a slow, gradual increase in yields as new topsoil develops on protected *land*.

Off-site benefits are:
- *sedimentation* control, preventing loss of capacity of a damsite,
- reducing of flood damage
- reducing aggradation of stream and riverbeds (Moldenhauer pers. com. 1989).

d5) *Cover* management is very often the most important influence on *erosion hazard*, and often it can be used to some degree for *soil conservation*.
*Crop residue mulch* applied at a rate of about 10 t/ha/yr reduced *soil-loss* on slopes by up to 15 percent. The mulch also helped to maintain organic matter content, improve soil physical properties, and maintain *soil productivity* (Suwardjo & Sofijah Abujamin 1985:613).

d6) In conditions where agricultural *land-use* can be combined with the growing of trees, *agroforestry* techniques may be employed.

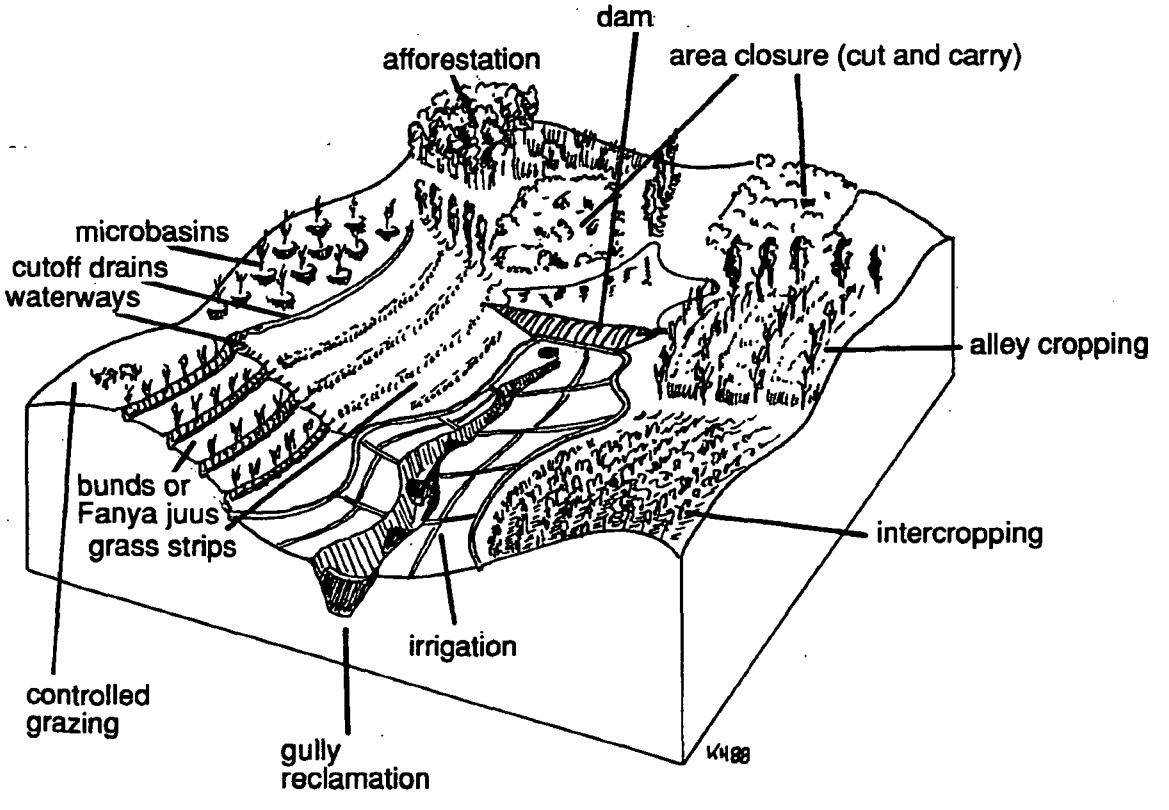
d7) In semi-arid regions it is difficult to counteract *soil loss* by vegetative *cover* (Bennema & de Meester 1981).

d8) *Soil conservation practices* for steep *lands* (Hurni 1988:39) are very important. Possibilities for improvement are discussed for aspects of:
- *land use* - *slope length*
- ground *cover* - soil properties
- land management - slope *gradient*

d9) The main practices that are recommended in conditions of Mali (Hallam & van Campen 1987) are the *permeable* microdams and the *progressive* terracing method. They are better and less harmful than the *diversion terraces* that are often suggested.
These practices are:
Local stones are laid along the *contour*. They form a permeable microdam. Soil will deposit at these lines, even when the *overland flow* can pass through the gaps. Gradually a *terrace* will grow as a *colluvial step*.
The advantages are:
- they are simple and cheap
- the terraces are built naturally, progressively, without additional work for the farmers
- the microdams being numerous, low and permeable, they offer no risk during catastrophic events of intensive showers. Excess water that had not infiltrated and was not stored in the field (*tied ridging*) may flow over the grass protected *embankments*.

The size of the fields may be subdivided by the colluvial steps. Hallam & van Campen met conditions where the field boundaries were accepted. There the micro-dams are useful, but the gradual growth into colluvial steps may be a disadvantage that has to be avoided. In the conditions that Roose (1987) describes, long fields along the *contour* are advocated, having a constant width to allow mechanised and really intensive agriculture. The field length can reach 200 to 400 metres.
Another consideration in the application of these practices is the soil depth. If *erosion* and cultural practices bring progressively the soil down the cultivated strips, the depth of the arable layer will increase in the lower part, but decrease at the upper part. One can compensate for the loss of nutrients and organic matter in the upper part. However when rocks appear at less than 50 cm, *cultivation* practices must be made to move the soil upward again and keep an evenly deep *topsoil* (Roose 1987:633).

Soil and water conservation practices



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## 11. AGROFORESTRY as Central Concept

***Related terms:*** alley cropping = hedgerow intercropping

**The integrated land use that involves deliberate retention or admixture of trees and other woody perennials in spatial or temporal association with crop- or grazing-land to benefit from the natural ecological and economic interactions.**

a) The term
b) The concept
c) Components and practices of systems
d) Erosion reduction
e) Other applications
f) Modelling
g) Handbooks

a) The term

a1) Agroforestry is a collective name for *land use systems* and practices where woody *perennials* (trees, shrubs, palms, bamboos, etc) are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence (Lundgren & Nair 1985:704).

b) The concept

b1) Nearly all agroforestry takes place on agricultural land: "it is planting trees on farms" (Young 1989).

b2) In agroforestry there are both ecological and economical interactions between the different components (Lundgren & Nair 1985:704).

b3) A strict scientific definition of agroforestry should stress two characteristics common to all forms of agroforestry and separating them from other forms of *land use,* namely (Lundgren 1983:7-12):
- the deliberate growing of woody *perennials* on the same unit of *land* as is used for agricultural crops and/or animals, either in some form of spatial mixture or in sequence.
- there must be a significant interaction (positive and/or negative) between the woody and non-woody components of the system, either ecological and/or economical.

b4) The ecological interactions between trees and crops, acting through the microclimate, and the sustaining of soil fertility, are the most distinctive features of agroforestry. Trees improve the soil fertility by maintenance of organic matter (*litter,* prunings and root residue), nitrogen fixation, uptake and recycling of nutrients, and other processes.
Where forage crops are produced together with the establishment of the forest, only cutting of forage and feeding outside the area should be permitted. The removal of litter for burning or composting must be prevented (FAO 1977:101-103).
Certain trees may halt or reverse *soil degradation* by fertility enhancement properties, for example Acacia senegal and Acacia albida in the semi-arid zone. Prosopis species also have a demonstrated capacity to improve soil fertility in semi-arid to dry savanna regions (Young 1987).
*Cover crops* such as in rubber, coconut and oil palm estates in Malaysia reduce weeding costs, decrease soil temperature, maintain *soil structure,* organic matter content and fertility. Disadvantages are: twining plants may damage the permanent crops, there is an increased risk of fire and there is a danger of harbouring diseases and insects (Bunting & Milsum 1927, quoted in Lal 1977:207).



*Strips of lemon grass in an agroforestry system of coffee, upland rice and trees, Northern Thailand (photo H. Hurni).*

b5) The ECONOMIC INTERACTIONS refer to a widening of the range of products for cash or subsistence, by means of multipurpose trees such as fuelwood and fruit (Young 1989). A combination of forestry and agriculture can also be connected with forage production for animal feeding (FAO 1977:101-103).

b6) *Inputs* to be provided for the introduction of agroforestry are: tree seeds or seedlings, establishment and management of nurseries, training of extension staff and farmers, and some research. When the cooperation of the farmers is obtained, agroforestry systems are highly cost effective (Akachuku 1985; Young 1989:1017).

c) Components and practices of systems

c1) An agroforestry practice is an arrangment of components (trees, crops, pasture, livestock, etc) in space and time (Young 1989). Examples are: alley cropping, boundary planting of trees, use of woody *perennials* in soil conservation, tree gardens, woodlots on agricultural lands, etc. (Nair 1985).

c2) An agroforestry system is:

c21) A distinctive local example of a practice, characterised by environment, plant species, management and social and economic functioning (Young 1989). It extends over a locality to the extent of forming a *land utilisation type* of the locality (Nair 1985).

c22) It denotes a type of agricultural or forestry *land use* of the locality, described in terms of its main biological components, level of management, nature of output, and so on (Nair 1985).

c23) It is a type of agroforestry *land use* that is specific to a locality and is described according to its biological composition and arrangement, level of technical management, or socio-economic features (Nair 1985).

c3) The agroforestry systems and practices can be grouped according to (Nair 1985):

= the structure (components and arrangement of components):
- agri-silviculture: crops including shrub/tree crops and trees
- silvo-pastoral: pasture/animals and trees
- agro-silvo-pastoral: crops, pasture/animals and trees and other specialised systems such as:
  . apiculture with trees
  . aquaculture in mangrove areas
  . multipurpose tree lots, etc.

= the arrangement of components in time or space

= the functional basis, referring to the main output and role of components especially the woody ones:
- productive function such as for basic needs of food, fodder, fuelwood, or others
- protective function such as for soil conservation, soil fertility maintenance or improvement

= the ecological basis, for any defined agro-ecological zone such as:
- lowland humid tropics
- arid and semi-arid tropics
- tropical highlands, etc.

= the socio-economic scale of production and level of management of the system:
- commercial
- intermediate
- subsistence

The broad terms used to describe specific systems are usually clear enough to portray the basic nature of the system, for example (Nair 1985):
- rice production system,
- subsistence agricultural system,
- plantation crop system
- mixed cropping system
- maize-wheat rotation system
- livestock production system
- commercial timber production system, etc.

c4) The agroforestry sub-system refers to a part of a system with a more restricted role, content and complexity than the system itself. For instance, sub-systems can be distinguished according to the type and arrangement of their components (Nair 1985). One of the subsystems produces a certain basic commodity as its major output, so that there can be a food subsystem, an energy subsystem, a shelter subsystem, a cash subsystem, etc. (Nair 1985).

c5) Agroforestry systems and practices are being investigated. Research requires time for the trees to grow. Specific research started around 1981 (Young 1989) and an early overview is by MacDonald (1982).

c6) ALLEY CROPPING is a well known form of agroforestry, it is also called "hedgerow *intercropping*". The practice is capable of maintaining soil fertility and crop yields under conditions where control plots under annual crops alone show *soil degradation* and declining yields (Young 1987, Lal 1988).

c7) Main characteristics of some existing agroforestry systems. (in the Pacific Islands, Vergara & Nair 1985):

| System/practice | Country/ territory | Major Component | |
|---|---|---|---|
| | | Woody | Herbaceous |
| AGRO-SILVI-CULTURAL | | | |
| 1. Improvements to shifting cultivation | | | |
| a - Introduction of tree species in the fallow phase | Several countries: Papua New Guinea Solomons | Various fruit trees Incarpus edulis, Morus nigra Spondias dulce Leucaena | Common subsistence crops (tubers, cereals, bananas, vegetables) |
| b - intercropping in tree stands | Papua New Guinea | Leucaena | sweet potato, other tubers |
| | Solomons | Gliricidia + cocoa | food crops |
| | West Samoa | Erythrina | yams |
| 2. Crop combinations with plantation crops | | | |
| a - Integrated production of plantation crops in mixed, dense associations. | Papua New Guinea highlands, Solomons and others. | Cocoa &/ coconut &/ coffee in association with Casuarina oligodon, Gliricidia, Leucaena,etc. | Subsistence food crops |
| b - Shade trees for commercial plantation crops | Many countries | Casuarina, Leucaena, Gliricidia | - |
| c - Intercropping in stands of plantation crops | Fiji, Papua New Guinea, Tonga, Vanuatu, West Samoa | Coconut, coffee | Food crops as banana, papaya, sugarcane, etc. |
| SILVI-PASTORAL | | | |
| Cattle under trees | Fiji, Kiribati, Solomons, Tonga, West Samoa, Vanuatu | Coconuts | Pasture grasses for cattle and goats. |

c8) **There are hundreds of agroforestry systems, but only some 20 distinctive practices. Below is a classification of these (Young 1989:1018).**

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MAINLY AGRO-SILVI-CULTURAL (trees with crops)

Rotational: interactions between trees and crops take place predominantly over time.

1. Planted tree fallow
2. Taungya

Spatial mix: (interaction over the whole area)

3. Trees on cropland
4. Plantation crop combinations: - with upper storey trees
   - with lower storey trees
   - tree/shrub crops
   - with herbaceous crops
5. Tree gardens: - multistorey tree gardens
   - home gardens

Spatial zones: (trees in rows, on soil conservation structures, in bands)

6. Alley cropping
7. Boundary planting
8. Trees for erosion control - in barrier hedges
   - on grass barrier strips
   - on *bunds*
   - on terraces
9. Windbreaks and shelterbelts (also silvipastoral)
10. *Biomass* transfer

MAINLY or PARTLY SILVI-PASTORAL (trees with pastures and livestock)

Spatial mix:

11. Trees on rangeland or pastures
12. Plantation crops with pastures

Spatial zones:

13. Live fences - mainly barrier function
    - multipurpose
14. Fodder banks

TREE COMPONENT PREDOMINANT

15. Woodlots with multipurpose management
16. Reclamation forestry leading to multiple use: - on eroded land
    - on salinised land
    - on moving sands

OTHER COMPONENTS PRESENT

17. Apiculture ( bee keeping) with forestry
18. Aquaforestry (trees with fisheries)

SPECIAL ASPECTS - trees in water management
- irrigated agroforestry

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c9) Description of cases of existing systems:

A - Tree gardens
An intimate mixture of timber trees, fruit trees, shrubs, bamboos, vegetable crops and livestock. It is evidently capable of maintaining the soil fertility. It has all advantages of agroforestry: high production, sustained fertility and of being completely practical (Young 1989).

B - Alley cropping.
Trials are running in Ibadan, Nigeria for a lowland moist subhumid climate (Aw) on level land with a Psammentic Ustorthent soil. Leucaena leucocephala was planted in hedgerows 4 metres apart, intercropped twice a year with alternating maize and cowpea. The Leucaena was pruned, the woody stems harvested but herbaceous matter and crop residues returned to the soil. Over a six year period crop yields were sustained and organic matter increased slightly (Young 1989).

C - Spatial mix plantation-crop combination.
In Central and South America coffee and cocoa is interplanted with Erythrina poeppiggiana and/or Cordia alliodora. It is found under lowland and highland humid climates (Af, Am, Cf, and Cm), commonly on sloping land, in a range of acid, red soils (Oxisols and Ultisols). The Erythrina is pruned and the prunings laid on the soil, the Cordia is allowed to grow, supplying litter by leaf fall, and felled for timber. The amount of nutrient returned to the soil is of the same order as that removed in harvest (Young 1989).

D - Traditional agroforestry systems, Philippines.
Several systems occur in a small community of migrant farmers, seven of them are described, including the effect of parcelling of farm holdings, on level and sloping land. The acceptance of social forestry programs is discussed (Olofson 1985).

E - Agro-silvicultural plantation-crop combination.
In the forest zone of Nigeria, a hardwood Gmelina arborea Roxb., was interplanted with a) yam (Dioscorea rotundata) and maize (Zea mais) and b) cassava (Manohot utilissima) and maize. These practices increased the farmers income. *Benefit cost ratios* were 2.3 for yam and maize and 2.4 for cassava and maize. If 5 % of the farm families in the area practice agri-silviculture, each family cultivating one hectare, there will be enough fuelwood after five years growth (Akachuku 1985).

F - Comparison between forest garden and mixed garden (Wiersum 1979).
The forest garden is a land use form on private lands, dominated by planted and sometimes natural perennial crops, mostly fruit and other trees, under which no annual crops are cultivated so that a natural herb and/or litter layer can develop.
The mixed garden is a form of land use on private land dominated by planted perennial crops, mostly trees, under which annual crops are cultivated, demanding soil tillage.
The forest gardens provide good protection even on steep slopes. The mixed gardens give much less soil protection, but they almost never occur on steeper slopes. Due to human interference, which occurs also in some of the planted and secondary forests by uncontrolled felling and disturbance of soil litter, some erosion can occur.

CHARACTERISTICS OF THE FOREST GARDEN AND THE MIXED GARDEN

| Characteristic | Forest garden | Mixed garden. |
|---|---|---|
| Average age | about 30 years | 4 - 7 years |
| Trees/ha | 1200 - 1500 | 600 - 700 (light needed for annuals) |
| Average height | 10 - 17 m | 6 - 10 m |
| Average diameter | 15 - 18 cm | 6 - 10 cm |
| Basal area/ha | 30 - 40 m2 | 2 - 6 m2 |
| Tree species/plot | 3 - 7 | 1 - 3 |
| Erosion on slopes | | |
| Degrees 0 - 10 | no erosion | no erosion |
| 10 - 30 | no erosion | slight erosion |
| > 30 | no erosion | (not present) |

G - Cocoa under laurel and poro shade trees, for wood production and litter production and decomposition in Costa Rica (Heuveldop a.o. 1988).
The study is taken as an example of the many recorded in the international journal "Agroforestry Systems".
During 7 years yields of cocoa under Cordia alliodora and Erythrina poeppigiana shade trees were recorded as respectively 626 and 712 kg/ha/yr oven dry weight. Harvests have gradually increased over the years and the plantation has now reached maturity.
Natural plant residue production was measured over 4 years and reached 7.1 t/ha and 8.9 t/ha respectively. The shade trees have contributed 47 and 57 %, respectively.

c10) In the south Pacific region the major agroforestry systems and practices include combinations of tree crops such as coffee, coconut and cocoa with nitrogen-fixing trees such as Casuarina, Gliricidia and Leucaena, and food crops (mostly tubers) such as cassave, taro, sweet potato and yams (Vergara & Nair 1985).

c11) TREE SPECIES commonly used in agroforestry, which fix nitrogen (50-200 kg/ha) are:
- Acacia
- Casuarina
- Prosopis
- Erythrina
- Gliricidia
- Inga
- Leucaena leucocephala (improved by breeding) produces up to 500 kg N/ha
(Young 1989).

c11) Calliandra calothyrsus is found in Burundi (Balasubramanian & Sekayange 1992; Réseau d' érosion; Bulletin 12; ed. E.Roose, Montpellier) to be the best agro-forestry tree for wood production. Ratios of leaf mass to wood mass are:

| | |
|---|---|
| Cassia spectabilis | 2.38 |
| Leuceana diversifolia | 1.58 |
| Leuceana leucocephala | 1.41 |
| Calliandra calothyrsus | 1.31 |

The rootsystem distribution is found to be:

| depth | Calliandra calothyrsus | Cassia spectabilis | Leuceana leucocephala |
|---|---|---|---|
| 0-30 cm | 66 % | 64 % | 32 % |
| 30-60 cm | 30 % | 30 % | 53 % |
| 60-90 cm | 4 % | 4 % | 10 % |
| 90-120 cm | 0 % | 2 % | 6 % |
| total weight: | 490 g. | 620 g. | 760 g. |

d) Erosion control

d1) In erosion control agroforestry can contribute both to the *cover* and the barrier approaches. The cover approach is usually less costly, and unlike the barrier approach it contributes to the maintenance of fertility. The system promises to give increased income or production and also act as a soil conservation practice (Young 1989).

d2) The trees can be planted in such a way as to achieve the barrier effect in additional to or in place of conventional earth structures for soil conservation: the practice of "barrier hedges" or "biological *bunds*" and "alley cropping" have this effect.

d3) Experimental evidence shows that the influence on *erosion* of the tree component alone is usually slight and may even be negative (shadow, moisture and nutrient competition). Teak, for instance, strongly reduces the growth of interplanted maize (Verinumbe & Okali 1985).
It is the ground surface *COVER* OF TREE *LITTER* which leads to the low rates of *erosion* under woodland. Practices that lead to a litter cover should be the primary aim in agro-forestry in order to control erosion, and the second aim should be the establishment of *runoff* barriers.

d4) An adaptation of the USLE for forest conditions and agroforestry situations has been made by Dissmeyer & Foster (1981), by adjusting the C-factor. They consider the following subfactors of the *cover* effect in forest conditons (those marked by + have potentially a great effect):
- % bare surface +
- % *canopy cover* above bare surface
- soil re*consolidation* after tillage (reduces *erosion)*
- high organic matter content in forest floor *topsoil*

- presence of rootmat +
- time since last tillage (residual binding effect of organic matter and roots wears off)
- *depression storage* +
- steps of *litter* and *debris* accumulation +
- plough direction

d5) In terms of the USLE, agroforestry influences the *erosion slope length* factor L, the *cover factor C*, and possibly with time the *soil erodibility* factor K and the steepness factor S.

e) Other applications

e1) The system enables farming on SLOPING LAND, where millions of farmers must obtain their livelihood (Young 1989).

e2) There is substantial evidence, in part qualitative or indirect, that agroforestry can contribute substantially to MAINTENANCE OF SOIL FERTILITY.
Sanchez (1987) warns that "while evidence exists for the beneficial effects on soils of certain agroforestry technologies there is a tendency for over - generalisation and extrapolation of *soil productivity* and sustainability benefits of agroforestry systems to other more marginal sites."

e3) The small farmer can often not afford chemical fertilisers. Other means are necessary for the maintenance of fertility and sustained yield.
Agroforestry is a practical management option for small farmers and a relatively inexpensive form of land development (Young 1989). Agroforestry may play a role through *mulching* and recycling of soil nutrients from deeper layers than annual crops can reach, and by nitrogen fixation for instance (Young 1989).

e4) For farmers with higher input management the system can improve the plant response to fertiliser through improving *soil structure* and organic matter content (Young 1989).

e5) Some improvement in the system of shifting cultivation is obtained by the use of Casuarina oligodon before abandoning the swidden, such as in the Papua New Guinea highlands, and by *intercropping* food crops in tree crop stands (Vergara & Nair 1985).

e6) Important considerations for its application are (Sanders 1988:279-280):
- normally the agricultural aspect is the farmer's main concern. Trees must be managed in a way that is useful to farmers, they are usually not interested in thick logs of wood, such as foresters traditionally aim to produce. The farmer's requirement may be relatively thin poles for building, fencing, and firewood.
- agroforestry systems are generally within the physical and managerial capacities of the farmers. This may mean making more use of multipurpose trees and varieties that will produce at least some fruit or timber in the short term.
- land tenure of the farmers on their *land* may not be long-term, so they are unlikely to be interested in planting trees.
- suitable varieties of seedlings must be available at a reasonable price near where they are to be planted, and farmers may need advice and assistance on how to best plant and then manage the young trees.
- the need to develop new markets if the introduced agroforestry system results in the production of, for instance, more fruit than the farmers family can consume.
- the need for more research on species to overcome problems that are now encountered. For example both Eucalypts and mangoes have frequently been advocated for use in agroforestry systems, but farmers do not accept these species because eucalypts tend to compete with crops for moisture, and mangoes produce too much shade.

f) Modelling

f1) Data on agroforestry are analysed on a computer model called "SCUAF", the Soil Changes Under Agro-Forestry. It is designed to estimate soil changes under specific agro-forestry systems, and to compare these with changes under other *land use systems*. It can operate to predict changes in rate of *erosion*, soil organic matter and nitrogen (Young 1987; Young, Cheatle & Muraya 1987; Young & Muraya 1989).

g) Handbooks and Journal

For information about agroforestry certain handbooks and review articles may be useful:

Rocheleau & Weber 1988

A handbook which describes practical methods of agroforestry for soil and water conservation, with particular reference to dryland Africa (semi-arid and dry savannah zones). It is directed at extension workers.

Gholz 1987

A comprehensive handbook, contains a global perspective and a world wide review and several case histories.

Nair 1985

A classification of agroforestry systems.

Young 1984

Evaluation of agroforestry potential in sloping areas, p.106-132 in: Siderius ed. 1986.

A specific journal is :

Agroforestry Systems, an international journal, published by Kluwer, in cooperation with ICRAF.

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## 12. RAIN EROSION HAZARD as Central Concept

***Equivalent term:*** soil erosion hazard

***Related terms:*** land degradation
erosion susceptibility

**The rate of soil loss expected in the near future, due to rain erosion, depending on the combined and interactive effects of all erosion hazard factors: climate, relief, soil profile, present erosion, land use and vegetation, and cultivation system.**

a) The term
b) The concept of rain erosion hazard
c) Assessment of erosion hazard
d) Classes of rain erosion hazard
e) Erosion hazard and conservation planning

a) The term

a1) When the context is clear the term may be shortened to "erosion hazard".

a2) The term erosion hazard is general, and does not specify the type of erosion. If a specification is needed, terms such as rain erosion hazard, *gully erosion* hazard, wind erosion hazard, *mass movement* hazard, could be used.

a3) If a type of *accelerated erosion* is to be specified, terms such as "accelerated rain erosion hazard" could be used.

a4) The part of the erosion hazard that is caused by the influence of the relatively permanent *factors* of climate, relief, soil profile and present erosion is called *erosion susceptibility*.

a5) OVERVIEW OF RAIN EROSION HAZARD TERMS

| Causal factor | Relevant term |
|---|---|
| Rain only | Rain erosivity |
| Soil only | Soil Erodibility |
| Climate<br>Relief<br>Soil (and present erosion) | Soil Erosion Susceptibility |
| Climate<br>Relief<br>Soil (and present erosion)<br>Vegetation and land use<br>Land Management | Soil Erosion Hazard |

b) The concept of rain erosion hazard

b1) Erosion hazard is the probability of serious *erosion* starting in the near future, the farmer's immediate future, a period of about 3-5 years. When serious natural or *accelerated erosion* is already occurring, the erosion hazard expresses the intensity of the erosion processes that is expected, the expected rate.

b2) *Land use* and the supporting practices are the most important *factors* of the USLE equation and are indeed the most important erosion hazard *factors* because of their great potential for reducing *erosion* and their manipulative nature (Moldenhauer & Foster 1981:23).

b3) The influence of the *factors* of natural vegetation and cultivated plants, land management and *cultivation* system, is variable and relatively easy to change. This is because of the growing seasons with *stages* of crop-growth, and *crop rotations* and other changes in *land use* and farming practices. Consequently erosion hazard is strongly variable in time.

In arable *land*, the type of crop and its *growth stages* are considered when studying the annual *crop cover* effect on erosion hazard. This takes into account the *erosivity distribution* and soil cover variation over the seasons.

b4) Erosion hazard maps may be out of date in a few years when *land use* has changed. The concept of erosion susceptibility greatly facilitates updating of erosion hazard maps, after changes of *land use* have occurred.

c) Assessment of erosion hazard

c1) The expected rate of *erosion* can be expressed in a quantitative way, when the available data in an area allow this. It may then be expressed as expected *soil loss* in t/ha (Wischmeier & Smith, 1978) or in a relative way.

c2) Assessment is by studying the erosion hazard *factors* and their interactions. Several systems may be used:

- a single parameter, such as slope steepness or *gully* density, which locally has proven to be strongly correlated with the *erosion* intensity (Keech 1968; Evans 1981:523).
- a system of factorial scoring, based on local experimental data, expert opinion and pragmatic evaluation of the particular conditions of the area.
  Such a system is subjective, but offers the possibility of accepting any factor that seems of importance. The system is easy to use, and can help in a first inventory of the *bad spots* for erosion hazard (Stocking 1981:381; Morgan 1979; Morgan 1981:517).
- a system that is largely based on the USLE, wherever this seems justified. Hazard factors for mapping units on large to medium scales may be described by classes that roughly differ by a factor of 2, allowing the combination of the different factors of erosion hazard to conclude on ranges of expected soil loss (Bergsma 1986).
- a system that allows quantitative soil loss prediction such as the USLE for the USA or SLEMSA for southern Africa (Elwell 1981:281) or the modified USLE for southern Germany (Rogler & Schwertmann 1981; Schwertmann 1986). It uses correlation of soil loss with erosion hazard factors based on numerous regional experimental data.
- mathematical *models* of erosion (see also Central Concept of Models of Rain Erosion).

d) Classes of rain erosion hazard

d1) Because the distinction between natural and *accelerated erosion* is often vague, the rain erosion hazard classes are designed to be the same as the classes of soil erosion hazard.

d2) The classes are defined degrees of soil erosion hazard, qualitative or quantitative, often indicating the degree of measures needed for control.

d3) An example of qualitative, relative classes are (Houghton & Charman 1986:51) :

- low erosion hazard
  Low erosion hazard is sometimes associated with a combination of the erosion *factors* that result in no appreciable erosion damage occurring during or after the development of the particular land use under consideration. *Soil conservation* management should however include simple practices, such as *topsoiling* and conservation tillage where appropriate.
- moderate erosion hazard
  Moderate erosion hazard implies that significant erosion may occur during development of the particular *land use*, but provided appropriate soil conservation measures are adopted during development, both short term and long term erosion problems may be avoided.
- high erosion hazard
  High erosion hazard implies that significant erosion will occur during development of the particular land use and that appropriate erosion control measures are needed in order to minimise long term erosion problems. Control of short term erosion could be provided by simple soil conservation measures but long term erosion control would involve intensive measures.
- very high erosion hazard
  Very high erosion hazard implies that significant erosion will occur during development and after the land use has been established, even with intensive soil conservation measures. Such an erosion hazard infers that planning will need to carefully consider the balance between the probability of long term erosion damage and the maintenance or repair needed to ensure the viability of the land use
- extremely high erosion hazard
  Extremely high erosion hazard implies that erosion will occur to such an extent that economic

control utilising conventional soil conservation measures is impractical. If implementation of the land use is imperative, detailed engineering, geotechnical and/or other appropriate studies will be necessary to ascertain its viability.

d4) For surface rain erosion five quantitative classes of erosion hazard are often used:

| Relative classes | Quantitative classes |
|---|---|
| Class name | Soil loss range in t/ha/yr |
| Very low | 0 - 5 |
| Low | 5 - 12 |
| Moderate | 12 - 25 |
| High | 25 - 60 |
| Very high | 60 - 150 |
| Extremely high | 150+ |

The classes have a regularly increasing width for higher hazards and a greater accuracy in the range of lower hazards. The first two classes cover the range of the usual *soil loss tolerance* values, the moderate class covers the range of hazards that often have to be accepted. The higher hazards represent increasingly disastrous conditions of erosion. For a *bulk density* of the *topsoil* of 1.2 g/cm3 the boundaries of the hazard classes equal a loss of soil depth of about 0,4 - 1 - 2 - 5 - 12 - mm/yr.

d5) Erosion hazard classes are sometimes defined by the degree of damage that is expected (Houghton & Charman 1986:51). This correlation however is subject to the *yield sensitivity* of the soil, and depends in general on the land suitability and its rate of decline by *erosion.* The *land productivity* may be affected by increasing cost of tillage, fertiliser use, damage by *deposition* and other effects. A simple relationship between *soil loss* and yield, or between soil loss and land productivity can in general therefore not be expected.

e) Erosion hazard and conservation planning

e1) For conservation planning it may be useful to split the erosion hazard into the influence of *land use* and practices and the relatively permanent part called erosion susceptibility. One can then apply the following classification of *land* (Heimlich & Bills 1984):

- erosion susceptibility so low that any locally common *land utilisation type* is acceptable, the resulting erosion will always be below tolerance.
- erosion susceptibility so high, that any locally common land utilisation type will result in erosion above tolerance level. Improvement can only come from a change of land use, a new land utilisation type.
- erosion susceptibility in between the two former categories. Some locally common land utilisation types will result in too much erosion, some others will cause an acceptable degree of erosion. By considering more intensive practices of conservation, some more areas may get acceptable erosion rates.

The quantification of this appraoch depends on the availibility of an extensive data set.

## Rain erosion susceptibility, or soil erosion susceptibility

***Related terms:*** erosion hazard
potential land degradation
resistance to erosion, a land quality

**The soil loss expected under the influence of rainfall, relief, soil and present conditions of erosion, in the absence of plant cover and control practices, that is on bare land, ploughed up-and-down the slope.**

a) The term

b) The concept

## RAIN EROSION HAZARD

a) The term

a1) The term is derived from Beek a.o. (1965) who indicate that it is the rather permanent part of the erosion hazard, in contrast to the variable part of the hazard depending on *land use* and farmer's practices.

a2) Other terms sometimes occur such as erosion risk or potential erosion. The first term is not preferred because "risk" has commonly the same meaning as "hazard" and this may be misleading.
The second term is misleading in that it suggests a maximum level of erosion. This maximum is not always reached in natural conditions. For instance the faulty application of sprinkling on sloping fields may cause an erosion rate above that occurring on bare land, tilled up-and-down the slope. In this case the erosion hazard is greater than the erosion susceptibility. The term "erosion susceptibility" is preferred.

a3) Stocking (1981:381) and Riquier (1977:36) use "*erosion risk* " to indicate the potential erosion, which is determined by the relatively permanent erosion *factors* of soil, climate and topography (also Houghton & Charman 1986:51).
It is used in small scale *mapping* of the present and potential erosion by FAO. It is defined by Riquier as: The rate of *erosion* on bare soil, without the protection of natural vegetation or crop, expressed in t/ha/yr. It is to be compared with the present rate of erosion, to bring out the strong influence of natural vegetation or the use and misuse of the *land* by man (Riquier 1977:36).

b) The concept

b1) The erosion susceptibility is a characteristic of a land area. It describes the *erosion* to be expected without protection by plants and in the absence of *conservation practices* (Beek a.o. 1965; Bennema & de Meester 1981:79-80).
It is therefore a useful concept for planning land development, when alternative *land utilisation types* are considered. Each alternative may result in a different erosion hazard for one unit of *land* having a certain erosion susceptibility.

b2) Because the concept of erosion susceptibility is a (rather) permanent characteristic of a piece of *land*, or mapping unit, it is a *land quality*. In fact it is the opposite of the land quality called "*resistance-to-erosion*". A low resistance to *erosion* is equal to a high erosion susceptibility. In rating by classes the class-numbers are identical for both, low susceptibility is rated 1 and a high resistance to erosion is rated 1, being both the most favourable rate. When five classes are used, a susceptibility class 4, high, is similar to a resistance class 4, low (Bergsma 1983).

b3) In most cases the erosion hazard is much lower than the erosion susceptibility, both expressed as the expected rate of *soil loss*. The effect of (low) *plant cover* is dominant over the effect of rainfall, slope, or soil profile, which is fortunate for mankind. Plant cover often strongly reduces *erosion*, while in many cases *conservation practices* may also cause a great reduction in erosion rates.

b4) Different types of *land use* may interact in a different way with the soil profile, and one can say therefore, that the influence of the erosion susceptibility is not constant, but varies with the type of *land use*. It seems however preferable to consider the effect of interaction between certain plants and the soil as part of the plant effect. The enduring part of this interaction has been called the *residual effect* (Wischmeier & Smith, 1978) indicating that the changes in the soil (*structure*, porosity, organic matter, *litter*) remain present for some time after the causal *plant cover* has left. This occurs for example in *crop rotations*, or conversion of forest or grassland into arable cropping land.

b5) Effects of present *erosion* are taken into account because the development of erosion towards a new natural equilibrium usually takes many years, and therefore the present erosion is a rather permanent conditon of the land. The different stages of *gully* development, as well as stages of *interrill erosion* and *rill erosion* often take several years, the time span which is also taken for the erosion hazard.

b6) In a wider sense, regarding the effect of erosion damage on the suitability of the land, effects of the loss of nutrients by erosion should also be taken into account (Shaxson 1981:390; Moldenhauer pers. com. 1989).

b7) The concept of erosion susceptibility is related to *potential land degradation* (Dudal 1981:5). The last is a wider concept including also *degradation* by other causes than *soil loss* .

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## 13. SOIL LOSS TOLERANCE as Central Concept

***Equivalent term:*** permissible soil loss

***Related terms:*** actual land degradation soil life
land husbandry soil vulnerability to erosion
land productivity sustained use
rain erosion yield sensitivity to erosion
rain erosion hazard

**The maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be obtained economically and indefinitely.**

a) The concept
b) Values
c) Allowable reduction in productivity
d) Yield sensititvity to erosion
e) The vulnerability of productivity to erosion
f) Conservation planning
g) Deposition, linear erosion and off-site effects

a) The concept

a1) *Erosion* starts mostly as a slow process and is often unnoticed until it reaches a damaging intensity (National Committee 1981), this is a strong argument for using soil loss tolerance values in *land use* planning.

a2) Inclusion of a soil loss tolerance value in land use planning and policy is a matter of *LAND HUSBANDRY* (Shaxson 1981; McCormack & Young 1981; Stocking 1981).

a3) Soil loss tolerance values may be determined relative to *soil loss* from the profile, affecting plant yield, or it may be determined relative to *sediment* production, affecting water quality or *sediment concentration* in *dam lakes* (Mannering 1981:346).

a4) Values have been based on "SOIL RENEWAL RATES". They concern however the *topsoil* renewal, not the *solum* renewal. In this respect the *soil loss* tolerance values may be too high. The upper limits are considered far too high for fragile tropical soils with low levels of soil fertility (Lal 1985:239,245) where no compensation for soil depth exists in a rich topsoil.

a5) The values of *soil loss* have a complex origin. *Sediment yield* may have been an important consideration in arriving at the value of 11 t/ha/yr which has been widely accepted as a maximum allowable rate of soil loss in the United States (Flach & Hytry 1987).
It is arbitrarily determined, taking into account soil depth, physical properties and other characteristics affecting root development, *gully* prevention, on-site *sediment* problems, seeding losses, and soil organic matter reduction and plant nutrient losses (Houghton & Charman 1986:119) This concept is in contrast to that of the tolerance values based on soil renewal rates, levels of fertiliser management and regular plant variety improvements (Pierce a.o. 1983).

a6) A basis of WEATHERING RATE to determine *soil loss* tolerance ignores the edaphic aspects of nutrient availability and the importance of organic matter and the clay fraction in plant growth (Lal 1985:241). It also does not take into consideration the off-site damage caused by *soil erosion* (Lal 1985:245).

a7) The few centimetres of surface horizon, rich in organic matter, are very important. Currently used rates for tolerable *soil loss* of 12.5 t/ha/yr are far too high for fragile tropical soils with low levels of fertility (Lal 1985:245).

a8) Agricultural production causing a *soil loss* below tolerance will take place without serious *actual land degradation* or decline in *productivity* as a result of man's activities (Houghton & Charman 1986:119). Such an *erosion rate* does not change the *land suitability* for a specified kind of *land use*, for a specified level of technology and *inputs* (Dudal 1981:6,7). It allows *SUSTAINED USE* of *land* without severe or permanent deterioration of land resources.
*Permissible soil loss*, in the context of land evaluation at the farm level, is the soil loss which does not negatively affect the main ecological and management qualities of a *land evaluation* unit associated with a specific *utilisation type* (Bennema & de Meester 1981:80).

Soil depth is the critical soil property for *degradation* caused by *surface erosion* (FAO 1983:x). Surface rain erosion may cause soil depth to become a limitation to use, a *land characteristic* which adversely affects the potential of land for a specified use (FAO 1983).

a9) It should be noted that in more or less arid conditions, such as exist in many parts of Australia, soil formation rates may be close to zero, and therefore the soil loss tolerance would be correspondingly low.

b) Values

b1) Commonly used values are 5 - 12 t/ha for shallow to deep soils (Crosson 1985:234; Lal 1985:245). Evans reported (1981:527) soil renewal rates for England as less than 1.3 t/ha/yr, concluding that yield will decrease on shallow soils when the *soil loss* is lower than the usual tolerance limits of 2-5 t/ha/yr.

c) Allowable reduction in productivity

c1) The concept of *soil loss* tolerance has been reconsidered, to become much wider, and less definite, than that of the soil loss tolerance values or T-values, based on soil renewal rates. The allowable reduction in *soil productivity* is proposed to be that under which crop yields are maintained by (Pierce a.o. 1983; Crosson 1985:234):

a) Soil renewal rates,

b) Advances in technology and

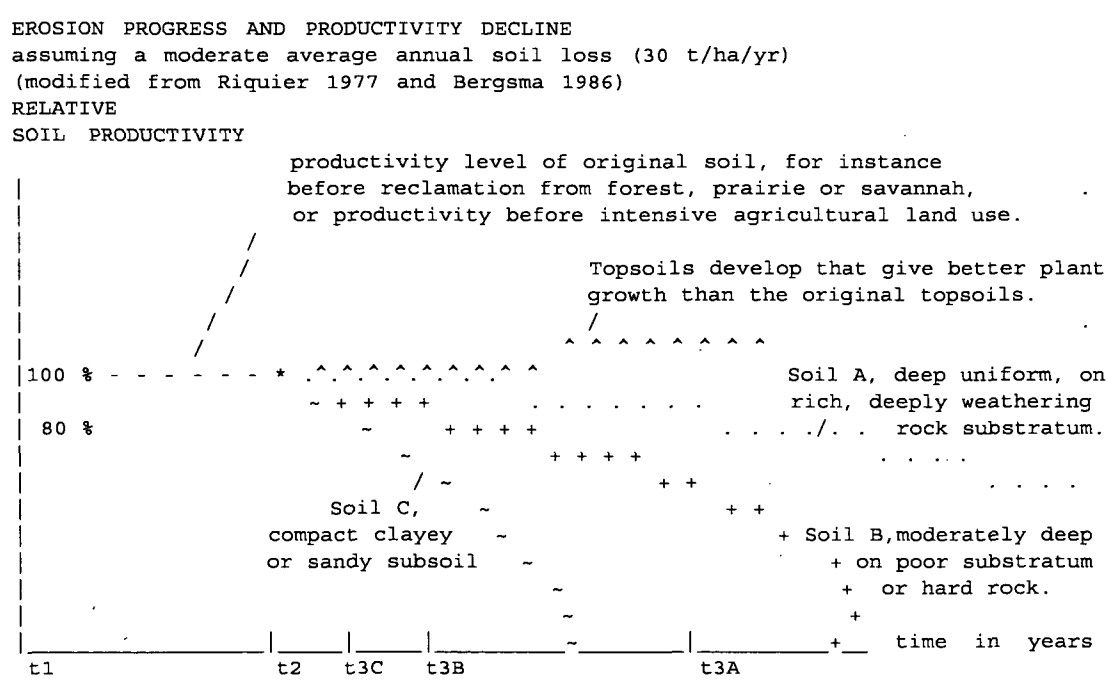
c) Advances in crop genetic potential

This means a deviation from former policy where the soil loss tolerance was considered only in relation to the soil renewal rates. It raises various questions, including: if the soil's inherent productivity is allowed to decline, what will occur when a change in policy or economic conditions reduces the effects of b) and c) ? Second, if *erosion* is allowed to progress, there may come a time when too great an input of b) and c) is needed to compensate for the soil loss, or the erosion may have progressed to the stage where it becomes too destructive.

c2) When soil loss tolerance is determined by an acceptable *productivity* loss it usually refers to only one crop. A soil loss tolerance that defends the soil for its whole RANGE OF POSSIBLE FUTURE *LAND USES* would be better. It could best be based on estimates of *topsoil* formation, as was done in case of soil loss values between 5 and 12 t/ha/yr (Houghton & Charman 1986).

d) Yield sensitivity to erosion

d1) It is the yield reduction caused by *erosion* of a unit depth of soil, for instance per 1 cm *soil loss* (Kohnke & Bertrand 1959; Land Evaluation Project 1983).
Soils with shallow unsuitable layers will have a high *vulnerability*. This is illustrated in the following schematic diagram; similar curves based on measured data for certain crops are given by Lal (1985:240).



Legend t1 = natural state, or low intensity traditional agriculture
t2 = beginning of intensified agricultural use
t3 = loss of productivity is 20% (main crop or grain equivalent)
t3A, t3B and t3C for soil A, B and C, respectively.

The diagram indicates that a certain amount of *soil loss* causes a different decline in *productivity* for different soils, and sometimes an increase in productivity. These soils have a different *YIELD SENSITIVITY*, or decline in yield per unit of erosion. This is because soils differ with respect to the soil properties that determine productivity. This will play a role especially in soils with strong contrasting *topsoil* and *subsoil* properties.
Examples of these soils are: clay illuviation soils, humus iron illuviation soils, clayey over sandy *texture* soils. Soils with rather uniform topsoil and subsoil are, for instance, some deep forest profiles, or old strongly weathered tropical soils. Soils with more favorable subsoils are, for instance, leached calcareous loess or vertisols on basalt (New South Wales).
When soil loss tolerance is based on sustained productivity, the soil vulnerability may play a role, but when soil renewal rates determine soil loss tolerance, probably little variation in tolerance values would be expected.

e) The vulnerability of productivity to erosion

e1) Soils that have an unfavourable *subsoil* are especially *YIELD SENSITIVE* to erosion. Also the *vulnerability* to erosion may vary strongly between soils. It is the RATE OF *PRODUCTIVITY* DECLINE on a certain soil for a unit of *erosion* (Pierce a.o. 1983), for instance erosion of 1 cm/year.
It is expressed in percentage productivity or yield reduction over a certain period (time horizon). Costs of production and benefits from the *land use* are considered. Compensating for erosion by application of fertilisers, unequal tillage conditions at the land surface, and *filling* of gullies for restoring communications are examples of increasing costs due to erosion.

f) Conservation planning

f1) *Vulnerability* gives a correction on the priority for conservation as determined by "HAZARD ABOVE TOLERANCE". For establishing priority areas for conservation of arable *land*, a combination of the expected soil loss above tolerance and the soil's vulnerability indicates where the greatest relative damage is to be expected to the output of the arable land. Farmers with soils of a high vulnerability qualify for high priority of conservation input, when *erosion hazard* is high.
See the diagram "Steps in Conservation Planning". Note in the diagram the place of land evaluation (FAO 1983), the vulnerability of the soil to *erosion* (Pierce a o. 1983, 1984 b), and the overriding link with the farmers concerns (Perrens & Trustrum 1984; Purnell 1986; Young 1986).
The PRIORITY FOR CONSERVATION, given insufficient funds for a policy based on expected soil loss above tolerance, can be based for instance on:
1) the soil profile's *yield sensitivity* to erosion
2) the vulnerability to erosion of the production costs and benefits
3) the present *land suitability* and its expected decline

f2) If one can decide on the acceptable reduction in *productivity* in a certain regional or national context, and when a certain planning horizon is used, one can determine the allowed soil loss per year to take place over the period of planning. Usual planning periods are 200 years, 100 years or 50 years. In some cases, the acceptable reduction in productivity is set, for instance, at 5% over a planning period of 100 years. In this way a soil loss tolerance value can be calculated on the basis of the soil's productivity.
Averaging the rate of *erosion* over long planning periods is, of course, only an approximation, because the natural rates of erosion will gradually change with the stage of erosion development.
When the tolerable decline in productivity is expressed as a percentage reduction, the resulting soil loss tolerance value will appear more favourable for soils of lower productivity than for the high productivity soils (stricter limit: better conservation). It may therefore be better to express the allowed productivity decline in absolute terms of yield/ha. and convert this amount to a relative value to arrive at a *vulnerability* index for the planning period (Pierce et al. 1983, 1984a, 1984b).

f3) In some cases (USA) soil loss tolerance is determined taking into account soil depth, physical properties and other characteristics affecting root development, *gully* prevention, on-site *sediment* problems, seeding losses, soil organic matter reduction and plant nutrient losses (Houghton & Charman 1986:119).

g) Deposition, linear erosion and off-site effects

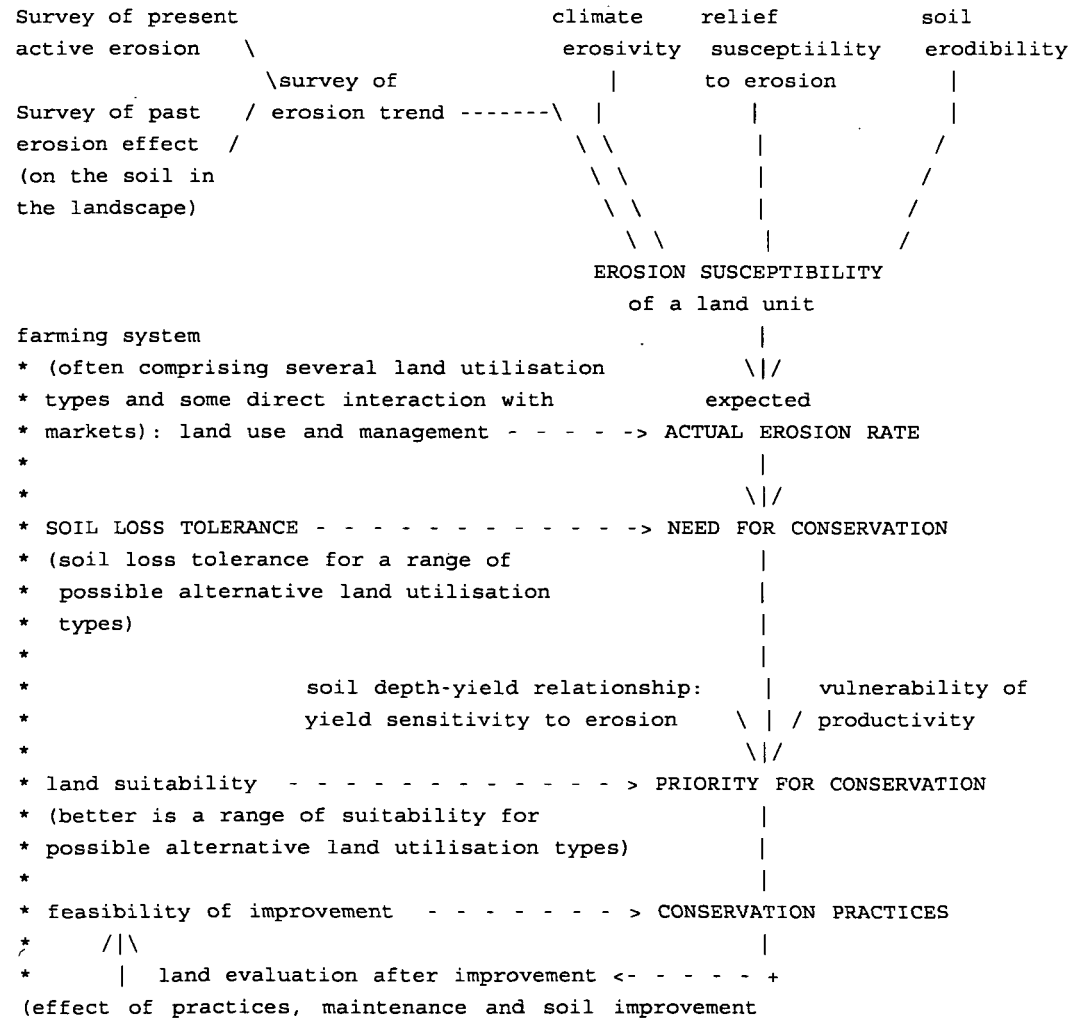
g1) *Rain erosion* affects *land suitability* or *land productivity* not only by *surface erosion*, also by on-farm *linear erosion* and deposition and by several very serious off-farm effects as well.

g2) The soil loss tolerance value can be viewed from different angles (Pierce a.o. 1983, 1984a, 1984b). Usually, the soil loss tolerance is determined from the depth of the soil profile (Smith & Stamey 1965; McCormack & Young 1981) affecting plant yield, using the minimum allowable and optimum soil depth, as a reference for the present soil depth (Lal 1985:240). This may however lead to erroneous decisions, that do not consider other *land uses* than the present one.
Soil loss tolerance may also be determined relative to the *sediment production*, affecting water quality or *sediment concentration* in *dam* lakes (Mannering 1981:346). A value T1 is now often defined on the basis of *productivity*, and a T2 value is defined by other consequences of *erosion*, such as off-site concerns, a critical degree of *gully* formation, crop damage caused by *deposition* or flooding, etc.
Incomplete knowledge of the costs of off-site effects, and about the influences of the mass of soil that leaves the farm but does not reach a *waterway*, makes it difficult to decide which erosion ought to have priority for treatment, and how each effect influences the soil loss tolerance (Crosson 1985:234-236).

g3) A tolerable value of *sediment concentration* is used in modelling by Rose (1985:779,780).

STEPS IN CONSERVATION PLANNING (Bergsma 1987:1250)

*ATTENTION:*
*What is the farmers need ? Is it electricity? Is it new roads ?*
*Or is it soil conservation ?*
*What is his aim, optimising production ? minimising risk ?*
*securing perhaps an amount of leisure ?*



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## 14. LAND and SOIL PRODUCTIVITY as Central Concept

### LAND PRODUCTIVITY

**The capacity of a certain unit of land, characterised by a certain land suitability, to yield arable, livestock, and/or forest production under a certain management system.**

a) Replacing losses in land productivity.
Losses in land productivity from *erosion* are related to a change in replaceable and non-replaceable soil attributes. Replaceable soil attributes are principally plant nutrients. Replacement of course involves a cost. Irreplaceable attributes are principally reductions in available water- holding capacity and plant rooting depth (Larson a.o. 1985:262).

b) *Rain erosion* affects land productivity.

b1) *Surface rain* erosion affects the land productivity by
= reducing crop production through effects on soil productivity:
- reducing fertility (in *topsoil)*
- reducing available water (in topsoil)
- reducing available rooting space above a shallow unfavorable layer
- deteriorating topsoil structure, water *infiltration* and air infiltration

= causing irregular surface microrelief (Mannering 1981:341; National Committee 1981). This has negative implications for fertiliser use, tillage timing and effect, weeding, crop growth and harvesting (National Committee 1981)
= affecting the cost of water control structures by (McCormack & Young 1981:367):
- increasing maintenance
- reducing effectiveness

= causing loss of harvestable crops by erosion and *deposition*
= causing loss of fertilisers
= reducing soil regradation potential (National Committee 1981; Stocking a.o. 1987:422)

b2) *Linear erosion,* if unchecked, affects land productivity increasingly by interfering with:
- tillage,
- travel paths, or farm communications
- lowering of the groundwater table of a wide area around the gullies.

Deposition affects land productivity by:
- covering crops
- damaging roads and drainage systems

c) Erosion development.
Erosion starts mostly as a slow process and is often unnoticed till it reaches a damaging intensity.

## SOIL PRODUCTIVITY

**The capacity of a soil in its normal environment to produce a specified plant or sequences of plants under a specified system of management.**

a) The concept
b) Relation to yield
c) Indices of soil productivity

a) The concept

a1) It is a function of the soil's chemical, physical and biological properties as well as climate, *management* and other non-inherent factors used to produce crops (Renard & Follett 1985:692).

a2) Under good *management*, maximum use is made of a soil's fertility status, whether natural or artificial, and physical properties such as available *water holding capacity*, *bulk density* and *permeability*.

a3) *Erosion* on soils with unfavorable *subsoil* and substratum characteristics exhibit drastic reductions in productivity. On other soils erosion does not rapidly damage the rooting medium and growth potential; they are not strongly affected, even though they are being *eroded* at high rates (Renard & Follett 1985:693).

a4) Points that receive attention as indicators of soil productivity and therefore have consequences for crop management/land management in the semi-arid tropics, are (Pathak a.o. 1987:533-550):
= poor crop stand due to
- *crusting* (limiting water entry)
- rapid drying of surface soil
- high soil temperature
= poor crop growth due to
- unreliable soil moisture supply
- low soil fertility
- soil workability problems
- compact sub *soil layer*
= declining land productivity due to
- poor crop *canopy*
- crusting, *sealing* and soil *consolidation*

b) Relation to yield

b1) The *yield sensitivity* of a soil to *erosion* may vary strongly between soils. Soils that have an unfavorable *subsoil* are especially *"yield sensitive to erosion"*.

b2) Soil productivity may be evaluated relative to *land qualities*, such as the availability of nutrients or the availability of water, some of which are affected by *erosion*, resulting in a change of soil productivity for certain crops or *land utilisation types*.

b3) The *erosion productivity* relationship for maize at IITA in Ibadan showed little effect on yield by erosion of up to 4 mm of top*soil*, but a strongly declining yield for higher soil losses up to 40 mm, when the relative yield has become 20% (Lal 1985).

b4) The relationship between soil productivity, erosion and time shows how the benefit of soil conservation increases very much with time. The accumulated difference in returns on investment in land use (for instance yield) between the case of no conservation and the case of soil conservation becomes massive with time (Stocking 1992:103).

b4) It may also be evaluated by using certain productivity indices, which however are often only of local relevance.

c) Indices of soil productivity

c1) An index is needed to rate the soil on its productivity potential (Lal 1985:247)

c2) The effect of *erosion* on the productivity of *land* was evaluated by 3 methods (Crosson 1985:221): the first was the USDA Resource Conservation Assessment (RCA), the second the Productivity Index (PI) method, the third a statistical analysis of the erosion, fertilisation and management influences on yield over the past 30 years.
The results of the three methods were similar, an 8% yield reduction over the coming 50 years (under erosion as in 1977), a 5-10% decrease in yield over the coming 100 years, and the 1980 yields of corn

and soybeans in their major producing areas were reduced by about 2.5 % because of erosion, given the trends of yield increase for 1950-1980.

c21) In the first method yield was considered to be a function of:
- depth of *topsoil* and of two sub*soil-horizons*
- average slope of the land
- land capability subclass as defined by the USDA
- *soil-texture*
- whether the *land* was irrigated or rainfed
- characteristics of the producing area.

c22) The second method is the use of the soil Productivity Index PI. The model quantifies the change in productivity. It indexes the soil according to its suitability as an environment for root growth (Larson 1987:389) and water depletion (Larson a.o. 1985:264). Soils with a deep permeable uniform *subsoil* will show less productivity decline by *erosion* than soils with an unfavorable subsoil or substratum at shallow depth.

The index assumes that high technology management is applied, and that fertilisers and cultural practices are not limiting. The potential productivity is assessed by an index. The index is based on the five parameters which most determine root growth:
- *water-holding-capacity*
- *bulk-density*
- pH
- aeration
- electrical conductivity (as a measure of salinity)

For a soil each parameter is normalised between 0.0 and 1.0. An actual case is compared to this norm to assess the "sufficiency" of each parameter. Each soil is weighted relative to an ideal root distribution between 0 and 100 cm depth. PI, the Productivity Index, varying between 0.0 and 1.0, is calculated as:

$$PI = \sum_{nr\ 1}^{horizon\ number} (Ai \times Bi \times Ci \times WF)$$

PI is the productivity index
Ai is the sufficiency in waterholding capacity
Bi is the sufficiency in bulk density
Ci is the sufficiency in pH
WF is a weighing factor

The Productivity Index is used for long term prediction of yield decline. For instance the yield after removal of the upper 25 or 50 cm soil (Larson a.o. 1985:271).

c23) In the third method (Crosson 1985:225) a statistical separation has been made of the *erosion* effect on yield, the technology and the management. It was found that the C and P did not vary much over time and between different USA counties. For the crops investigated, corn, soybeans and wheat, the overall relationship between yield and erosion was, of course, negative as expected. But with erosion less than 11 t/ha, the more erosion the higher were the yields.

c3) An index of soil productivity decline through *erosion,* for the case of *surface rain erosion,* is provided by the model EPIC: Erosion Productivity Impact Calculator (Jones a.o. 1985:307; Laflen a.o. 1985:292; Williams 1985:272).

The model is operational. It has produced reasonable results under a variety of climatic conditions, soil characteristics, and management practices. It has also demonstrated sensitivity to erosion in terms of reduced crop productivity (Williams 1985:283).

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## 15. RAIN EROSION MAPPING as Central Concept

rain erosion mapping = erosion mapping when context is clear

**The representation of the areal distribution of rain erosion on a map, possibly showing information about types, degrees and expected rates of rain erosion, respectively called a "rain erosion feature map", a "rain erosion degree map", and a "rain erosion hazard map".**

a) The concept
b) The role of airphoto-interpretation
c) Applications

a) The concept

a1) *Rain erosion* maps do not always show the same kind of information. There are three categories of erosion maps, which may also occur mixed:
- the "EROSION FEATURE MAP", showing the active (and fossil) *erosion features* due to *sheet erosion, rill erosion* and *gully erosion,* and in a wider sense the processes of *riverbank erosion,* flooding and *mass movements.* By showing the active features, the map gives a picture of the present distribution of the processes which depend, often strongly, on the protection by the *land use* at the time.
- the "EROSION DEGREE MAP", the degree to which *erosion* has affected the soil profile. This is similar to an "erosion damage map", the analysis of erosion forms and the changes in the soil profile (Hurni 1981:187).
- the "EROSION HAZARD MAP", showing the expected rates of *soil loss* in the near future, qualitatively or in quantitative classes (Bergsma 1983).

a2) Different scales of erosion maps may be distinguished, which are related to the size of the survey area and the amount of detail to be shown on the map, but even within one category a range of scales is possible, depending on the requirements for the survey and the conditions in the area.
One may distinguish:
- Farm surveys
  Scales are usually 1:10 000 to 1:25 000. The purpose of the survey is to make a farm conservation plan.
- *Catchment* surveys
  Scales are usually 1:10 000 to 1:100 000. The purpose of the survey is to provide an erosion hazard map, commonly to be used in *land use* planning, using *landevaluation* and including other forms of *degradation* besides *erosion.*
- inventory surveys
  Scales are usually 1:100 000 to 1:500 000. The purpose is to obtain an overview of the erosion problem for general planning purposes.
  If very large areas are to be surveyed, as has been done for a world *land degradation* map, a generalised map results, with scales down to about 1:10 million. (FAO 1979).

ASPECTS OF EROSION SURVEYS ON DIFFERENT SCALES (Bergsma 1982)

| Survey scale / Character of map | Farm plan survey | Catchment erosion survey | (National) Inventory survey |
|---|---|---|---|
| Erosion features, present rate of processes | detailed classes of types and intensities | description of mapping units by some erosion type classes and few intensity levels | broad classes of serious erosion types |
| Erosion degree (erosion effect on soils) | eroded phases and colluvial cover phases of soils | degree of erosion reflected in soil classification, depth and texture phases | a few broad classes |
| Erosion hazard & susceptibility (future rates) | detailed classes or quantitative soil loss prediction on some sites | semi-quantitative, or relative classes, supported by soil loss measurements | a few general qualitative classes |
| Conservation planning | practices in detail, but exact location and dimensions set in the field | semi-detailed planning, priority areas in large catchments | location of problem areas |
| Approximate scale of final map | 1:1000/1:5000 | 1:25000/1:100000 | 1:200000/ 1:1000000 |
| Approximate range of AP-scales | 1:1000/1:5000 enlargements | 1:10000/1:40000 | 1:30000/ 1:100000 |
| Example of detail in airphoto-interpretation | fields, parts of fields, slopes. | relief forms, parts of relief forms, groups of fields. | landtypes, associations of landforms, broad classes of land use |
| **Survey means** | **their importance** | | |
| Use of satellite | - | + | ++ |
| Use of airphoto interpretation | + limited use | +++ complete photo-interpretation is very usefull | ++ small scale |
| Field survey | +++ | ++ | + |

a3) The use of satellite imagery allows ecologically homogeneous areas to be distinguished (Shaxson 1981:392).

a4) As with any map, one has to consider the ACCURACY and the PRECISION of the erosion maps. Accuracy indicates the degree to which the classification criteria shown on the map are satisfied by the properties of the sites in the field.

The disadvantages of inclusion/purity measurement may be that all deviations from the class definitions are equally weighted regardless of their type or extent. It may occur that no allowance is made for variations within the class limits (Marsman & de Gruijter 1986).
Precision or homogeneity indicates how homogeneous the mapping units are with respect to certain erosion *factors*. The factors may be measured or observed directly, or they may be derived, (Marsman & de Gruijter 1986) such as age/development stage of *gully erosion* and erosion trend.
Both aspects of quality are influenced by the method of survey, in which random sampling can be compared to selective sampling. The last often includes the use of airphoto interpretation, creating physiographic mapping units as a preparation for soil and erosion maps. (Marsman & de Gruijter 1986).

a5) Mapping of *erosion* has to consider the variability in erosion *factors* and the occurrence of *erosion features*, for a mapping unit. The variability depends on the scale of the study. Plot, field and *watershed* scales are considered in a study that uses the geostatistical technique of structural analysis of the data, which are considered partly random and partly continuous. *Slope length*, slope steepness and *soil erodibility* were analysed by semivariogram (Rogowski a.o. 1985).

b) The role of airphoto-interpretaton

b1) For the survey of *erosion* a major contribution comes from airphoto- interpretation. Photo-interpretation elements are discussed in Bergsma (1974), with the concept of *erosion toposequences* in the landscape, of which the presence as well as the absence gives indications about erosion conditions in the area.

b2) An overview of erosion *factors* surveyed by different means is shown in the table below:

ASPECTS OF EROSION FACTORS SURVEYED BY AIRPHOTO INTERPRETATION AND FIELDWORK

| Erosion factor | Airphoto-interpretation: Direct image | Airphoto-interpretation: Indirect evidence | Fieldwork and data records |
|---|---|---|---|
| CLIMATE | | vegetation types and relief forms indicate general type of climate | meteo-data |
| | | orographic rainfall: abrupt, large, extensive barriers to rainbearing winds indicate affected zones | |
| RELIEF | slope steepness, form, length, position, exposition | relief covered by vegetation | steepness, length of overland flow, zone of *deposition* |
| SOIL PROFILE | | boundaries between soil mapping units | soil observations, soil surface gravel, overland flow potential |
| EROSION | serious active surface erosion, gullies, strong deposition | erosion hazard | surface erosion degree, gully depth and age, colluviation |
| NATURAL VEGETATION CULTIVATED PLANTS | density of cover, plant rows, row crops | | crop rotations, degree of cover, cropping seasons |
| LAND MANAGEMENT | *contour-* farming practices | tillage direction, colluviation at field boundaries | type of tillage, colluviation, conservation practices, maintenance of terraces |

c) Applications

Erosion survey may be done for research purposes, but its main interest lies in conservation planning (Bergsma 1983, 1986). The planning of soil conservation based on surveys of *erosion hazard* has several steps, including land evaluation (Bergsma 1989).

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## 16. MODELS OF RAIN EROSION and CONSERVATION as Central Concept

**Description of erosion by mathematical equations, more or less simplified, using as input the information about erosion factors and having as output the soil loss and/or the overland flow, for a field or hillslope, or the sediment yield and discharge for a catchment area or the effect of erosion and conservation on nutrient losses, yield or benefit/cost of the land use system.**

a) The concept
b) Models for rain erosion subprocesses (such as splash)
c) Models for (total) on-site surface rain erosion
d) Models for gully erosion
e) Models for roadway erosion
f) Models for runoff and sediment yield from catchments
g) Models for the effect of erosion/conservation on soil productivity

a) The concept

a1) Erosion models may be of three kinds (Renard 1977:32) besides expert systems.

a11) STOCHASTIC MODELS, describing *erosion* according to probabilistic laws, with the process developing sequentially in time. For example a probability distribution was used for predicting *sediment yield* in the Negev area (Laronne 1990).

a12) BLACK BOX MODELS, describing *erosion* by some input on erosion *factors* and an output of *soil loss*, without using knowledge of the processes involved (Renard 1977:37). Aspects are:

a) Relationships are found, which may be very useful, but remain pragmatic, and they do not improve insight into the erosion processes.

b) An example of this type of modelling is the multiple regression technique. Results may be, for instance: *sediment yield* as a function of precipitation - temperature ratio, average *watershed* slope, % soil particles coarser than 1 mm in *topsoil*, and the *aggregation* index.

a13) ANALYTICAL COMPONENT MODELS, based on the physics of the *erosion* processes. Aspects are:

a) This type of model is the most expensive for prediction, because of the more detailed physical description of the process, increased computer use and more field data gathering.

b) It should provide the most reliable results of all model types, especially when management alternatives are involved.

c) It may be the main object of future model research.

a14) RULE BASED EXPERT SYSTEMS (Harris & Boardman 1990) are systems to predict *erosion*, based on decision rules of the type "if - then" extracted from a given knowledge base. Aspects are:

a) These systems seek to uncover logical relationships within the database, expressed in the form of rules rather than in the form of mathematical equations.

b) There are two important provisos for these systems. First, the systems work most efficiently within a local domain, as for soil loss prediction.
Secondly, they assumes that there exists in the data some underlying pattern or structure and that the data are not random.

c) Expert systems can complement human expertise for diagnosing and solving complex problems. An example is developed by the Hawaii Soil Erosion Group to produce conservation recommendations (El-Swaify 1989:68).

a2) The statistical, black box approach was necessary at a time when considerable plot and *watershed* data were available for analysis but the physical processes involved were not well understood. Recent advances in understanding basic principles and processes that are involved in *soil erosion* and sediment movement provide knowledge needed for the development of physically based models (Meyer 1981:38).

a3) By careful construction of the model, fewer experiments can be used to develop information that applies to many conditions other than those considered in the research (Moldenhauer & Foster 1981:21).

a4) Fundamental to modelling *rain erosion* is the distinction between transport and *detachment* by rainfall and *runoff*, and the consideration about which process is limiting. Also the *routing* of the sediment from one part of the slope to another is important (Meyer & Wischmeier 1969).
Another fundamental aspect of *erosion* is the transport of material throughout a field. Convex, straight and concave slope forms must be distinguished, instead of assuming a mean slope steepness. In addition, attention has to be paid to lateral slope form also (Onstad a.o. 1967).

a5) One of the complications for describing *erosion* by modelling is the SPATIAL VARIATION OF SOIL SURFACE CHARACTERISTICS. *Soil erosion* itself increases this variability (National Soil Erosion Committee 1981, Toshiro Sakuma & Harunobu Takeuchi 1989).
*Accelerated erosion* in the Hokkaido area with intensive upland *cultivation* was surveyed using photo-interpretation and fieldwork. Spatial variation of soil characteristics was studied in a grid of 20 x 20 metres. The variability proved to be related to *denudation and sedimentation* processes, which depend on the position in the landscape. That means the position on the slope, divergence or convergence of flow lines, downslope form and slope steepness. Spatial differences are also introduced by heavy tillage, causing a mechanical transport of surface soils by cultivation itself.

a6) Stochastic variability can be used for description of hydraulic soil properties in modelling (Bresler 1987). The interest of the farmer is in a few statistical averages over his field, rather than a detailed description of the variables in space and time.
The estimation of space averages of water content, soil salinity, and even crop yield may be relatively simple. The variance due to spatial variability may, in many cases, be much larger than the variance related to the approximations incurred by a model, rendering the use of more accurate models irrelevant. Hence, in spatially variable fields, stochastic modelling may represent realistically the actual field phenomena, and may provide the main statistical moments: mean and variance, by simplified models. These general ideas are expressed in the models that describe:
- non-steady *infiltration*
- subsequent post-infiltration redistribution
- modelling crop yield for a spatially variable field

Inputs required are: *hydraulic conductivity*, air entry value, actual soil water content, soil water content at saturation and at dry state, and two constant empirical coefficients. For the conclusion, it is assumed that the hydraulic conductivity varies strongly, and the other four variables by comparison will vary to an insignificant degree. The space variability is expressed mathematically with the aid of the joint probability density function. Hysteresis and lateral flow are neglected.

a7) Variability depends also on the scale of the study. Plot, field and *watershed* scales are considered in a study that uses the geostatistical technique of structural analysis of the data, which are considered partly random and partly continuous. *Slope length*, slope steepness, *soil erodibility* were analysed by semivariogram. Data came from 80 points in a 60 x 90 cm grid, a 100 x 100 metres grid over 150 ha, and a 1 x 1.5 km grid over 340 km2 area (Rogowski a.o. 1985:149). Experimental and computed data were compared with data generated by a computor erosion-deposition model developed by Khanbilvardi & Rogowski (1984).

a8) Quantification as obtained by models can be used to produce large numbers of data, often for large areas. There is a great potential to combine models, used for extrapolation of relationships to wide areas, with data bases used for storage and manipulation of the data into a geographical information system, GIS. A discussion of the relationships between modelling, databases and GIS is given in Loran a.o. (1989) for the application to *erosion*, conservation and *land use* planning.
An example of USLE data evaluation by means of a data base is given by Pelletier (1985).

a9) Developments in *soil erosion* and *deposition* models is towards the description of *erosion* and the consequent deposition by the processes involved. Sediment flux, *entrainment* and re-entrainment are important (Rose 1985).

b) Models for rain erosion subprocesses

b1) Next to the developments resulting in the USLE, and conceptual models, a development of physically-based erosion models took place. An overview of kinematic wave equations for *overland flow*, and the *interrill* and *rill* terms for *erosion* are given in Lane a.o. (1988) where the shallow water equation, the kinematic wave equations, equations for erosion by overland flow, the interrill term and the rill term are discussed. Simplified equations with analytical solutions are given.

b2) If the concept is valid that the sediment concentration is the outcome of the three dynamic processes of *deposition*, *detachment* and *entrainment*, then the factors relevant to *soil erosion* which we should be measuring or investigating are:
- the efficiency of entrainment
- soil detachability
- the fall velocity of sediment, most of which is transported as *aggregates*.

The rather shattering conclusion is therefore that while many soil factors are routinely measured, those factors on which *erosion* and deposition appear to depend are currently not extensively determined (Rose 1985a:778).

b3) *SPLASH DETACHMENT* - including parameters for *cover* (Morgan 1985:377).
When there is no cover, splash detachment can be expressed as:

$DET = k^b KE$, where
DET = splash detachment
k = experimentally derived measure of the detachability of the soil
KE = *kinetic energy* of the rainfall
b = exponent depending on the *soil texture,* ranging from 0.8 for sandy soils to 1.4 for clayey soils, with a value of 1 being reasonably representative and mathematically convenient. A value of b=1 is valid for bare soil.

One can account for the effect of plant cover by reducing the predicted detachment rate by a ratio that varies with the height, *canopy* cover, and ground cover of the plant assemblage:

$DET = k (KE.e^{-a.INCEP})^b$, where INCEP is the percentage of rainfall that is used in permanent *interception* and *stemflow* and therefore does not contribute to splash detachment (The coefficient probably has a relation with drip). This equation has been adopted for the splash detachment phase in a model to predict the mean annual *soil loss.*
Percentage interception ranges from 0.03 to 0.15, with 0.06 being reasonably representative.
Values of k can be determined experimentally for a series of storms. They are relatively high for crops with large leaves on which raindrops combine and produce *drip* with large drop sizes. In these cases b becomes negative.

b4) When *soil loss* is generated by *sheet erosion,* the interaction of the *raindrop impact* and the surface water flow can be considered in terms of the product of rainfall *kinetic energy* and *runoff* rate. If RUNOFF RATE has not been measured directly, this product can be approximated by replacing runoff rate by the positive difference between rainfall intensity and an average *infiltration rate* for the event (Kinnell 1985:399-405).

b5) *INFILTRATION* of water into the soil (Slack & Larson 1981) is a key process in water management, *runoff* and *erosion.* The Mein-Larson equation which predicts the time when *surface ponding* begins, can be combined with the Green-Ampt equation, corrected for delayed ponding to determine *infiltration velocities* after ponding begins.

b6) The MOISTURE CONDITIONS in the soil will affect the *erosion* process strongly. SWATRE is the simulation model of the water balance of a cropped soil (Belmans a.o. 1983). Parameters are:
- constant or varying rooting depth
- constant or varying output increments
- groundwater level and its maximum change
- flux from the saturated zone
- flux towards ditches and deep percolation
- flux of capillary rise
- precipitation
- soil evaporation
- plant transpiration
- potential evapotranspiration
- depth of soil profile
- depth and number of different *soil layers*
- maximum moisture content
- one third atmosphere point
- wilting point
- saturated *hydraulic conductivity*
- period.

b7) A *RILL EROSION* model is developed by Takagi a.o. (1989).
The water flow at the mouth of the *rill channel* network, and *soil erosion* along the rill channels is recorded. Hourly average rainfall intensities are used in a formula for predicting rill erosion. Exponents in the equation are estimated and *soil loss* is calculated and compared with observed amounts.
Input data are:
- rainfall intensity
- *runoff coefficient*
- total length of each rill or rill *catchment* length
- width of the *basins* annexed to each rill
- *gradient* of the basin annexed to each rill
- duration of the storm

An intermediate output is the water flow rate at a distance x from the source or rill confluence for each rill.
It was suggested that a certain coefficient in the formula represented *soil erodibility* as a function of *slaking*.
The model worked well once concentrated *runoff* had sufficient capability to transport sediment (Takagi a.o. 1989).

c) Models for (total) on-site surface rain erosion

c1) The UNIVERSAL SOIL LOSS EQUATION or USLE - The character of the equation

c11) It is an *erosion* equation designed to compute longtime average *soil losses* from *sheet* and *rill erosion* under specified conditions (Wischmeier & Smith 1978), developed mainly using data from the eastern USA.

c12) The equation groups the many influences on the *erosion* process into five categories:
- climate
- relief
- soil profile
- vegetation and *land use*
- land management practices, including *conservation practices* such as *contouring* and *terracing*.

c13) These five groups of influences, the well known erosion *factors*, are each characterised by a value in the equation. The product of these five values gives the expected *soil loss* in t/acre or t/ha depending on the dimensions used in the climate and the soil factor. The other factors are dimensionless ratios that compare the studied situation with a standard reference situation (Wischmeier & Smith 1978; Meyer 1981:31).

c14) The USLE is: A = R L S K C P, wherein
- A is the average annual soil loss
- R is the *rain erosivity* factor.
- S is the percent slope
- L is the *length* of slope
- K is the *soil erodibility* factor
- C is the *cover* and management factor
- P is the conservation practices factor

(Soil Cons. Soc. Am. 1982:181; Houghton & Charman 1986:118,119).

c15) It is meant to be universal in that the *factors* used are responsible for *accelerated erosion* universally.

c1.6) Because of its clarity it is widely used in education and research as a starting point in developing understanding of *erosion hazard* prediction.

c17) When the predicted losses are compared with given *soil loss tolerances*, the USLE can provide guidelines for effecting *erosion control* by specified practices to bring soil loss to a specified level (Wischmeier & Smith 1978).

c18) It is also useful for construction sites and other non-agricultural conditions, but its does not predict *deposition* and does not compute *sediment yields* from *gully-*, *streambank-*, and streambed erosion, nor from large mixed catchments or single storm events (Wischmeier & Smith 1978).

The UNIVERSAL SOIL LOSS EQUATION or USLE - applications to other countries

c19) Its strength lies in its extensive database from important agricultural regions in the United States. It has helped greatly to extrapolate from a data base to other situations.
Other countries have had difficulties in amassing such a database, and there is some uncertainty in predictive use of the USLE, especially where its hydrologic simplicity may limit its utility, as is the case with Vertisols.

The application of the equation is meant for certain conditions, and care has to be taken to fulfil these conditions (Peterson & Swan ed. 1979) As the USLE was developed from data derived from small plot studies, the validity of extending it to larger areas may be questionable (Rogowski a.o. 1985:161).
Use of the USLE may lead to large errors unless the values proposed for the United States are confirmed by measurements before they are applied in other countries (Bolline 1985:213).

c110) For West Africa the use of the USLE includes adaptations and modification related to the scarcity of data, and the differences with the USA in soils, crops and practices (Roose 1976).

c111) For the application of the USLE in Rwanda, 100 one-year plot data were used to calibrate the equation for local conditions. Erodibility was based on local parent material, crop *cover* was evaluated in 5 classes. An extensive list of C-factors was produced. For the practices, the P-factors were computed (Lewis 1988).

The UNIVERSAL SOIL LOSS EQUATION or USLE - improvements

c112) Because the USLE cannot predict *deposition,* it tends to overpredict *erosion,* particularly on a large area where the use of a sediment delivery ratio is little more than a crude empirical attempt to alleviate the problem (Rogowski a.o. 1985:161). The USLE provides estimates of gross erosion from plot-size areas and does not indicate what leaves the field or *watershed* without the inclusion of a *delivery ratio* factor. The USLE is based entirely on storm energy and the effect of *rainfall impact* and volume on erosion. Research on deterministic, process-oriented models ultimately may complement the USLE and relieve limitations (Rose & Freebairn 1985:549-557).

c113) The USLE is only associated with *rainfall energy.* Following its development, *surface erosion* was described by modifying the USLE to a combination of the effect of rainfall and *overland flow.* The effect of rainfall is usually dominant for short slopes with no vegetative *cover* under intense rains.

c114) The *factors* in the USLE have been modified to be applicable to individual rain storms. For R the *MUSLE* or the Onstad Foster modification has been considered and for C the use of subfactors for prior *land use,* crop- *canopy,* residue-cover and *surface-roughness* is proposed (Laflen a.o. 1985:286).

c115) The *interrill erosion* and *rill erosion* components, the empirical and process-based approach, the contribution of *ephemeral gullies* and the case for non-uniform landscapes are discussed by Foster (1990).

c116) The USLE has been combined with an annual sediment transport equation to estimate average annual sediment yield from *overland flow* areas. It is based on the Yalin sediment transport equation together with a relationship between the USLE's *rainfall erosivity* factor and overland flow characteristics.
In this relationship a *runoff* factor is used which is the product of total runoff volume and peak *discharge* for a storm. *Surface roughness* also is included, partly derived from the effect of surface *mulch. Depression storage* is taken into consideration (Neibling & Foster 1977).

c117) In a major effort by the Agricultural Research Service, USDA, the USLE will be replaced by a less empirical model. The new model is called WEPP, the Water Erosion Prediction Project. It still contains empirical elements. Tropical sites should be included in the development of WEPP, to have a cost-effective approach by making use of all existing information (El-Swaify 1989:64,68).

c2) In MUSLE, the Modified USLE, the rainfall factor R is replaced with a *runoff* factor (Cooley & Williams 1985).

c21) The Williams model predicts small events accurately, the USLE poorly. For the large storms the opposite is true. This suggests that sediment yields for small storms are limited or characterised by the amount of *overland flow* while rainfall characteristics limit sediment yield for large storms. In large storms the readily available amount of *erodible* material becomes exhausted and further supply depends on *detachment* by impact, while the *transport capacity* of the overland flow is sufficient (Cooley & Williams 1985:513).

c22) Amongst the flow parameters used are *runoff* volume and peak runoff rate. They have a relationship with the occurrence of *rill erosion.* For small storms rilling may be more critical for sediment yield than in the case of large storms. The USLE would assume the presence of *rills.* (Cooley and Williams 1985:513), but to a limited degree.

c23) The MUSLE contains a built-in *delivery ratio.* It uses volumes of *runoff* and peak flow rate and should better account for *watershed* conditions, such as *antecedent soil moisture,* because runoff tends to integrate all of the *factors* (Cooley and Williams 1985:516-517).

c24) The MUSLE equation is expressed as:
$Y = 11.8\ (Q \times q)^{.56}$ KCPLS , where Y = sediment yield from an individual storm
Q = the storm runoff volume
q = peak runoff rate and KCPLS are the same factors as in the USLE
The equation was derived using watershed sediment yield; hence the *erosivity* factor expresses the effect of the delivery ratio (Laflen a.o. 1985:286).

c25) The applicability for six small *watersheds* in the Polish Carpathians was studied. Results show a tendency to overpredict the sediment yields using the original parameters. Verification before the application in other areas appears to be necessary (Madeyski & Banasik 1989).

c3) SLEMSA, a Soil Loss Estimation Method for Southern Africa (Elwell 1981:281-292).

c31) The structure of the model is similar to that of the USLE. Four physical systems are recognised: crop, climate, soil and topography. Tillage or management effects on the soil are accounted for in the soil system.

c32) Five control variables are used in these systems: the *rainfall interception* by vegetation, seasonal *rainfall energy*, the *soil erodibility*, *slope length* and steepness.

c33) The model goes on to three submodels, 1) reflecting a crop ratio, 2) a combination of *soil erodibility* and *rainfall energy* representing the soil loss from bare fields of standard topography, and 3) a topographic ratio. For each submodel a nomograph is developed. The *soil loss* is assessed by combining the results of the submodels through a final nomograph.

c4) GUESS. A process-based model developed and described by Rose & Freebairn (1985:549-557). It provides a continuous analytical solution of *erosion/deposition* processes by relating sediment flux to its causative factors. It can be used for approximating *enrichment ratios* and nutrient losses (Rose a.o. 1989).

c41) In this model the amount of sediment transported off a field or a slope is determined by the amount of flow and the concentration of sediment.

c42) It is assumed that the geometrical representation of *land* between *contour bunds* on sloping land or for land of low slope is a plane surface, and that the amount of *runoff* is related to the distance from the top of the slope. Both assumptions can frequently not be accepted.

c43) Determining *infiltration* characteristics from spatially distributed field data is desirable. During rain the infiltration may change because raindrops can affect infiltration velocity by breaking down *soil structure*. Taking this into account, the excess rainfall rate is calculated from measured *runoff* and calculated "average" infiltration.

c44) The *erosion* and *depositon* processes are described by
- rainfall *detachment* by *splash*,
- sediment *deposition* through *settling*,
- rate of sediment *entrainment* by *overland flow* in or between *rills*.

c45) The total sediment concentration c, is:

$$c(L,t) = (a\ Ce\ P^2 / R_1\ I) \sum_{i=1}^{1} (1/\gamma i) + rg\ SKCr\ (1-x^*/L)\ kg/m^3, \text{ while } L \geq x^*$$

If $L<x^*$, the second term is taken to be zero. The first term on the right is the net contribution to c by rainfall detachment over *deposition* ($\gamma i$).
The second term on the right is the net contribution to c by entrainment over deposition. The symbols represent:

c = total sediment concentration, $kg/m^3$
L = length of slope
t = time
a = parameter of detachability of soil by rainfall rate P, $kg\ s/m^4$ (measured by *splash* cups)
Ce = the fraction of the soil surface exposed to raindrops
P = precipitation intensity, m/s
$R_1$ = excess rainfall rate, or runoff rate per unit plane area, a function of t, m/s
I = number of sediment size ranges employed
$\gamma i$ = $1 + vi/R_1$, indicator of deposition, vi is the settling velocity for size fraction i, m/s
r = density of water, $kg/m^3$
g = acceleration due to gravity, $m/s^2$

S = slope of the plane (sine of inclination angle)
K = 0.276eta ($sec^2/m$) where e is: the non-dimensional factor for the efficiency of the entrainment process, even during rainfall, and $0 | <e | <1$
Cr = the fraction of the soil surface unprotected from runoff by *mulch* or stones in contact with the soil surface
x* = the threshold distance downslope where entrainment of sediment commences
x*/L is also (Lo a.o. 1989) expressed as: the critical stream power required to entrain sediment W/m2 over the stream power = r g S q in $W/m^2$, where q = runoff flux $m^2/sec$

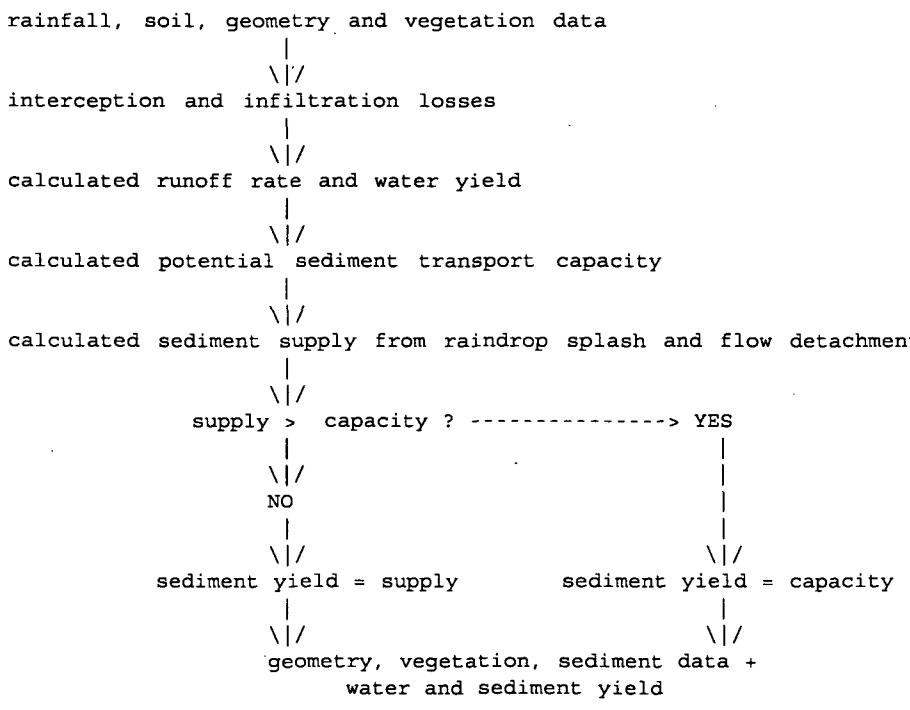
c46) For major *erosion* events ( depth of *overland flow* 5 - 10 mm) the theory may be simplified, "a" being small because greater depth of overland flow protects the soil surface; "e" can, at present, only be determined by fitting the theory to measured data. The first term on the right hand side of the equation is in major events small relative to the second term. This is especially true when a major proportion of the sediment is in the form of relatively large *aggregates* (sum of 1/gi is small). For L>/ 20 m the value of */L is negligible compared to 1.
The equation is then:
c = 2700 SeCr ($kg/m^3$) and Qs, the total sediment loss per unit plane width can be evaluated from:
Qs = 2700SeCrRtL (kg/m). From measured data it appears that there is a strong functional dependence of e on Cr.

c47) A comparison between the *entrainment* efficiency of the GUESS model was made with the *soil erodibility* values of the USLE. For most soils investigated a very good agreement was found (Lo a.o. 1989). Entrainment efficiency is determined for dry and wet experimental runs. Differences in results occur between the two, and it is explained that the breakdown and *slaking* of large *clods* into detachable fragments had not been completed over the duration of the *rainfall simulation* period.

c5) The effect of a SINGLE RAINSTORM is modelled on the basis of soil availability and the force of transport of *runoff*. The availability is determined by the subfactors of raindrop and runoff *detachment* rates and *erosion* rates. The availability of material was found to have a linear relationship with *shear strength* (Chisci a.o. 1985:563).

c6) Estimating ON-SITE *SOIL EROSION* was done by Simons, Ruh-Ming Li & Ward (1977:95-102).

c61) The flow chart shows the conceptual linkage of model components. It is presented here because the model uses components that often are used also in other process description models:



c62) The model is derived for planar surfaces, a constant rain intensity and duration, and instantaneous maximum *discharge* rate. Sediment yield will depend on the overall sediment availability and the total *transport capacity* for the whole *runoff* period. The armouring effect of the water layer and loose soil is assumed to be negligible.
c63) The sediment yield estimation is made according to different sediment sizes. The simulated and actual size distribution of the transported material agree very well.
c64) For reality many of the model steps are too simplified. For instance, for the calculation of the transport capacity use is made of the average flow depth. This in turn is used for the calculation of the average flow velocity (Simons a.o. 1977:97). This is based on the assumption of a planar surface, but the processes themselves will soon modify a planar surface.
c65) A feature that often recurs in other models is the question in the flow chart about the supply of erodible material and the transport capacity of the *overland flow.*

c7) MASL, the Minimum Achievable Soil Loss (Phillips 1989).
c71) The MASL concept was developed as an *erosion control* goal-setting framework which recognises the contraints on erosion control in developing countries.
c72) A physical model was developed for implementing the MASL concept, based on identifying the minimum annual *soil loss,* as a proportion of some maximum or existing level of soil loss, given the *land use,* social, economic and technological constraints on soil conservation, and the natural environment.
c73) It has input requirements which are appropriate for situations where data and data-acquisition are limited.
c74) It is based on the assumption that surface conditions, slope *gradient* and steepness, and *infiltration rate* can be manipulated, while climatic factors and other soil properties can not. The two conditions which determine the ratio of minimum achievable *soil loss* to the present or potential soil loss thus differ only in factors that can be manipulated.
c75) The model is based on Bagnold's stream power concept and a kinematic approximation of *surface runoff.*
c76) The model depends on assumptions of a transport-limited system, *overland-flow* which is adequately described by the *Manning* equation, and sediment *transport capacity* as a function of stream power.
c77) The model assumes a linear slope and no convergence or divergence of flow.
As these assumptions are unrealistic for most real slopes, subdivision of slopes into regular facets, or adjustment factors for slope forms are suggested to obtain more realistic results (Young & Mutchler 1969; Moore & Burch 1986; Wischmeier & Smith 1978).

c8) The Precipitation-Runoff Modelling System, PRMS (Carey & Simon 1984).
c81) Simulation of upland *erosion* by the PRMS requires the user to estimate two rainfall *detachment* parameters and three hydraulic detachment parameters.
One rainfall detachment parameter can be estimated from *rainfall simulator* tests. The second parameter can be computed directly from rainfall detachment.
The three hydraulic detachment parameters consist of one exponent and two coefficients. The exponent may generally be put at 1.5; one coefficient reflects the soil's *resistance to erosion* and the other accounts for the sediment delivery process. Their values can be derived from other model studies or published empirical relationships.
c82) Interrill *detachment,* interrill transport, rill detachment and rill transport are distinguished. Important are critical *shear stress,* dampening *raindrop impact* by *surface ponding,* areas of *erosion* and areas of *deposition.*

c9) WEPP = Water Erosion Prediction Process
c91) An model simulating the main processes of soil erosion, of which runoff is an important one (Lane & Nearing 1989).
c92) The parameters can be determined by using a simplification: the empirical relationship with readily measurable soil and vegetation characteristics.
c93) It can be used to simulate the impact of vegetation change to rangeland water cycles (Wilcox a.o. 1992).

c10) For all models the FREQUENCY OF TYPES OF SHOWERS is important to consider.
In areas with a pronounced dry season, some very heavy showers may cause most of the *erosion*, as for instance on the Cape Verde Islands. In these conditions average long term *soil loss* or *runoff* data have not much meaning.
A probability distribution was used for predicting sediment yield in the Negev area (Laronne 1990).

c11) A computer erosion-deposition model is developed by Khanbilvardi & Rogowski (1984).

d) Models for gully erosion

d1) Thorne & Zevenbergen (1990) developed a prediction model for ephemeral *gully erosion* in the south-eastern United States.

d11) The method is intended to predict ephemeral gully erosion only for the first year of gully development - that is from gully initiation following *seedbed* preparation to its eradication about one year later by annual tillage.

d12) The basis of the method lies in the analysis of field topography, topographic lows and swales where flowlines converge to produce concentrated *overland flow* (Zevenbergen & Thorne 1987). The technique is easy to use and does not require data to be collected over long periods.

d13) The index to predict the intensity of the process is called the Compound Topographic Index, CTI. It incorporates the upstream drainage area and local slope, representing streampower. A threshold value is needed for the stream to initiate incision. This value varies according to climate, soil, crops, management and practices. It is calibrated for the site in question.

d14) Gully cross-sectional area is then derived from an equation including the CTI index. A nomograph helps to determine the cross-sectional area and CTI from field data.

e) Models for roadway erosion

e1) The model ROSED, Road Sediment.It has components for *interception, infiltration, overland flow routing* using a kinematic wave assumption, sediment *detachment* and transport using *raindrop splash* and *shear stress* from overland flow. The model treats *cut and fill* slopes, road surfaces, ditches, and *culverts*. Road characteristics include *gradient*, length, width, ground *cover*, sediment size distribution and *infiltration* characteristics. The model has been applied to forest and mine haul roads (Ward 1985:190).

f) Models for runoff and sediment yield from *catchments*

f1) ANSWERS, The Areal Nonpoint Source Watershed Environment Response Simulation model (Beasley 1982, 1983).

f11) It is used primarily to assess impacts of alternative management schemes on agricultural *land*.
The model allows simulation of phenomena with spatial and temporal changes such as *runoff*, drainage, *erosion*, and transport. The ANSWERS model is event oriented. It can incorporate different management scenarios on all or a portion of the *watershed*, for instance different tillage methods with their effect on *surface roughness, infiltration velocities*, and *surface retention*. It was modified to predict phosphorus transport.

f12) It is also used for comparing sediment control practices related to CONSTRUCTION SITES (Dillaha a.o. 1982). In a study in Indiana, practices were compared between each other and in relation to the preconstruction response of the *watershed*, using a design storm concept (8 year *recurrence period)*. The *catchment*, prior to construction, had a *land use* of 85 % row crops, mainly corn, 15 % trees and 2 % lowlands. Typical construction practices left the soil in an exposed, disturbed state resulting in sediment yields exceeding those under the area's original *land use*. A major problem in planning and maintaining effective sediment control on construction sites is predicting accurately the movement and fate of sediment.
Often the USLE is used with a sediment *delivery ratio*, to describe the effects of sedimentation between the area of *erosion* and downstream. This is a lumped parameter model. ANSWERS workes better because it includes the spatial variability of the controlling parameters.
Results showed that seeding of exposed areas, gravelling of roadbeds, and exposing as little soil as possible resulted in smaller *soil losses*.
Structural measures such as sediment basins and *diversions* produced variable sediment yields. With proper management, sediment yields on construction sites can be lower than on the same *land* in row crops.

f2) A simplified sediment yield model SIMSED (Cotton & Li 1985)

f21) It is physically based and can be solved with a hand held calculator. It can be applied over a wide range of soils, covers, and treatment conditions. Transport by splash is ignored. Total sediment supply is the sum of raindrop plus flow *detachment*. If the sediment supply from raindrop detachment exceeds the sediment *transport capacity*, flow detachment for the time interval becomes zero and the supply from raindrop detachment would account for the total supply.

f22) If the supply exceeds *transport capacity*, than transport capacity controls sediment yield. If transport capacity exceeds available supply, then the supply controls sediment yield. Determination of the controlling factor is made for each time interval and particle size.

f23) The *catchment* conditions are described by:
- catchment area
- slope (average slope of catchment)
- ground *cover*
- slope *roughness* for *overland flow*
- *soil detachment* coefficient (function of % clay)

The hydrologic conditions are described by:
- hydrologic soil group, depending on the surface characteristics, disturbed areas and reclaimed areas.

The sediment supply and transport conditions are described by:
- overland flow rate
- total raindrop detachment
- sediment *transport capacity* (four sediment size classes)
- critical flow coefficient

f24) The application of SIMSED is to compare sediment control practices and structures on small *catchment* areas of mined *land*.

f3) The Stanford Watershed Model (Egbuniwe 1981:453-454).

f31) The model describes the hydrological cycle from precipitation to outflow from the *watershed* by mathematical equations for processes. It is a water accounting system in which occur:
- the soil water status
- the sum of all applied water
- minor gains or losses
- *discharge*
- deep percolation
- *evapotranspiration*.

f32) It is a lumped, conceptual model, useful for a wide variety of problems, provided that flow data are available for calibration (Morris 1981:431).

f33) When the parameters have been adjusted to the case study to make the model reproduce closely the recorded streamflow, individual parameters may be varied to simulate various conditions that are expected in development plans for the area.

f4) The Agricultural NonPoint Source pollution model, AGNPS model (Young a.o. 1987; Onstad & Young 1989).

f41) The model was developed to provide estimates of *RUNOFF* WATER QUALITY from agricultural *catchments* (in Minnesota). The model simulation predicts runoff volume and peak rate, *eroded* and delivered sediment, nitrogen, phosphorus and chemical oxygen demand concentrations in the runoff and the sediment, for single storm events for all points in the *watershed*.
After a catchment has been identified as having a potential pollution problem, remedial measures can be recommended based on an assessment of the effects of applying alternative management practices.

f42) The model is event-based and simulates sediment and nutrient transport from agricultural *catchments*.
Basic model components are:
- hydrology
- *erosion*
- sediment and chemical transport.

In addition it considers:
- point sources of sediment from gullies
- *inputs* of water, sediment, nutrients and chemical oxygen demand from animal feedlots.
- water impoundments such as tile-outlet *terraces* as *depositional* areas for sediment and associated nutrients

f43) The model operates on a cell basis. The cells subdivide the *catchment.*
Potential pollutants are routed through cells from the catchment *divide* to the outlet in a stepwise manner so that flow at any point may be examined. For catchments of over 800 hectares, a cell size of 16 hectares is recommended, with smaller cell sizes for smaller catchments.

f44) The hydrology for the model is based on the *runoff curve* number system, but it will be replaced by the Green-Ampt *infiltration* approach. Peak *runoff* rates are estimated using an equation from CREAMS. *Soil loss* is estimated using a modified form of the USLE for single storms, and development is towards the incorporation of the WEPP relationships. Upland detached sediment is routed through the *catchment.* Effective *transport capacity* is computed using a modification of the Bagnold stream power equation.

f45) The chemical transport portion of the model estimates nitrogen, phosphorus and chemical oxygen demand throughout the *catchment.* The substances are divided in soluble and non-soluble.

f46) Overview of parameters:
Input (in each cell):
- cell number into which a cell drains
- hydrological curve number
- average land slope
- slope shape: convex, straight, concave
- average field slope length
- average *channel* slope
- average channel side slope
- *Mannings roughness coefficient* for the channel
- *soil erodibility factor K* of the USLE
- cropping factor C of the USLE
- practice factor P of the USLE
- surface condition factor ~ *land use*
- aspect (one of eight as principal drainage direction from the cell)
- *soil texture* (sand, silt, clay, peat)
- fertilisation level
- incorporation factor (% fertiliser left in top 10 cm of soil)
- point source indicator if needed
- *gully* source level
- chemical oxygen demand factor
- impoundment factor (impoundment *terraces* within cell)
- channel indicator (existence of a defined channel in the cell)

Output (from each cell):
on hydrology:
- *runoff* volume
- peak runoff rate
- fraction of runoff generated within the cell

on sediment:
- sediment yield
- sediment concentration
- sediment particle size distribution
- upland erosion
- amount of *deposition*
- sediment generated within the cell
- *enrichment ratios* by particle size
- *delivery ratios* by particle size

on chemicals:
- nitrogen, sediment associated mass
  concentration of soluble material
  mass of soluble material
- phosphorus, sediment associated mass
  concentration of soluble material
  mass of soluble material
- chemical oxygen demand,
  concentration in runoff

f5) GAMES is the Guelph model for evaluating the effects of Agricultural Management systems on Erosion and Sedimentation (Dickinson a.o. 1990)

f51) It was developed to predict water erosion and the subsequent delivery of sediment from field to stream and downstream in agricultural areas.

f52) Components of the model are:

a) *soil loss,* by a modification of the USLE

b) the percentage of soil loss delivered to downstream fields and the main stream by a sediment delivery function which incorporates in turn:

- *surface roughness*
- land slope
- hydraulic condition
- length of the *overland flow* path

f53) There are field size land cells. A seasonal time frame allows variation in rainfall characteristics, *soil erodibility,* and land management-conditions which affect *soil detachment* and transport.

f6) A determination of the *Manning's roughness factor* can be made by assessing the surface irregularity, the obstructions to *overland flow,* the proportion of basal ground *cover,* and the type and height of the vegetation (Phillips 1989:229).

FACTORS THAT DETERMINE THE MANNING ROUGHNESS COEFFICIENT (n = n1 + n2 +v3n4)

| | | |
|---|---|---|
| Degree of irregularity of the surface (n1) | | |
| Minor | 0.001 - 0.013 | Minor irregularities; a few rises and dips |
| Moderate | 0.014 - 0.025 | Frequent rises and dips; significant depressions and small ridges may exist |
| Severe | 0.026 - 0.050 | Very irregular. Many rises, dips, small depressions and ridges; or furrows perpendicular to flow |
| Obstructions (n2) | | |
| Negligible | 0.000 - 0.010 | A few scattered (*debris,* stumps, exposed roots, ogs, isolated boulders); occupy < 5 % of area |
| Minor | 0.011 - 0.048 | Occupy 5 - 15 % of area |
| Appreciable | 0.049 - 0.076 | Occupy 15 - 50 % of area |
| Vegetation cover (v3) | | |
| Proportion | 0.000 - 1.000 | Proportion of ground vegetated |
| Height and characteristics of vegetation (n4) | | |
| Small | 0.001 - 0.025 | Flexible, supple vegetation; flow depth 2 to 3 times plant height |
| Medium | 0.026 - 0.063 | Flow depth 1 to 2 times plant height; or 2 to 3 times for dense woody or stemmy plants |
| Large | 0.064 - 0.126 | Depth of flow more than half plant height, or forest if hydraulic radius > 0.6 metre |
| Very large | 0.127 - 0.252 | Depth of flow less than half plant height; heavy timber stand with flow below branches |
| Extreme | 0.253 - 0.504 | Dense vegetation with heavy litter in full foliage; maximum flow contact with branches and foliage |

g) Models for the effect of erosion/conservation on soil productivity

g1) EPIC, Erosion Productivity Impact Calculator (Williams a.o. 1983; Williams 1985; Williams & Renard 1985; Jones a.o. 1985)

g11) *Land productivity* as affected by *erosion* is approximated by the model EPIC (Williams a.o. 1985). A parameter to express productivity is the PRODUCTIVITY INDEX (Pierce a.o. 1983). An international application and adaptation is presented in Rijsberman & Wolman (1984, 1985) with case studies from USA, Hawaii, Nigeria and India using the Productivity Index described by Pierce a.o. (1984).

g12) EPIC was developed specifically for application to the erosion- *productivity* problem. User convenience was an important consideration in designing the model. The model works with a daily time step, and can simulate many years of *erosion* development.
The drainage area considered by EPIC is relativel small, about 1 ha, because in the model soils and management are assumed to be spatially homogeneous. The model can accomodate any profile variation with depth, and can describe ten soil layers. The upper horizon thickness is set at 10 cm, and by erosion it will become the second horizon, and absorb gradually its qualities, and if erosion continues the upper horizon becomes the third layer, etc.
It is generally applicable to the USA. It can use *inputs* from large data bases such as those of the USDA Soil Conservation Service files. It can deal with management effects and changes. It can link up with economic models, and simulate long periods. The model is discussed in the general context of the effects of soil erosion on soil productivity by Renard & Follett (1985). An application is briefly reported in Williams a.o. 1990.

g13) Components of the hydrology of the model are:
- *surface runoff,* predicted by a model similar to CREAMS, but EPIC has a variable soil layer thickness and includes a provision for estimating *runoff* from frozen soil. Required data are: daily rainfall, hydrological
  curve number, moisture *retention,* which is related to the soil moisture content
- peak runoff rate, predicted from a modification of the *rational-formula.*
  Required data are: *time of concentration* involving *channel* length, *Mannings roughness factor,* average channel slope, *watershed* area.
- percolation into the root zone, predicted from a storage *routing* technique and a crack flow model. Flow through a soil layer may be reduced by saturation of a deeper layer. Required data are: the *hydraulic-conductivity, field capacity,* the clay content of each soil layer, soil temperature (frost can be taken into account). In a crack flow model use is made of the amount of cracking
- lateral *subsurface flow,* using lateral flow travel time as in percolation
- presence of an artificial drainage system
- *evapotranspiration,* predicted from: daily solar radiation and the albedo of the soil, crop and snow cover, the above ground *biomass,* the mean air temperature, daily average air temperature, the *leaf area index,* plant evaporation when water supply is limited.
- irrigation
- snowmelt

g14) Because of the crude time step of one day, the hydrological flow processes are simulated by using 4 mm increments of water for wetness changes.

g15) Weather data include the daily precipitation, maximum and minimum air temperature, solar radiation, and wind. There are options for missing data to be generated by simulation.

g16) Soil properties used are: plant available water, field water-holding capacity, *hydraulic conductivity, bulk density,* temperature, *slope length* and steepness, pH, *texture,* cation exchange capacity, Al-concentration, organic carbon, salinity, exchangeable sodium percentage.

g17) *Erosion* is calculated using the modified USLE with a rainfall and a *runoff factor.* Under irrigation, the erosion in the *furrows* is estimated by using the *MUSLE.*

g18) Nutrients. A submodel for the N and P budget includes fertilisation, organic and inorganic transformations, crop demand and uptake of N and P (Jones a.o. 1985). It includes denitrification, leaching of nitrate, losses by wind and water erosion. N budget factors are: amounts of N contained in the *runoff,* lateral flow and percolation are estimated as the products of the volume of the water and the concentration, organic nitrogen transport by sediment, denitrification, mineralisation, immobilisation, crop uptake, addition by rainfall, fertiliser. The phosphorus regime is predicted from: soluble P in *surface runoff,* P transport by sediment, mineralisation, immobilisaton, cycling of mineral P, crop uptake.

g19) Crop growth model, involving potential growth and growth constraints.

g110) Tillage.

g111) Economics, the model keeps a budget of crop cost and yield.

g112) Policy, links with policy models for *watershed management* are possible.

g2) The model SOILEC for the on-site physical and economical effects of *erosion* (Dunsday & Seitz 1985:296-306).

g21) To quantify the payments to be made under a conservation contract program, a model SOILEC was developed for the on-site physical and economical consequences of erosion.

g22) The model uses the USLE to estimate the *soil loss*. Four erosion rates are recognised:
- no erosion
- medium erosion = 100 mm of *soil horizon* A remaining
- severe erosion = no horizon A remaining
- very severe erosion = no A or B horizon, only parent material remaining

g23) Costs and yields are related to each of the erosion states, accompanied by linear interpolation between the erosion states.

g24) The model operates from 8 groups of assumptions, dealing with:
- discount rates
- prices
- technological change
- residue production
- mechanical control practices
- rotation tillage cover factors
- rotation-tillage budgets
- location/soil characteristics

g25) The physical output of the model includes *soil loss*, crop yield, and depth of soil. The financial output of the model includes for each management system, and in comparison with a base management system: net present value over time, remaining annual soil loss, reduction in annual soil loss, and cost of reducing erosion.

g3) THEPROM, the Theoretical Erosion Productivity Model (Biot 1990).

g31) It is developed to calculate the residual suitability of *land*, and it can be used to study the dynamics of the *land use system* and its responses to management.

g32) The residual suitability is calculated from:
- definition and calibration of a productivity index
- design and calibration of a *land use* model which contains the productivity index and the way in which this is affected by the prevailing *land degradation* processes
- integration of the land use model between the present and the minimum allowable *productivity* level of land, the latter as determined by socio-economic criteria

g33) Different degrees of sophistication of the modelling components are allowed, depending on resource and data availability

g34) The *land use system* involves vegetation, *litter*, organic matter, and mineral soil.

g35) The link between soil and vegetation is made through the proposed productivity index AWSC (Available Water Storage Capacity). This index is calulated from data on the effective rooting depth and the available water capacity.

g36) Underlying assumptions and sources of inaccuracy are discussed in the case of an application to *rangeland* in Botswana (Biot 1989).

g37) A concept deduced from AWSC modelling of *erosion* effects is the residual economic lifespan of the soil. This concept depends on the minimum allowable level of AWSC. This minimum will be different for different *land use*, and therefore the application should be made carefully so as not to preclude changes in land use which may become advisable in new market or technological conditions.

g4) SCUAF, Soil Changes Under Agro-Forestry, a model developed to indicate soil changes in *agroforestry* conditions. (Young 1987; Young a.o. 1987; Young & Muraya 1989).

g41) It is designed to estimate soil changes under specific agroforestry systems, and to compare these with changes under other *land use systems*. It currently predicts changes in rates of *erosion*, soil organic matter and nitrogen levels.

g42) There are eight sets of input data:
- environment
- spatial and temporal structure of the agroforestry system
- initial soil conditions
- plant growth
- removals
- organic additions
- soil processes

g43) Where data are lacking the model provides best estimates by a system of default values. The outputs are estimates, for a period specified by the user, of:
- changes in soil organic carbon
- changes in *soil erosion*
- changes in plant growth, as brought about by the soil
- changes in harvest

g5) CREAMS, assessing Chemicals, Runoff and Erosion of Agricultural Management Systems (Knisel 1980).

g51) It is a field scale model that comprises three submodels: hydrology, *erosion* and chemistry which predict the volume of *runoff*, the rate of erosion and the loss of dissolved and adsorbed chemicals (Knisel 1980). The erosion submodel is the USLE, so that its application for a certain area depends on validation of the USLE for that area.

g52) The applicability of the model for predicting hillslope *runoff* and *erosion* was investigated in the Silsoe area of Bedfordshire, England. It was suggested that the model needs calibration with local data whenever possible (Morgan a.o. 1987).

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## 17. MULTIBAND REMOTE SENSING and EROSION as Central Concept

TERM: remote sensing = teledetection
The subject is here restricted to multiband use of remote sensing data.

***Related terms:*** greenness
soil brightness
leaf area index
soil line

**The collection of information about an object or phenomenon by the use of sensing devices not in physical or close contact with the investigated subject.**

a) The concept
b) Radiation from soil
c) Radiation from sparse vegetation
d) Radiation from cultivated plants
e) Geo-information systems (GIS's) to handle the satellite data
f) Satellite data interpretation and mapping in erosion studies

a) The concept

a1) In a general sense it includes the use of aerial photography as well as other forms of electromagnetic recording; in a more narrow sense the use of airphotos is sometimes excluded, referring specifically to multispectral data mostly recorded by satellites (Mulders 1987).

a2) The study of *natural resources* usually employs aeroplanes or satellites with devices recording electromagnetic energy received from the earth's surface (Mulders 1987).

a3) The distance of separation between device and subject is often several hundreds of kilometres, as in the case of satellites orbiting the earth (Houghton & Charman 1986:100).

a4) Typical of the satellite data is that they can be (Mulders 1987):
- multispectral, observation in different wavebands, to obtain a spectral signature of an object
- multistational, observation from different positions, enabling stereoscopic observation of overlapping areas
- multitemporal, observation at different dates or seasons, enabling study of the dynamics of such features as plant growth, flooding, grazing.

b) Radiation from soil

b1) General information on remote sensing can be found in handbooks. An example is Mulders (1987), which contains chapters on:
- Image characteristics,
- Aerial photography,
- General directions for physiographic interpretation of remote sensing imagery in soil mapping,
- Interpretation of airphotos for soil mapping and *land evaluation,*
- Airborne line-scanning in the 0.3 - 8 mu zone,
- Remote sensing from space in the 0.3 - 3 mu zone,
- Thermal infrared line scanning and radiometry in the infra-red and microwave zones.

b2) Different soils have different reflection curves, depending on several soil properties: These properties are mainly: moisture zone defined by Thornthwaite index, parent material, *cultivation,* slope, internal drainage, *texture,* colour, organic matter content, iron oxides, moisture content; these properties are related to the soil classification with family modifiers (Stoner a.o. 1980).
Types of soil spectral reflectance curves can be distinguished according to curve shape, presence or absence of absorption bands, and dominant soil organic matter and iron oxide composition. Some of these properties show a correlation with the soil classification system of Soil Taxonomy (Stoner & Baumgardner 1981).

b3) The *SOIL SURFACE ROUGHNESS* has an influence on the spectral response of bare soils in the visible and the near-infra-red range. This influence is described by a model which contains as a parameter the shadowed area of soil fragments. The study involved 12 soils on different slopes between 0 and 30 degrees (Cierniewski 1987).

b4) The measurement and estimation of reflectance FACTORS has to be done with care and precision. The errors due to different arrangements of radiometer and targets play a role (Marjoram a.o. 1985:187-194).

c) Radiation from sparse vegetation

c1) For the study of *erosion,* an important question is how well satellite information can indicate soil protection by plant material against rainfall.
Questions arise such as:
- how can bare soil be recognised ?
- how can low degrees of *plant cover* be recognised ?

c2) The ratio of the relative reflectance in the 0.58-0.62 mu band to the relative reflectance in the 0.80-1.00 mu band can be used to observe increases in ground *cover.* This is the ratio of the relative reflectance in the chlorophyll absorption band to the relative reflectance in the near infrared band.
Chlorophyll absorbs at 0.65 mu in the visible wavelengths, and it is assumed that as the *canopy* becomes more dense it would absorp more strongly, and hence reflect less, in this region.
The 0.72-1.3 mu wavelength range is the region in which little absorption takes place in green vegetation and in which almost all light is transmitted or reflected. Multiple leaf layer experiments have shown that reflectance in this wavelength region increases with increasing leaf layers. Therefore the reflectance of a crop *canopy* may be expected to increase in this region when canopy density increases.
Soil reflectance generally increases slightly in going from the red wavelength region to the near infra-red wavelength region. The amount of increase for a particular soil depends mainly on the soil moisture content.
With the increased reflectance in the near infra-red and the increased absorption by chlorophyll with increasing crop cover, the ratio between the two bands (chlorophyll absorption band over the near infrared band) would decrease with increasing crop canopy. The value of the ratio can be used to make an estimate of the crop density, for a given crop and a given soil.

c3) The problem is especially noticeable in arid and semi-arid environments.
*Canopy* spectral responses can vary with the amount of soil exposed, soil colour, soil moisture, and cultural practices. Indices have been developed in an effort to distinguish green vegetation and soil background (Huete a.o. 1984).
Kauth and Thomas (1976) and Kauth a.o. (1979), in a study of the distribution of soil spectra in four-dimensional Landsat MSS signal space, found most of the variability of bare soil signals to be attributed to *SOIL BRIGHTNESS.*
Soil spectra vary with surface moisture content, organic matter content, particle size distribution, soil mineralogy, *soil structure, surface roughness, crusting* and presence of shadow (Huete a.o. 1984).
The 4-space diagonal line, describing maximum variations in soil spectral response, has been named *SOIL LINE* or *SOIL BRIGHTNESS* VECTOR (Kauth & Thomas 1976; Richardson & Wiegand 1977).
The emergence of green vegetation over a soil causes composite red radiance to decrease because of chlorophyll absorption and overall infra-red response to increase as a result of leaf mesophyll structure. Thus, deviations of spectral data from the bare *soil line,* in an appropriate direction, may be attributed to the presence of GREEN *BIOMASS* (Huete a.o. 1984).
Richardson & Wiegand (1977) using infra-red and red band combinations, developed a two-dimensional perpendicular vegetation index (PVI) with the orthogonal distance of a spectral point to the soil line as the measure of VEGETATION DENSITY (Huete a.o. 1984).
Although the soil line may shift with atmospheric conditions and Landsat calibration factors, it has generally been assumed that there exists one unique soil line emcompassing a wide range of soil types and soil surface conditions (Huete a.o. 1984).
Jackson a.o. (1980) reported deviations from linearity when a wide spectral range of soils were plotted. Such deviations among soils could shift the slope of the soil line and alter the orthogonal distance of a vegetation signal to the soil line. Thus, in areas where the soil line does not match that derived by Kauth & Thomas (1976), *GREENNESS* may become sensitive to soil background and vegetation analysis becomes less reliable. Furthermore, bare soil spectral deviations from the soil line in the *soil brightness* - plant greenness plane (Kauth & Thomas 1976), may interfere with the discrimination of green vegetation from bare soil (Huete a.o. 1984).
The width of the soil line precluded greenness assessment below 25 *% cover* (Huete a.o. 1984).
For greater accuracy, separate soil-dependent greenness scales would have to be developed since the full canopy wheat point, with no soil showing, is independent of soil background (Huete a.o. 1984).

Data on various mixtures of vegetation with different soil backgrounds can be compared using measures of greenness, including the near infra-red - red band ratios and the perpendicular vegetation index. Greenness measurements appeared to depend strongly on *soil brightness*. Soil-induced greenness changes were greater with increasing amounts of vegetation, up to 60% green cover. It is concluded that soil and plant spectra interactively mix in a non-additive, partly correlated manner to produce composite *canopy* spectra (Huete a.o. 1985).

It appeared that the soil effects on vegetation indices can be separated into three categories (Huete & Tucker 1991):

- shifts in the soil line owing to atmospheric or soil composition, affecting the *brightness* of bare soil.
- soil variance related to surface artifacts such as lag gravel, in this study area derived from ferruginous shales and limestone deposits. It gives a darker colour to the soil which affects reflectance factors, while at the same time reducing the number of digital counts.
- soil-vegetation spectral mixing. Increasing organic matter contents are associated with higher *biomass* amounts, leading to darker surface conditions, which may also be caused by the associated plant shadowing and more humid atmospheric conditions regionally.

c3) The density of open vegetation can be approximated in certain conditions by using band ratios. Estimation of the vegetation contribution to the 1.65/2.22 mu ratio in airborne thematic-mapper imagery was made for the Virginia Range, Nevada. The ratio of band 9/7 is corrected for the presence of sparse vegetation by its relation to the leaf water content, reflected in the near IR/red ratio, 083/0.66 mu. The vegetation is characterised by the *leaf area index*. In that way the soil and vegetation components are separated (Elvidge & Lyon 1985).

d) Radiation from cultivated plants

d1) The soil and sun angle interactions on partial *canopy* spectra play a role in the reflectance behaviour. An incomplete cotton canopy where the soil and plant spectral contributions were separated, showed that canopy reflectance behaviour in relation to solar angle depended on the reflectance properties of the underlying soil. Sunlit and shadowed soil surface parts changed the vegetation index behaviour with sun angles (Huete 1987).

d2) The green *LEAF AREA INDEX*, LAI (Baret a.o. 1988, Clevers 1988, Huete 1988) is a *canopy* parameter defined as the horizontal leaf surface area (one side of the leaves only) per unit of ground area.

d21) It is used to describe *canopy* structure.

d22) It is a measure for the state of grassland, the *biomass* of a vegetative *cover* (Wardley & Curran 1984).

d23) It varies from 0.0 for bare soil to 10 for annual crops and more than 15 for very dense *perennial* forest.

d24) Percentage ground cover plotted against LAI gives a convex up curve, with a rather linear part from no cover up to 80 % cover (Stoner, Baumgardner & Swain 1972).
The LAI has a linear relationship with the ratio of channels 8/7 that are 0.82/0.65. The line may have a shift in ratio values and a small rotation depending on flight date (Stoner, Baumgardner & Cipra 1972).

d25) The index has a steep concave relationship with the ratio of channels 1.20/0.65 mu (Stoner, Baumgardner & Cipra 1972), a linear relationship with the ratio of normalised bands 1.65/2.22 mu (Elvidge & Lyon 1985) except for full ground cover, and a linear relationship with the ratio of channels 0.82/0.65 mu (Stoner, Baumgardner & Cipra 1972).

d26) *Canopy* spectral responses depend not only on vegetation parameters but also on soil background and other factors. Vegetation indices were developed to distinguish the influence of vegetation from that of soil background and irradiance geometry, which create noise around the relationship of canopy parameters and reflectance.

d27) The Normalised Difference Vegetation Index, NDVI, is a vegetation index that enhances the contrast between soil and vegetation reflectance or radiance in the red (Rred) and near-infra-red (Rnir) space. It is determined as: NDVI = (Rnir - Rred) / (Rnir + Rred)

d3) Total *biomass* can be used as an indicator of *plant cover*. In the case of fescue grass vegetation Landsat Thematic mapper bands were selected for characterising the biomass. TM band 4 was the best estimator of total wet biomass and *canopy* height.

d4) The percentage *canopy cover* was best correlated with TM band 7 and TM bands 1,2,3 (r=0.93). Canopy cover showed a linear relationshp with spectral reflection. Band ratios were more significant than individual bands (Ripple 1985:1373-1384)

d5) The growing seasons will have different crop covers in the case of annuals and some *perennials*. This variation can be detected and quantified to some extent by certain indices, which in certain conditions also allow to make a spectral estimate of yields (Wiegand 1984) to be made.
Indices for plant cover and *biomass* are for instance:
- *canopy* temperature
- vegetation indices such as *greenness*
- *leaf area index*
- percent cover
- estimates of light absorption.

e) Geo information systems (GIS's) to handle the satellite data

e1) The Bolivian digital geographic information system is an example which shows the advantages and disadvantages of grid and polygon information systems (Bartolucci a.o. 1983).

f) Satellite data interpretation and mapping in erosion studies

f1) Combining digital maps and terrain data (height) with Landsat can be done in different ways:
a) preclassification scene strata
b) postclassification class sorting
c) classification modification by more channels and by probabilities.
It appeared that a) and b) are efficient but suffer from deterministic decision rules, c) can improve accuracy but needs many more observations than the others (Hutchinson 1982).

f2) Digital analysis of satellite data only is insufficient for *erosion* studies in most cases. The use of the satellite information is most useful when a COMBINATION OF DIGITAL AND VISUAL ANALYSIS of the data is made. Support by AIRPHOTO-STUDY AND FIELDWORK is essential in most cases.
In an area of central Tanzania, with a semi-arid climate, erosion was studied on airphotos and Landsat images by the *land use* and land *cover*. Field survey data were used about lithology, soils and vegetation. Three intensities of erosion could be recognised, which occurred in association with certain landforms (Mushala 1986).
A comparison between digital Landsat MSS and visual Landsat MSS in combination with airphotos is an example of a good basis for the analysis of soil erosion. The reference for results of Landsat data interpretation and for aerial photo-interpretation was intensive fieldwork done previously in an area near Bogota, Colombia (Mower & Ardila 1984).
Although the use of digital remotely-sensed data offers the possibility of developing and applying automated methods of classification, algorithms which allocate image pixels to classes cannot be applied in the absence of any JUDGEMENT ON THE PART OF THE OPERATOR. One way in which this judgement may be exercised is through the process of REGIONALISATION. The division of an area into regions may serve to establish the limits of extrapolation of relationships between ground properties and remotely sensed data (Haines-Young & Mather 1981).

f3) As soils are three dimensional pieces of landscape a soil map shows differences in relief as well as in soil profiles. Therefore the mapping of soils can be a good basis for the study of *erosion* and *erosion hazard*. A case of soil mapping using remote sensing techniques is given in Karale a.o. (1984).

f4) *Erosion* in dry areas can be recognised by the variations in vegetation over a distance. In areas with open vegetation, limited by moisture availability, erosion will cause locally uniform absence of vegetation. Such patterns can be analysed by the use of certain band ratios, i.e. 4/6 plotted against 5/6 MSS. Using the mean, variance and spatial autocorrelation, areas of *SOIL EROSION*, STABILITY AND *DEPOSITION* in arid central Australia could be distinguished (Pickup & Nelson 1984; Pickup & Chewings 1988).

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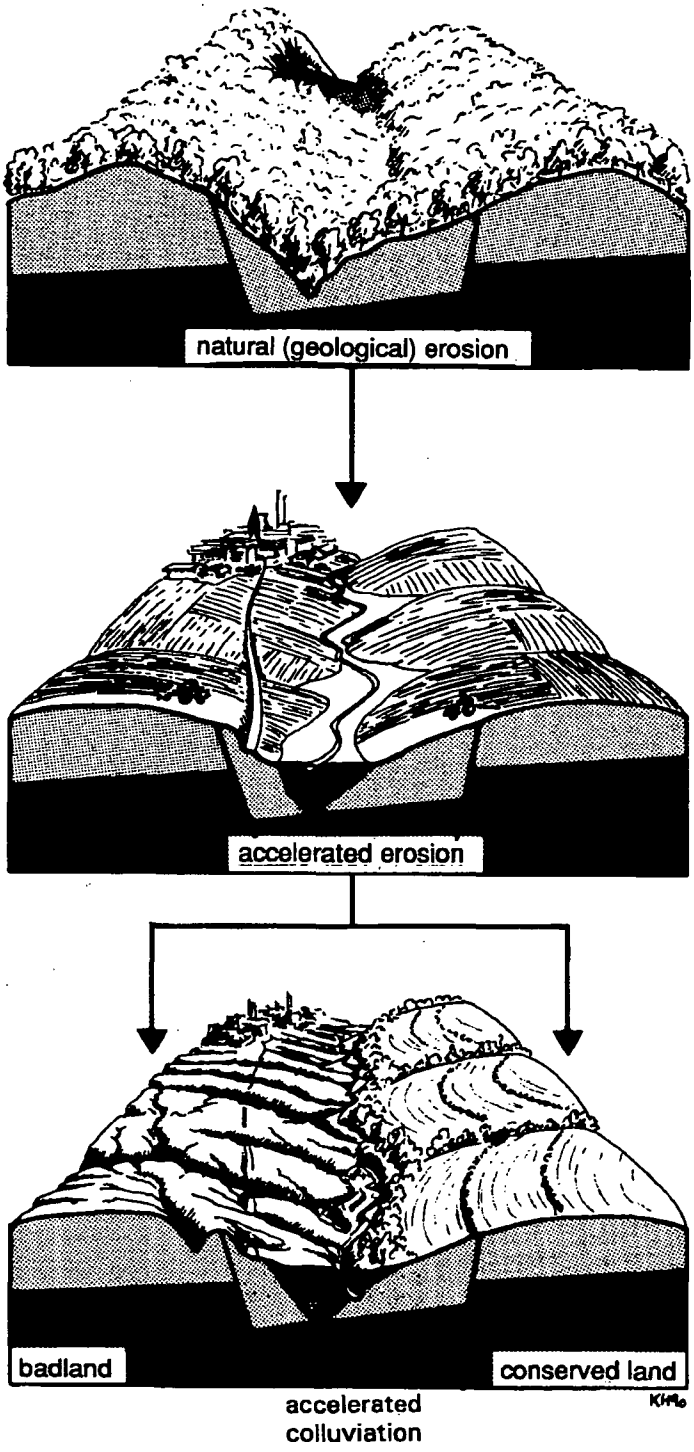
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Erosion and conservation: the importance of land husbandry



**absorption bank/terrace**
A level bank/terrace with a turn-up at each end, and designed to pond water to a predetermined depth.
a) They are especially used in grassland where overtopping does not present a great erosion hazard.
b) Not normally used on impermeable soils or on arable land (Houghton & Charman 1986:16), because of the likely formation of seepage areas.

**accelerated erosion**
Erosion much more rapid than normal, natural or geological erosion, mainly resulting from activities of man, or in some cases of animals.
a) Normal, geological or *natural erosion* is usually very slow. Under certain conditions, such as after a tectonic movement, after a river capture or on scars of natural *mass movements*, the *erosion* rates are much greater: fast *geological erosion*. These rates are comparable with the high rates of *erosion* that may be caused by the influence of man through agriculture, road construction and *urbanisation* (Hudson 1981:34).
b) Causes of *accelerated erosion* most often relate to poor or non-existent plant *cover* of the *soil* (Hudson 1981:34).
c) Such erosion has had an impact virtually everywhere in the temperate and tropical zones of the world that have been cultivated, heavily grazed, or logged. The process has been slowed down in many areas, but is continuing strongly in others. It is worsening rapidly in many hilly and heavily populated areas. The technology to reduce *erosion* to tolerable levels is available. What is often needed is the national will to act (Dregne 1979).
d) *Accelerated erosion* is probably the most serious and least reversible form of *land degradation* particularly in the tropics (El Swaify 1981:549).
e) Irreversibility of *soil erosion* has long been recognised. A depletion of land resources may result if not compensated for by new technological means, such as fertilisers, crop varieties or *cultivation* methods. But improvements are not guaranteed. Therefore a general conservation ethic is a good guideline (McCormack & Young 1981:365-374) so that basically one aims at conserving the *soil* within renewal rates, accepting higher *soil losses* only when unavoidable (McCormack & Young 1981).
f) *Soil erosion* and civilisation are related. *Erosion* became a significant menace to civilisation after the development of agriculture. In some cases *land* was destroyed. A discussion of this question is given for the different continents and regions of civilisation in Troeh a.o. (1980:25-51) and Hallsworth (1987).

**actual land degradation**
~ land degradation
~ potential land degradation.
The rate of decline in land suitability which actually occurs under a certain type of land use or natural vegetation cover, by erosion (soil loss, dissection, deposition), salinisation, pollution, or overuse.
a) It is an expression of the natural tendency to deterioration of the land when modified by human factors or by the protective effect of the natural vegetation (Dudal 1981:5).
b) *Erosion* is one of the causes of *land degradation*, but it may however, in certain conditions, have a favourable influence on the productivity of the soil. This is the case in the loess area in the south of Holland, where the calcareous B horizon gives better yields (*seedbed* quality) than the original decalcified A-horizons (FAO 1983; Bennema & de Meester 1981).

**afforestation**
The establishment of a forest on land that has not previously, or not recently, grown trees.

**afterflow**
The overland flow continuing after rain has stopped.

**aggregate**, see soil aggregate

**aggregation**, see soil aggregation

**agroforestry**, see also as Central Concept
The integrated land use that involves deliberate retention or admixture of trees and other woody perennials in spatial or temporal association with cropping or grazing land, to benefit from the natural ecological and economic interactions.

**airphoto greytone = photo tone**
Shades of grey, varying between almost white and almost black, in the image of a black and white airphoto.

**airphoto (greytone) texture = photo texture**
Greytone grade, size and shape of the smallest spots of one greytone observed at a scale formed by a defined means of observation.
a) Greytone texture is formed by tonal repetitions too small to be discerned as individual objects, which depends on airphoto scale (Manual 1960:104).
b) Greytone texture is the way different shades of alternating grey, black or white form a greytone. The individual parts of which the tone is composed can hardly be distinguished separately at the scale of observation.
c) Airphoto texture or photo texture refers to the frequency of tone changes in the image (Glossaire 1970).
d) One can speak of a coarse or a fine airphoto texture.

**airphoto greytone structure**
Density and arrangement of elements of airphoto greytone that are large enough to be delineated but occur with such frequency that they are considered together forming a larger unit.
a) One can speak for instance of a fine or coarse, blocky or polyhedral greytone structure.

**airphoto greytone mottle**
Areas of greytone contrasting with surrounding areas in composition of greytone structural elements, and clearly large enough to be delineated.

**airphoto greytone pattern**
Regularity in the density and arrangement of large greytone structural elements or greytone mottles of the airphoto image, either natural or cultural.
a) One can speak for instance of a linear, speckled, or striped greytone pattern.

**airphoto (greytone) flow pattern**
A special case of a greytone pattern, which shows elongated greytone mottles, occurring somewhat parallel, often bending slightly, in river floodplains or in valley bottoms, and in areas of sheetflooding or other forms of overland flow.
a) It indicates river overflow deposits and flood channels (splays, *spillway* deposits), *drainageways* with temporary flooding or *overland flow* forms such as *braids* and *gully fans*.

**airphoto stereothreshold**
The minimum height or depth of an object that gives a stereo-impression (in fifty percent of cases) to the average observer of a stereopair of airphotos, under average conditions of accomodation such as lighting.
a) The stereothreshold is approximately (Steiner 1951):

$$\frac{\text{scale number}}{10\,000} \times \frac{\text{focal length of the aerial camera in mm}}{150\text{ mm}} \times 0.5 \text{ metre.}$$

**alley cropping**
A form of agroforestry, also called "hedgerow *intercropping*", which subdivides the land into strips of crops, preferably along the contour, separated by rows of trees and shrubs, which have a beneficial effect on crop yield and give their own product.
a) The practice is capable of maintaining soil fertility and crop yields under conditions where control plots under annual crops alone show *soil degradation* and declining yields (Young 1987, Lal 1988a).
b) Farmers have been reluctant in some places to adopt Leucaena in alley cropping, because it takes up too much room, spreads too quickly and requires too much labour (Macklin a.o. 1989:279).

**alluvial fan**
~ rill fan
~ gully fan
A relief form created by deposition from streamflow, starting at a point of gradient decrease in a channel and formed by diverging flow lines below this point; over time these may form different *channels* radiating from this point, bringing further deposition.
a) A typical location is where a stream emerges from a narrow upland valley onto a plain (Soil.Cons.Soc.Am. 1982:6).
b) The texture of the *sediments* becomes finer down the fan.
c) The foot of the fan may show *seepage*, while the upper part is often excessively drained.
d) When the channel branches give rise to overbank *deposition*, they may form fan levees and fan basins and cause texture differences in a finger pattern.

**alluvium**
Soil and rock material deposited by flowing water from streams.

**angle of repose**
The maximum slope angle at which material can form a stable deposit.
a) When exceeded, mass movements can be expected, caused by destabilising influences, such as lateral erosion at the foot of a slope (Suarez 1965:289).

**antecedent soil moisture content**
The moisture content of a soil just before a rainshower or irrigation.
a) It depends on the *evapotranspiration* at the site (determined by temperature, wind speed, humidity, air pressure and type of plants), the previous rainfall, *overland flow* and *subsurface flow*, all interacting with the drainage condition of the site or mapping unit (Toy 1977:10).
b) It has an important influence on the likelihood of *runoff* occurring as a result of subsequent rainfall, because antecedent moisture restricts the amount of *infiltration* which can take place (Houghton & Charman 1986:13).
c) In certain catchments, it has an effect on *surface erosion*, which ranks in importance after rainfall, soil porosity, *sealing* and aggregate stability (Bork & Rohdenburg 1981).

**area closure**
~ controlled grazing
A protection system involving exclusion of grazing stock from land, to improve degraded vegetation and/or soil through natural regeneration.
a) Very important and well known are the adverse effects on people involved in this system, when no satisfactory compensation for their living

conditions is provided, such as alternative grazing land or fodder.

**arroyo**
A large and very wide gully, usually with ephemeral flow and with 0.5 m or more of unconsolidated alluvium, forming vertical walls.
a) It is commonly several metres to tens of metres wide, and some metres deep, like a giant *braid*.

**aspect of slope**, see slope exposition

**avalanche**
~ mud flow
The rapid mass movement of snow on slopes caused by instability of the snow cover. (Embleton & Thornes 1979:315-324)
a) The term avalanche originally referred to *mass movements* involving snow with or without debris (Embleton & Thornes 1979:156).
b) The snow may be dry or wet, it may collect varying amounts of debris on its way, it may slide in contact with the ground or snow surface, it may move on a cushion of air or it may be airborne.
c) Common causes are overloading, structural weakness in the snow, and percolating snowmelt.
d) Tremendous energy may be released in a major avalanche.
e) In some localities they represent infrequent events; in others they occur regularly, re-using the same routes year after year.
f) In distinction from the avalanche carrying snow, one speaks of a *mud avalanche* (lahar), a debris avalanche, etc.

**badland**
Area of barren land, usually broken by an intricate maze of narrow ravines, sharp crests, and pinnacles resulting from serious erosion of soft geologic materials.
a) Most common in arid or semi-arid regions (Soil Cons.Soc.Am. 1982:12).
b) Classified as a Miscellaneous Landtype in soil surveys (Soil Survey Staff 1951).

**bad spot (of erosion)**
~ badland
Severe erosion of a small unmappable area of land within a mapping or planning unit.
a) It is a pragmatic concept, pinpointing areas where *erosion* causes great damage to the *land*, but which are of limited extent and are overlooked in general *mapping*, depending on the scale.
b) Bad spots can occur in arable land, *grazing land*, forest land and peri-urban land. The origin of *bad* spots can be found in local areas of natural, human or animal influence such as (Bergsma 1986):
- roadside drainage systems (culverts, *furrows* and ditches)
- camping sites, recreation sites, footpaths
- overtopping of
  - ~ contour field boundaries
  - ~ *contour furrows*
  - ~ *conservation terraces*
- *drip* zones and *stemflow* (in forest land)
- *grazing* sites, cattle trails or trail bundles (groups of parallel trails or groups of trails converging to and diverging from a cattle crossing over a stream, road, etc.)
- drainage outlets of fields, village grounds or urban land
- concentrated traffic areas of man, animals and vehicles in peri-urban land.

c) Occurrence shows no regular physiographic pattern as in an *erosion toposequence* (Bergsma 1974).

**bank/terrace**, see soil conservation terrace/bank

**bare fallow**
~ fallow
Land left idle and without any plant cover during some period.
a) It usually contributes to water *conservation*.
b) The removal of any vegetation needs frequent weeding or the use of chemicals (herbicides).
c) It is different from natural fallow where plants are allowed to grow and maybe cover the *land*, though no crops are grown in the period.
d) It often represents a period of high *rain erosion hazard*, because of the absence of protecting plant cover.

**basal (plant) cover = surface contact cover**
The area of ground surface covered by the stems of plants, usually measured 2 cm above the soil, in contrast to the full spread of the foliage.
a) The basal cover may include at times the effect of an algae cover. This may be effective over short periods only, for instance a few weeks.

**baseflow**
Part of the discharge which enters a stream channel main from groundwater, but also from lakes and glaciers, during long periods when no precipitation or snowmelt occurs (UNESCO 1992:28).
a) It is the more or less permanent flow supplied to drainage channels by rather invariable sources.
b) It plays a role in analysis of the stream *hydrograph* to distinguish ephemeral peak flows (Dunne & Leopold 1978:288).

**base level of erosion**
Level below which a land surface cannot be eroded by running water (UNESCO 1992:28).
a) Such a level acts for large areas and may differ

from such higher levels which act more locally, up to levels upheld by a culvert in a gully.

**basic infiltration rate = saturated infiltration rate**
~ infiltration rate
The relatively constant infiltration rate that developes after some 3 to 5 hours of rain falling onto soil, after which time the upper soil is saturated.
a) If the *subsoil* has a different *permeability* from that of the *topsoil*, the curve of cumulative *infiltration* against time will often show a change of slope at the time when the wetting front passes the *soil horizon* or layer boundary (Landon 1984).
b) Bypass flow, entering through the macropores and temporarily leaving the microporosity of the inner peds unaffected, has to be considered to explain the curves of infiltration against time. A regular wetting front may not exist, especially not in coarse-structured clay *soils* (Bouma 1977:66,75,100).

**basin**
A. in the sense of river basin, see *catchment*
B. in the sense of a conservation structure
C. in the sense of an irrigation structure:
DEFINITION B:
An impounding structure to contain expected runoff and slow it sufficiently to permit the settling and collection of sediment.
a) Basin *terraces* in the US are built to catch all expected runoff and stop it from going further (Soil Cons.Soc.Am. 1982).
DEFINITION C:
A level plot or field, where water is held on flat ground,surrounded by dykes, ridges or checks, to be flood irrigated or used for water harvesting in dry areas.
a) Individual trees may be irrigated thus (Walker 1983).

**basin listing**
~ listing
Constructing a system of small ridges and ponds, using a special type of plough called a lister, to increase surface water storage.
a) Basin *listing* (*tied ridges*) is intended to catch all expected runoff, and is thus a practice of soil and water conservation.

**basin terrace**
A terrace for an individual tree, roughly semicircular, intercepting overland flow from upslope and retaining it.
a) It is used for fruit trees or food trees on steep slopes, often steeper than 50% .
b) It is used in combination with good ground *cover* in the interspace.

**batter**
The excavated or constructed face of a dam wall, embankment or cutting, produced as a result of earthmoving operations involving cutting and filling.
a) Batters created in the construction of *soil conservation banks/terraces* are identified by numbering them 1, 2 and 3 on the basis that number 2 is always the waterbearing face of the embankment, and the number 3 is the downhill side of the embankment, while the number 1 is the excavation batter which may be above the terrace channel or below it on the slope (Houghton & Charman 1986:20).

**bedload**
Sand, silt, gravel and rock detritus, mainly not in suspension, carried by a stream along its bed (UNESCO 1992:29).
a) It is moved mainly by *tractive* and gravitational forces, at velocities less than the surrounding flow (Soil Cons.Soc.Am. 1982 = Houghton & Charman 1986:22).

**bench terrace**
A terrace/bank where the slope has been levelled by cut and fill, often with a pronounced riser.
a) It is often level and *bunded* for irrigation, as in irrigated sloping land of old civilisations (Hurni 1986:50).
b) It can be level, outward-sloping or backsloping (Fang Zhengsan a.o.1981).
c) The terrace channel may be level, but usually is graded.
c) In Ethiopia bench terraces may be developed from Fanya juu terraces or from bunds (Hurni 1986:50).

**benefit cost ratio**, see cost benefit analysis

**berm**
In erosion control, a shelf or relatively flat area that breaks the continuity of a dam wall or cut slope, to increase stability.

**biomass**
The quantity of organic substance (derived from plant or animal sources) at a given time on a given area.
a) An example would be the weight of vegetative matter removed by clipping a sample area (FAO 58:133).

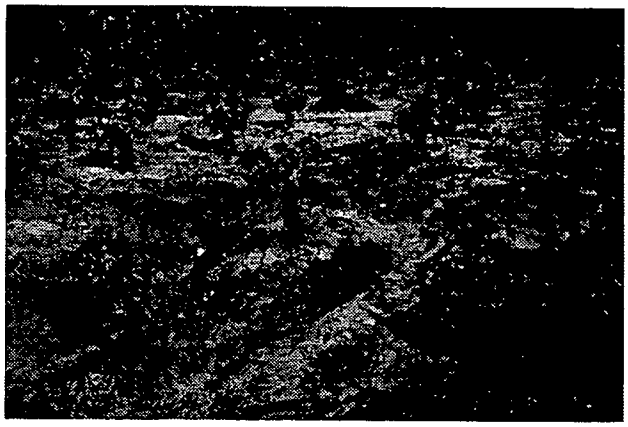
**block glide**
A mass movement slide of a block or part of a landscape or hillslope, where the material in motion is not greatly deformed and moves as a whole downslope along the plane of weakness.

**box culvert**, see culvert

**box inlet drop spillway**, see spillway

**braid or braided rill**
~ braidwash
~ floodbraidwash

A type of rill that is shallow and wide (width 0.5 - 3 m) and in which deposition and transport dominate over incision.



*Braid, Merida, Spain (photo E. Bergsma).*



*Wide braid, Merida, Spain (photo E. Bergsma).*

a) *Erosion* in this wide *rill* proceeds together with *deposition* elsewhere in the *rill*, as the flow is loaded to capacity.
b) Occurs with a strong supply of *sediment* under strong overland flow, on moderate and gentle slopes (Richter 1965); also in conditions of a strong plough-pan and a loose A horizon.
c) The wider braids (3-10 m) occur on the gentler relief. They are probably the ones called "Flutrinnen" by Richter (1965).
d) There are two common types of semi permanent channel: braids and *rills*, and these are associated with sandy and silt-clayey *soils* respectively (Carson & Kirkby 1972:191).
e) The term "braided rill" may be used in contrast to the *rill* that tends to incise which may be called an "*incision-rill*".

**braidwash**
Rain erosion characterised by braids (shallow, wide rills) which shift position over the hillslope with time.
a) Occurs most frequently in cases of heavy *runoff* and moderate slopes, but also in *drainageways* (Richter 1965).
b) It is sometimes called "concentrated flow erosion" (Laflen 1987:798), see also Auzet a.o.1990:388, showing a photograph of a *braid*.
c) *Floodbraidwash* is probably similar to Flachenhafte Rillenspulung (Richter 1965).

**broad-based bank/terrace**
A low profile bank/terrace with smoothed cross section and gentle batters which are well compacted.
a) The shape enables travel across them and tillage along their length with agricultural machinery.

**buffer strip**
~ filter strip
Strip of grass or other erosion-resisting and overland-flow-retarding vegetation between or below cultivated strips, or along each side of a drainage line.

**bulk density (of soil)**
Mass of an oven-dry soil sample per unit gross volume (including pore space) (UNESCO 1992:37). In soils, the mass of soil dried to constant weight (at 105 degrees Celcius) per unit of total volume, determined before drying. (Houghton & Charman 1986:24)
a) It is expressed in grams per cubic centimetre. Common values for *topsoils* are 0.8-1.2, for *subsoils* values are commonly 1.2 - 1.8 gr/cm3.
b) It is a measure of total soil porosity, but does not indicate the pore size distribution, and so it is only a general indication of moisture-holding capacity or permeability.
c) It is also a measure of *soil structure*, but does not indicate the *ped* sizes or shapes. Prismatic and platy *soil structures* often have higher values of bulk density.

**bund**
A long low elevation or low ridge of earth, made commonly by hand, to contain irrigation water or intercept runoff.
a) The cross-section can be semi-circular, triangular or trapezoidal; the direction is commonly along the *contour* (Orendain & Barrow 1986).
b) If not linear in plan, the bunds are placed with an overlapping pattern so that lower bunds catch the overflow from higher ones if it occurs (Orendain & Barrow 1986:432).
b) The design, location and layout of bunds and *cutoff* ditches needs careful study. There are several criteria that must be considered, including (Orendain & Barrow 1986:437):
- slope
- *catchment* area of slope

- type of *soil*
- amount of *runoff*
- siltation
- materials available to construct bunds
- maintenance

**C-factor**, see USLE

**Caesium-137**, see tracers

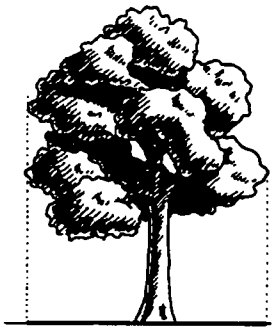
**canopy**

~ soil cover

The uppermost vegetation layer of leaves and branches in crowns of trees and shrubs and in tall crops.

a) The canopy may be open or closed. The extent and "closure" of *cover* is measured by the vertical projection downward (Soil.Cons.Soc.Am. 1982).
b) The amount of crown closure can be indicated as a percentage *canopy* cover.
c) Protection by canopy not only depends on its density but also on its height. Drip energy becomes similar to rain energy at heights above 3 metres.
d) The effect of the canopy will be subject to seasonal changes in crown density, such as by leaf-fall of deciduous trees, in contrast to the rather permanent crown density of conifers or olives, for instance. Serious *erosion* often occurs at the beginning of the rainy season when canopy cover is relatively poor.

Canopy cover



**canyon = gorge**

Deep valley with high, steep slopes, often with a river flowing along its bottom (UNESCO 1992:39).

**carrying capacity**

~ grazing capacity
~ overgrazing

The maximum use that the land can bear through the greatest period of stress each year without a permanent deterioration in its vegetation or soils. It is expressed by numbers of livestock, numbers of certain wild animals, numbers of tourist visits, etc. per unit area.

a) A distinction may be made between the *carrying* capacity and the *grazing capacity*, the first indicating the maximum number of animals that can survive the period of greatest stress each year on a given land area, the latter being the number of animals that can graze on a unit area of *land*, keeping a sustained production on the long term, that is with no *land degradation* resulting from the *grazing*.
b) The practice generally is to stock so as to prevent over-utilisation of the available forage in all but the years of the most extreme drought (Stoddart a.o.1975:183).
c) Some possible limiting factors are (Geerling & de Bie, 342-343)
   - climate: temperature, rainfall, seasonality
   - water: surface water, drainage
   - *soil*: fertility, texture, *erosion* risks
   - vegetatation: structure, species composition, forage quality
   - fauna: habitat and food requirements.

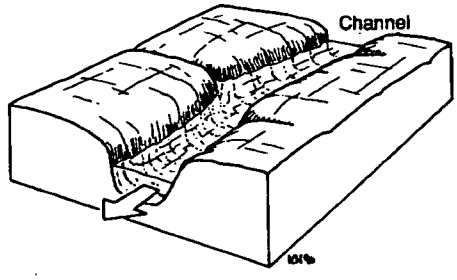
**catchment = drainage basin, river basin, catchment area, watershed**

The area which supplies water by surface and subsurface flow from rain to a given point in the drainage system.

**channel**

A passage that confines water sufficiently to hold it or allow it to flow, from one place to another, given sufficient head.

a) Typically it comprises a floor or bed, which carries the flowing water and sides or banks which confine it (Houghton & Charman 1986:26).




**channel detention**

Water that can be temporarily stored in channels during flood periods (UNESCO 1992:45).

**channel erosion**

Erosion of a specific channel form.

a) *Soil loss* is due to *scour* induced by runoff flow, often followed by sideslope instability.
b) It occurs in *rills*, *gullies*, and streams. (Kirkby & Morgan 1980: 48-51,163,290).
c) In river *catchments* it may produce up to one third of the total *sediment load*. In *rilled* and gullied areas, where *channels* and slopes are more closely linked, the contribution from *channel erosion* is much more. (Kirkby & Morgan 1980:163).

**channel roughness,** see hydraulic roughness

**checkdam,** see gully checkdam

**chute**
The steeply inclined section of a flume or other similar hydraulic structure, between the inlet and outlet, that conveys flow directly from one level to another.

**clay pan**
~ soil pan, plough pan
A dense and clayey subsoil horizon or layer.
a) It can be pedogenetic or formed by *infiltration* of flood waters (Suarez 1965:290) or formed from in situ clay formation (Soil Cons.Soc.Am. 1982:26).
b) It is usually hard when dry and plastic and sticky when wet (Soil Cons.Soc.Am. 1982:26).

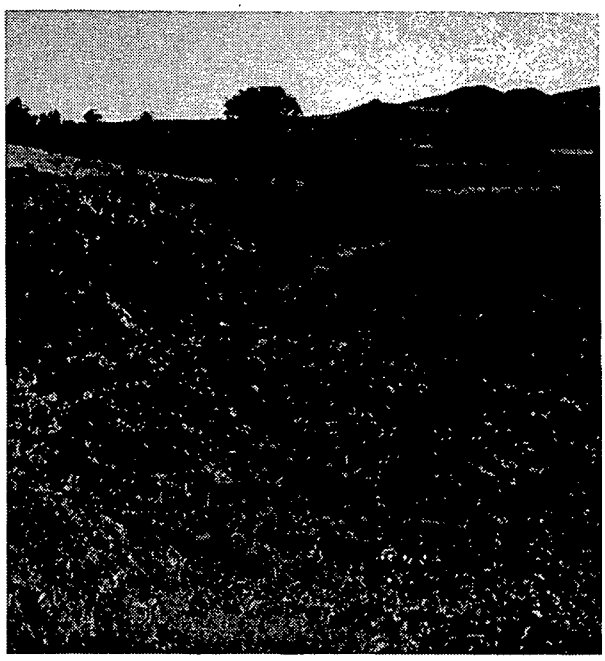
**clean weeding = clean tillage**
Cultivation of a field so as to remove plant residues and to prevent the growth of all vegetation except the particular crop being grown.
a) The system may be necessary to avoid the risk of insects and pests such as may be involved in crop residue retention (*mulching*), but it exposes the *soil* to *rainsplash*.
b) An example is the *cultivation* system for pepper in Malaysia. The crop is at risk of attack by a wide variety of pests and deseases, especially foot rot. Therefore complete clean weeded *cultivation* is used to reduce moisture and improve drainage. As a consequence the *land* under pepper is open to serious *erosion* (Hatch 1981:256).

**clod**
A lump of earth, formed artificially by soil management.
a) It is not a natural soil structural element, such as an aggregate.

**collar**
A flange (a projecting edge or rim on any object) fitted around a pipe to prevent seepage of water along the outside of the pipe.
a) Typically used in dams to prevent *seepage* along the outside of pipes passing through the wall (Houghton & Charman 1986:29).

**colluviation step**
~ colluviation terrace
A low, abrupt height difference in the terrain, running roughly along the contour and formed by colluvium accumulated in a barrier to overland flow.
a) Such steps often occur at field boundaries which run approximately along the contour.

**colluviation terrace**
~ colluviation step
~ Fanya-juu



*Colluvial step, Merida, Spain (photo E. Bergsma).*

A nearly level area of colluvium, developed over time by colluviation above a barrier to overland flow, with a batter/scarp or riser below.
a) The barrier firstly develops over time into a small *colluviation* step or scarp (Grunder 1988 ). Then a bench terrace can develop, especially on erodible soils.
b) Different types of barriers can be used (Wenner 1988:198).
- a strip of *land* left not ploughed in previous pasture.
- a strip of fodder grass or other *perennial* plants, left in one or more rows, or specially seeded. It is especially suitable in high rainfall areas and on gentle slopes.
- trash collected into ridges will decompose and grass will grow up. Not always suitable in dry areas where trash is used for other purposes or eaten by termites
- a stone wall can be constructed when material and labour are available.

**colluvium**
The poorly sorted material deposited on concave slopes or at the foot of steeper slopes, that has been moved by gravity and local wash.

a) The term is often used in soil survey for diffuse slope deposits from local *wash* (Soil Survey Staff 1951).
b) Colluvium has a linear source area, in contrast to an *alluvial fan* or *gully fan*, which has a point source for its *sediment*.



*Colluvium, note soil colour and weed growth, Merida, Spain (photo E. Bergsma).*

**compaction,** see soil compaction

**compound land utilisation type**
A land utilisation type consisting of more than one kind of use, either undertaken in regular succession on the same land, or simultaneously undertaken on separate areas of land which for purposes of land evaluation are treated as a single unit.

**conduit**
A constructed closed channel or pipe, lined with concrete or similar material for the conveyance of water.

**conservation, of natural resources**
~ land degradation
~ soil conservation
~ soil degradation
The protection, improvement and use of *natural resources* according to principles that will assure their highest economic or social benefits for the human race and the environment now and into the future.
a) It is the promotion of optimum *land use* in accordance with land capability so as to assure its maintenance and improvement. Conservation also means halting *degradation* and restoring *productivity* where it has been reduced (Dudal 1981:8).
b) Conservation is a positive concept, embracing preservation,maintenance, sustainable utilisation, restoration and enhancement of the natural environment. Living resource conservation is specifically concerned with plants, animals and micro-organisms, and with those non-living elements of the environment on which they depend. Living resources have two important properties in combination which distinguish them from non-living resources: they are renewable if conserved; they are destructible if not (Houghton & Charman 1986:30; National Conservation Strategy for Australia, 1983).
c) *Land* conservation denotes all aspects important for land utilisation, not only soil attributes and the derived qualities.
d) In technical, management and governmental concerns an element of *land husbandry* is indispensable.
e) While an individual may be held responsible for preventing damage to the *land*, some people would say it is society's role to see that the individual exercises that responsibility (Shaxson 1985:669).
f) To encourage stable *land use* without coercion, it will be necessary to change the factors, perceptions, or pressures to which the individual responds when making his other land use decisions. Three aspects of this may be:
   1) public incentives or restraints
   2) more or better information about the detrimental effects of *erosion*
   3) decreasing or eliminating key constraints to the farming and land use system decisions (Shaxson 1985:668).
g) To propose major land use changes for areas that have already been developed is a severe step of which the cost of change can often be avoided by a combination of less drastic, though perhaps less ideal, measures.
   Where initial costs have not been incurred, for example for undeveloped areas for which the use, layout and *management* is now being planned, future erosion damages and costs can be minimised. This can be done where assessments of the hazards, potentials, and *limitations* of each *catchment* are specifically used to guide the basic decisions on *land use*, and where layouts are set down on a *catchment* basis (Shaxson 1985:671).
h) Since the African mountain areas provide important resources for many African countries, specific ecologically oriented development policies are vitally needed to improve ecological and economic conditions (Messerli & Hurni 1990, preface p.ix). The questions, repeated by one of the audience (Suresh R.Chalise 1990:416) were:
   - who cares for the soil ?
   - who cares for agriculture ?
   - who cares for plant genetic resources ?
   - who cares for the wildlife ?
   The phrasing of these points of discussion, by the organisers of the workshop on African mountain areas, points to the need for a total commitment of persons who will dedicate themselves to the solution of these questions. An integration of scientific disciplines, team member's knowledge, means available and philosophy of life is asked for.

**conservation planning**, see soil conservation planning

**conservation practice**, see soil and water conservation practice

**conservation requirements**
The land use requirements largely or entirely related to conservation and sustained use.

**conservation structure**, see soil conservation practice

**conservation tillage**
Any tillage sequence that reduces loss of soil or water relative to conventional tillage; often a form of non-inverting tillage that retains protective amounts of residue mulch on the surface.

**consistence**, see soil consistence

**consistency index C5-10**
The difference in moisture content of a soil between the points for 5 and 10 impacts, on the curve which is obtained when determining the liquid limit of that soil, showing the number of impacts by the Casagrande apparatus against the soil moisture content.
a) It appeared to be a good indicator of sealing sensitivity on Belgian loams (de Ploey 1981:140).
b) It appeared to be also a good general index of soil erodibility of Belgian loams (Verhaegen 1984).

**consolidation**
~ settling
The process whereby a newly formed earthen structure reduces its volume by natural settling.

**contour**
A line or an imaginary line on the surface of the land along which all points have the same elevation.
a) Contours may be shown on a map as contour lines for the study of altitude and relief form. They may be plotted in the field to help construct *conservation practices* (Houghton & Charman 1986:30; Soil Cons.Soc.Am. 1982:34).
b) Runoff retention measures built along the contour hold *overland flow* with minimal lateral flow when designed properly, avoiding concentration and possible overtopping (Houghton & Charman 1986:30; Soil Cons.Soc.Am. 1982:34).

**contour ditch**
A level excavated *channel* designed to hold and spread water on low slope areas or, designed with a gradient, to conduct water.
a) The level ditch will accumulate and spread the water along its length, before spilling on a broad even front (Houghton & Charman 1986:31).

**contour farming**
Conducting farm operations, such as ploughing, planting, cultivating, and harvesting, along the contour, largely for the purpose of reducing erosion hazard.
a) The most important practices in contour farming are:
- *contour tillage*
- *contour strip cropping*
- *contour terracing*
b) The main purpose is to reduce *erosion hazard*. This works by preventing concentration of non-infiltrating rain, guiding *surface runoff* along gentle gradients and slowing down *overland flow* in dense vegetation.

**contour furrow**
A furrow ploughed approximately on the contour in pasture and rangeland to reduce runoff and increase infiltration; the term is also used for furrows laid out approximately on the contour for irrigation purposes.

**contour grass strip, or grass strip**
A band of grass laid out and retained on cultivated land along the contour.
a) Grass strips were found to be effective in reducing *soil loss* and *runoff* on a 10 % slope both during low and high intensity storms (Wolde & Thomas 1989:189).
b) In Ethiopia they are recommended to be one metre wide and spaced at one metre vertical intervals, to be used on soils with good infiltration, and on gentle slopes, while cattle must be excluded to maintain grass that is long (Hudson 1988b:123-124).
c) Considerations for the choice of the type of grass are several:
- palatable, grazed or cut and carried
- unpalatable
- spread by rhizomes or stolons
- propagated from seed or cuttings or by division of root clumps
- industrial use such as extraction of oils. (Hudson 1988b:123-124).
d) In some conditions they can be grown using Elephant grass (Thomas 1988).
e) In the Philippines single or double rows are used of Ipil-Ipil (Leucanea leucocephala). It can be grown from seed or cuttings; it grows rapidly, fixes nitrogen in the *soil*, and is a useful source of feed for livestock. Other grasses used are Vetiveria zizanoides, which however leads to *erosion* when it is excavated for the oil in its roots, and Pennisetum purpureum (Hudson 1988b:123-124).
e) When grazing is totally prevented contour grass strips are a way of achieving a terrace effect by slow accumulation of erosional material which grows into a *colluviation step* (Hurni 1986:40).

**contour hedge**
A dense row of shrubs or bushes along the contour to intercept and slow overland flow.

**contour interval**
The vertical distance between two adjacent contour lines.

**contour ploughing**, see contour tillage

**contour ridge**
A long low mound of soil made by tillage in one or more passages, approximately along the contour to reduce erosion hazard.

**contour ridging**
A ridge and furrow system of tillage in which the ridges and furrows follow the contour.
a) Alternate contour ridging and *contour strip cropping* are used in the cultivation of pineapples in the Ivory Coast (Valentin & Roose 1981:240).
b) *Hillside ditches*, *live barriers* (lemon grass, pineapple, or Leucaena) and contour ridging were used in El Salvador for the growing of maize, beans and sorghum. (Wiggins 1981:404).

**contour stone row**
A row of stones along the contour to slow down overland flow, increase infiltration, and cause deposition of erosional material.
a) Stone rows have a great effect on *overland flow* on gentle slopes. Data from Burkina Fasso show that after a wet season with 115 mm rainfall, a rain with a maximum 15 minute intensity of 82 mm per hour gave a much lower *overland flow* on the field with stone rows than on an unmanaged field. There was a 36% lower maximum flow, a 13 % lower volume of *overland flow*, and a 28% lower *soil loss* (Lamachere & Serpantie 1990).
b) The term should not be confused with *stoneline*.

**contour strip cropping**
~ strip cropping
The soil conservation technique of growing crops in rotation in a systematic arrangement of strips at right angles to the direction of the slope.
a) Protective crops alternate with high hazard crops in the strips, so that when *erosion* occurs, the *sediment* is deposited in the densely vegetated strip, where *overland flow* is slowed down and *infiltration* is good (Meyer 1981:37, Soil.Cons.Soc.Am.1982:34).
b) Strip boundaries may be parallel to the *contour*, they may be parallel to each other, or they may have a layout combining both, with *buffer strips* covering the irregular parts of fields left over.

**contour terracing**, see soil conservation terraces

**contour tillage = contour ploughing**
The operation of ploughing or other soil tillage along the contour, largely for the purpose of reducing erosion hazard.
a) This type of tillage has been also called contouring, *contour farming*, contour ploughing. Contour farming is in fact a wider concept.

**controlled grazing**
~ area closure
Direct grassland utilisation with livestock in such a way that no degradation of vegetation and soils occurs, by regulating the stocking rate.
a) It can be continuous or in rotation (Hurni 1986:54).
b) The control can be by herdsmen, but commonly uses fences.

**Cook's method**
A method of runoff prediction from small agricultural areas by rating relief, soil infiltration, vegetative cover and surface storage.
a) It is empirical, and depends on tables based on measurements at instrumented experimental *watersheds*. As the USA is the only country where sufficient data are available, the use of this method in other countries really depends upon guess work as to how the U.S. data should be extrapolated (Hudson 1988:125).

**cost benefit analysis**
The defining of the costs and the benefits of a plan or practice (e.g. soil conservation), against discount in time, expressed as a ratio between the sum of benefits and the sum of costs.
a) The time scale of the benefits and costs is different for the *conservation* planner, for the farmer and for the politician (Hudson 1981:52).
b) The relevance of the analysis depends on the degree of commerce versus the degree of subsistence in the farming purpose (Shaxson 1981:354).
c) On-site and off-site benefits may both be present (Wiggins 1981:401-410). Agricultural benefits or on-site benefits of soil conservation are:
   - the prevention of falling yields per hectare which would otherwise result from the loss of *topsoil*
   - an initial rise in yields consequent on implementing measures such as use of *mulch*, due to less fertiliser being washed out, increased soil moisture and improved *soil structure*.
   - a slow, gradual increase in yields as new *topsoil* develops on protected land .

   Off-site benefits are:
   - *sedimentation* control, preventing damage on downslope agricultural land, and prevention of loss of capacity of a dam or lake

- reduction of flood damage
- reduction of aggradation of stream and river beds.

d) On-site and off-site costs may both occur: (Wiggins 1981:401-410).
On-site costs are for example (Wiggins 1981:401-410):
- construction of land practices (planning, labour, equipment and material)
- maintenance (planning, labour, equipment and material)
- loss of surface area

Off-site costs may be:
- difficult access to construction sites
- temporary soil deposition downslope

e) All *soil conservation* programmes take some time before benefits are realised. Therefore, an analysis of benefits against *costs* is required to be done over a chosen period. Though their design life ranges from 15-30 years, the soil conservation structures become part of the landscape and are likely to give benefits for a much longer time, provided they are suitably maintained. Benefits that accrue in the distant future, such as 50 years from now, may be neglected.
Investment should pay back earlier, so periods of 10, 15 and 20 years have been used.
Deriving the benefit as well as the cost and their discount over the years, for the various components, gives the basis for the cost benefit analysis. Using different time periods has helped to find the minimum pay back period (Das & Shamser Singh 1981:434-435).

f) It is doubtful whether the cost benefit analysis on a farm scale, resulting in benefit-cost ratios for various practices, can be used as an argument for *soil conservation*. One has to look at the national scale. Here benefits are:
- greater food production and lower prices
- economic use of *waterways*, dams, irrigation systems- less relief work against flooding, impeded drainage of alluvial plains.

g) In conclusion: The nation must help the farmer meet the cost of *conservation* (Abernethy 1981:540)

**cover**, see soil cover

**cover crop**
A close growing crop grown primarily for the purpose of protecting and improving the soil outside periods of regular crop production, or between trees or vines in orchards and vineyards, or for the establishment of plants, particularly those which are slow to establish.

a) Cover crops may be useful for fodder or *green manure*, or as intercrops to protect other crops that are slow growing or that give themselves poor protection (Houghton & Charman 1986, Soil Cons. Soc.Am. 1982:37).

b) In Sarawak the *riser* slopes of pepper *terraces* were planted with a mixture of Stylosanthes gracilis , Centrosema pubescens, Pueraria javanica and Desmodium ovafolium (Hatch 1981:258-259).

c) On road banks, industrial compounds etc. permanent cover crops may be established.

**cover factor**, see USLE

**creep, or soil creep**
A slow, often imperceptible movement of soil as a body, down the slope of the land, by gravity under the effect of wetting and drying, heating and cooling, freezing and thawing, rooting and decay, and burrowing animals.

a) The upper part of the *soil* profile, where changes as described are more pronounced, has often the fastest creep rate, which decreases gradually with depth in the *soil*.

b) In some cases a rootmat causes the upper *soil* to move as one body, and a plane of transition occurs above which the creep is fast, below which the creep is slow. A similar transition plane may occur in *soils* developed in two layers of materials which are markedly different in creep-promoting properties.

c) Creep is referred to as the time-dependent deformation of rock and soil under constant stress (Embleton & Thornes 1979:29-36;176-184).

**critical area**
A small local area affected by serious erosion, where treatment is essential to the successful control of erosion in the surrounding area.

**crop growth stages**
Periods of main differences in plant development during crop growth.

a) For annual crops the main stages of importance for plant *cover* and its *interception* of rainfall are:
- *seedbed* stage
- initial growth stage
- maturing and ripening stage
- post-harvest stage

b) These stages have important differences in their effect on *erosion*. This effect can be expressed by the *cover factor*, which is the ratio of *erosion* in the presence of the plant *cover* in that growth stage to the *erosion* without any plant *cover* in the reference condition of ploughing up-and-down the slope (Wischmeier & Smith 1978:8).

c) In the calculation of the cover factor, the growth stage cover factors are weighted according to the relative erosivity of the respective growth stages, and then summed.

**crop requirement**
The needs of a certain crop to grow well, related to limitations in land qualities, such as the availability

of nutrients, water and air.

**crop residue**
~ crop residue management
~ mulch
The portion of a plant or crop left in the field after harvest.



*Sorghum residues arranged in a square pattern for water conservation, Southern Ethiopia (photo H. Hurni).*

**crop residue management**
Use of that portion of the plant or crop which is left in the field after harvest, usually for protection or improvement of the soil, and to allow a further crop or pasture to be sown:
a) It often provides a simple and for the farmer feasible means of protecting soil and reducing runoff, and is therefore extremely important for *soil conservation*.
b) An important constraint may be in favouring certain pests and diseases, located in the *residue*.

**crop rotation**
The growing of different crops and pasture in recurring succession on the same parcel of land with a view to increasing soil fertility and structural stability, and reducing plant disease and soil erosion hazard.

**cross grading**
The process whereby a rill, after joining with other rills and incising deeper, gains some gradient across the general slope, thereby increasing its catchment and eventually becoming a master rill.
a) It is a process leading to the growth of a *rill* into a *master rill* and eventually into a *gully* (Leopold a.o. 1964:411-416).

**crumb**
A type of natural soil aggregate or ped, typically created by soil animal activity and resulting in a good mixture of organic and mineral matter, and becoming porous, stable and roundish in shape.

**crusting,** see soil crusting

**cultivation**
~ cultivation system
A system of working the soil and growing of plants for the purpose of plant production.
(Mwonga & Mochoge 1989:39,47):
a) Cultivation can lead to adverse or beneficial effects on soil properties, depending on the type of tillage and *soil management*. Such effects appear to be closely connected to organic-matter changes.
b) The effect of cultivation on a *soil* is often a change in carbon and nitrogen content, cation exchange capacity and *bulk* density. The change can best be studied by comparing cultivated and adjacent uncultivated grassland or virgin forest *soils*.

**cultivation system**
A combination of soil management and plant management practices for a specified crop.

**culvert**
Close conduit for the free passage or surface drainage water under a highway, railroad, canal or other structure (UNESCO 1992:66).
A structure which allows the free passage of surface runoff under a road, railway, canal, etc. It may be a simple pipe or a construction built in situ or prefabricated.
a) Applies to practically all closed conduits used for highway drainage with the exception of storm drains (Orendain & Barrow 1989:432, 433-435).
b) Common types are concrete box culverts, concrete pipe culverts, metal arch culverts and metal pipe culverts (Orendain & Barrow 1989:432, 433-435).
c) When the conduits are of rectangular cross section, the culvert is known as a box culvert (Houghton & Charman 1986:35).
d) In concrete box culverts, the concrete is reinforced with high tensile strength and mild steel bars.
e) Concrete pipe culverts normally are non-reinforced structures with an internal diameter of 60 cm to 120 cm and a wall thickness of 10 cm.

**cut**
Portion of land surface or area from which earth has been removed by excavation; more in particular: the scarp face from the original ground surface down to the excavated surface.

**cut and carry**
Cutting and collecting forage material for stall feeding of stock and for provision of fuelwood in a zone around the living area.
a) It is a conservation based management technique to preserve soil and vegetation (Hurni 1986:50).
b) It provides fodder for livestock, and firewood and small fuelwood for cooking and heating (Hurni 1986:50).

**cut and fill**
Process of earthmoving by excavation of part of an area, using the excavated material for adjacent embankments or *fill* areas.

**cutoff**
A collar or other structure, such as a trench, filled with relatively impervious material intended to reduce seepage of water through porous strata, such as in the wall of an earth dam.

**cutoff bank**
~ cutoff ditch
A barrier constructed of earth or other materials to ensure that water flows into a constructed culvert or ditch.

**cutoff drain, ditch, trench**
~ cutoff bank
A channel used to collect surface runoff from the land above and to divert it safely to a waterway or river, thus protecting the land below from excessive erosion.
a) It may retain the water and be an effective means of runoff storage, or it may be designed to divert the water to a *drainageway* (Orendain & Barrow 1989:432).
b) To avoid scouring, the gradient of the channel should not exceed a safe value (Hurni 1986:76).

**cutoff wall**
A watertight barrier for preventing seepage or movement of water under or past a structure.
a) Usually a masonry wall, collar or core of impervious material, intended to reduce percolation of water along otherwise smooth surfaces or through porous strata (Houghton & Charman 1986:35).
b) Other functions may include providing anchorage of a hydraulic structure against downhill sliding, and providing protection against structural damage due to *scouring* at the *inlet* or *outlet* (Houghton & Charman 1986:35).

**dam**
A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, rock or other debris.
a) Dams used for *water conservation* on the farm are normally built of compacted *soil* and are called earth dams (Houghton & Charman 1986:35).

**debris**
~ landslide
Any accumulation of loose material arising from the waste of rocks. Int may occur in the place where it is produced, or it may be transported by streams or ice and deposited in other localities (UNESCO 1992:70).
a) It generally contains a significant proportion of coarse material (Houghton & Charman 1986:36).
b) It is *mass movement* material in which 20-80% of the fragments are greater than 2mm in size. This is a distinction from earth type movements, where about 80% or more of the material must be smaller than 2mm in size (Shroder 1971; Varnes 1978).

**debris cone**
Deposit of soil, sand, gravel and boulders at the point where a mountain stream meets a valley or other situation where its velocity is reduced sufficiently to cause such deposits. It consists of material lying on steeper slopes than an alluvial fan (UNESCO 1992:71)

**decapitation = truncation**
The removal of the upper part of the soil profile by accelerated erosion.

**deep ploughing**
A ploughing operation to a more than usual depth, for instance up to 50 or 70 cm, to break a soil pan that hinders plant growth and water movement in the soil, or to mix soil layers or horizons to obtain better soil properties.

**degradation**
~ soil degradation
~ land degradation
Disintegration and wearing down of the surface of rock, cliffs, strata, streambeds, etc. by atmospheric, aquous, biological and other action (UNESCO 1992:71).

**delivery ratio**, see sediment delivery ratio

**denudation**
Erosion by rain, frost, wind or water of the solid matter of the earth. It often implies the removal of the soil down to the bedrock (UNESCO 1992:71).
Stripping, removal, by natural or artificial means, of all vegetation and organic matter (UNESCO 1992:71)

**deposition**
The process of leaving soil material in a new place after transport by runoff water, when the transporting capacity becomes reduced.
a) Deposition takes place where slope steepness decreases, where flow is slowed by vegetation or *surface roughness*, where flow is stopped in depressions or retention structures or where flow volume is reduced by higher *infiltration* (for instance on pervious earlier *sediment*, as on a *gully fan*).
b) Forms of deposition may be: colluvial, with a linear source area and processes of *slope wash* and gravity; alluvial, with a point source area and processes of alluvial deposition, as on river *fans* and *gully fans*; and alluvial from decantation from

overbank flooding of a stream, as in the formation of levees and basins.

c) Deposition is selective, the largest and most dense particles *settling* first, the finer lighter particles being deposited farther away.

d) The transportability is limited by the *flow competence*, and the size of the particles, which may be aggregates or fragments of aggregates. The size distribution of aggregated *soil* depends on the amount of tillage, soil moisture at tillage and type of *erosion*. *Sediment* from interrill areas may be smaller than that from *rills* and *gullies*, with their higher turbulence of flow (Meyer 1981:34).
The frequent statement that *eroded* clay and fine silt are transported the farthest may be misleading for those *soils* where much of the *sediment* is removed in the form of coarse aggregates (Meyer 1985:173).

d) Deposition is difficult to estimate; it can occur within fields, in *terrace channels*, in *waterways*, through impoundments and on pervious sedimentary slopes (Moldenhauer & Foster 1981:24).

**depression storage**
~ runoff coefficient
~ surface storage
~ detention storage
The amount of water stored by depressions in the land surface.

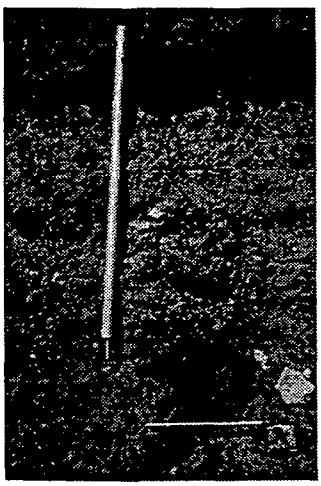
a) It is the *overland-flow* and rain which collects in depressions.

b) It may disappear by *infiltration* and by evaporation (Soil.Cons.Soc.Am. 1982:44).

c) It does not contribute to *runoff* lower down the *catchment* (Houghton & Charman 1986:37).

d) On ploughed land it is determined by the depth and direction of *ploughridges*.

e) Tillage that leaves the surface cloddy and rough may provide much surface storage (Meyer 1981:36).



*Field evidence of depression storage (bar is 50 cm long), Merida, Spain (photo E. Bergsma).*

**desaggregation**
The loss of soil aggregate structure.

**design capacity**
The calculated volume and/or discharge rate of a soil conservation structure.

a) It is based on a given set of hydrological conditions applicable to the site and the requirements of the structure, e.g. water storage or diversion.
Following its construction a structure's capacity should be checked to ensure it meets the design requirements. If the design capacity is not achieved, the structure may fail (Houghton & Charman 1986:37).

**design life**
The period of time for which a (soil conservation) structure is designed to perform its intended function.

**desilting area**
An area of grass, shrubs or other vegetation used for inducing deposition of silt and other debris from flowing water; located above a stock tank, pond, field or other area needing protection from sediment accumulation.

**desurfacing,** see soil scalping

**detachment,** see soil detachment

**detention,** see detention storage

**detention dam**
A dam constructed for the purpose of temporary storage of streamflow or surface runoff and for releasing the stored water at controlled rates.

**detention storage = runoff detention**
~ depression storage
That part of precipitation which is temporarily stored en route to or in the stream system, during or shortly after rainfall. Detention storage includes surface and channel detention, but does not include depression storage (UNESCO 1992:77).

a) As flow takes time, an amount of water is on the surface of the land during its flow towards the exit of the catchment.

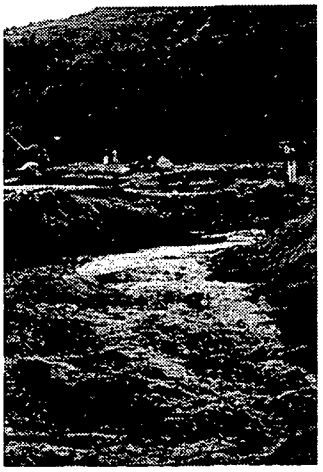
b) It comprises surface detention and channel storage.

**dike**
Earth embankment constructed to contain water or divert stream flow.

**discharge**
Rate of flow, specifically fluid flow, passing a certain point in the drainage system, and expressed in

volume per unit time, for instance cubic metres per second.

a) Units can be cubic feet per second, millions of gallons per day, gallons per minute, cubic metres per second (Soil Cons.Soc.Am. 1982:47).



*Torrent-like discharge due to soil erosion from cultivated land, Wello, Ethiopia (photo B. Messerli).*

**discharge point**
A location at which effluent is released into a receiving stream.

**dispersion**
The breaking down in water of compound soil particles, such as aggregates, into their component parts of sand, silt and clay.

a) In the case of clay, the process of dispersion can be followed by that of *suspension*.

**dispersion ratio = dispersion percentage**
The ratio of silt plus clay remaining in *suspension* after limited shaking in water and settling, following specific procedures, to the total silt plus clay as determined by mechanical analysis.

a) The greater this ratio, the easier the *soil* can be dispersed (Soil Cons.Soc.Am. 1982:48).
b) The ratio is determined by the amount of fine material that is dispersed after 10 minutes shaking in water, divided by the amount of dispersed material after shaking the soil sample for 120 minutes in water which contains a dispersant (Houghton & Charman 1986:40).

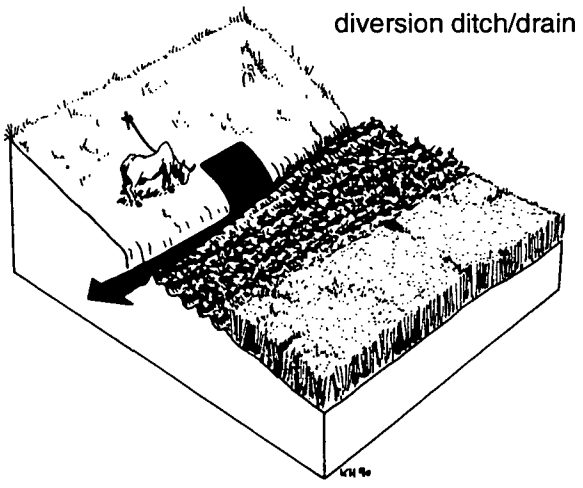
**diversion**
A channel embankment or other man-made structure made to divert water from one area to another.

**diversion bank,** see diversion ditch or channel

**diversion dam**
A barrier built across a stream to divert part or all of the water from the stream into a different flow path.

**diversion ditch**
~ diversion terrace/bank
An earth channel traversing a slope designed to protect adjacent lower slopes or development works by intercepting surface runoff and diverting it to a stable outlet.

a) It may run across a hillside to protect bottomland from hillside *runoff*, or it may be needed above a *terrace* system for protection against *runoff* from an unterraced area or to protect farm buildings from *runoff* (Soil Cons.Soc.Am. 1982:49).
b) It may also be made to divert water out of active gullies or to reduce the number of *waterways*. It is sometimes used in connection with strip cropping to shorten the length of slope so that the strips can effectively control *erosion* (Soil Cons.Soc.Am. 1982:49).
c) It is an individually designed *channel* (Soil Cons.Soc.Am. 1982:49) and should be parabolic or trapezoidal in cross-section to permit maintenance of protective vegetative *cover*. Such *channels* are typically graded (Houghton & Charman 1986:40).
d In case of small expected volumes of hillside runoff, a smaller construction may be used, such as a diversion terrace/bank.




**diversion terrace,** see diversion

**divide,** see drainage divide

**double cropping**
~ intercropping
A cropping procedure whereby two crops are grown in one year on the same piece of land.

**double furrow**
~ furrow:
A furrow made by ploughing adjacent rows in opposite directions.

**drag**
Force exerted by a flowing fluid, e.g. water, on an

object placed in or adjacent to the fluid, projected in the direction of flow (UNESCO 1992:85).

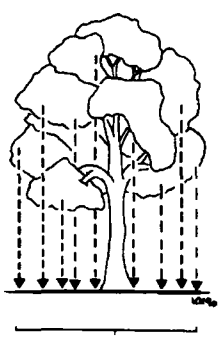
**drain**
~ mole drain
~ open drain
~ tile drain
A channel (open drain) or conduit (closed drain) for the purpose of interception and removal of excess surface or sub-surface water to a stable outlet.

**drainage basin** = **watershed** or catchment
= drainage area
= catchment area
= catchment
see catchment

**drainage divide**
The line dividing the supply area of one stream from the supply area of another stream, usually a ridge following the highest ground bordering the two supply areas; sometimes its position is adjusted to water-guiding layers in the substratum.

**drainageway**
A passage for flow of water to leave the land and reach the drainage system lower down in the landscape.

**drip**
Water drops falling from the canopy after rainfall interception, or after condensation from dew.
a) If the canopy height is low, the fall velocity of the *drip* is much lower than that of unintercepted rain. In these cases the canopy has a protective effect against erosion.
b) Critical canopy height is about 3 metres and at that height the reduction in *rain-erosivity* by the canopy is more than about 25 % (Wischmeier & Smith 1978).



drip

**drip irrigation**
A type of irrigation in which the water is slowly supplied in drops, produced from holes made at intervals in tubes and thus causing no increase in erosion hazard on sloping land.
a) Advantages are:
- limited water use
- application suitable for permeable soils
- steeper slopes are no constraint, as levelling is not needed and erosion hazard is not increased
- suitable for windy areas where sprinkling is not suitable (Advisory Committee on Technology Innovation 1974)

b) It is sometimes called trickle irrigation, when a small flow of water is supplied from each outlet.
c) The tubes may be of rubber or flexible plastic, and can even be laid to individual trees or plants.

**drop inlet**
A drop structure forming the entrance section to a hydraulic structure.

**drop structure**
A hydraulic structure to allow water to fall safely to a lower level.
a) The term may be applied to an entire structure incorporating an *inlet*, drop and *outlet*, which facilitates the entry and exit of water between two levels without causing *erosion*; or to asection of a hydraulic structure such as in a *drop inlet* culvert (Houghton & Charman 1986:44).
b) The drop is typically vertical but may be inclined provided the *nappe* does not touch the structure. Where a *nappe* does not form, the structure is referred to as a *chute* (Houghton & Charman 1986:44).
c) For *soil conservation* purposes a drop structure should include an energy dissipator (Houghton & Charman 1986:44).

**dry aggregation**
The size distribution of soil structural elements after standard dry sieving.

**dry sieving**
~ wet sieving analysis.
Determination of the size distribution of soil structural elements by sieving of air-dry soil.

**duripan**, see hardpan

**dust mulch**
~ mulch
A loose, finely granular or powdery surface soil condition usually produced by shallow cultivation when the soil is dry.
a) Its aim is moisture conservation, by disconnecting soil capillary pores from the evaporating land surface.

**ecology**
~ ethno-ecology
The study of relationships between living organisms and their environment.

**ecosystem**
The interacting system of biologic community and its non-living environment; a community together with its environment; an ecological system.
a) It is a description of a natural environment for plants and animals (Soil. Cons.Soc.Am. 1982:52).
b) It is often damaged or destroyed by human activity, and therefore is a subject of *conservation*.

**effective porosity**
Amount of interconnected pore space available for fluid transmission. It is expressed as the ratio of the volume of interconnected interstices to the gross volume of the porous medium, inclusive of voids (UNESCO 1992:93).

**effective precipitation**
That part of the total precipitation that contributes to some effect, be it use by plants, production of runoff, supply of soil moisture and recharge of groundwater, or the part falling on strongly inclined slopes and therefore limited by the cosinus of slope angle.
a) In hydrology it is the part of the precipitation that produces *runoff*. It is approximately equal to the rainfall minus evaporation and *interception* storage (Chorley 1978) and it excludes the rainfall lost to deep percolation below the root zone.

**embankment**
A low elongated elevation of earth, that is built above the natural surface of the land and is used to contain, divert, or store water, support roads or railways, or made for other similar purposes.

**energy dissipator**
A structure used to absorb excess kinetic energy of flowing water.
a) The energy to be dissipated is acquired by the water through an increase in its velocity, such as in a *chute* or over a *weir* (Houghton & Charman 1986:48).
b) Energy dissipators are incorporated into the design of hydraulic structures to reduce turbulence and the *erosive* power of fast-moving water (Houghton & Charman 1986:48).

**enrichment ratio**
The ratio of the concentration of a plant nutrient element in eroded soil material to that in the soil before erosion.
a) The nutrients are relatively more abundant in the finer soil fractions, which are in turn most subject to *erosion* (Alberts & Moldenhauer 1981).
b) Values of enrichment ratios for K and P of 1-2, and for Ca and Mg of 1-3 occur. (Gachene 1989:35).
c) The concept is of great importance for the evaluation of the damage that *erosion* does to the *land*. A small amount of erosion can be much more damaging to yield relative to larger soil losses. The enrichment ratios are especially high when *soil losses* are small (Auerswald 1989).
d) A case study for phosphate is discussed in Sharpley & Smith (1990). The enrichment ratio is related to the amount of *soil loss*.
e) A particular case is that of radioactivity, which may stem from low concentrations of settling dust, but which accumulates in deposited sediments.

**entrainment**
Process of picking up and carrying away of the material produced by erosive action from the bed and banks of a channel (UNESCO 1992: 98).
a) Entrainment is by a *tractive* force, bringing particles into the stream. The flow may be *overland flow* or streamflow (Bryan 1977).
b) It is part of a series of processes: *detachment* - entrainment - transport - *deposition*.
c) Flow velocity necessary for entrainment (the critical threshold entrainment velocity) decreases with soil particle size down to 0.2 mm (at 0.18 cm/sec) and then increases again. Flow velocity necessary for transport decreases with particle size (Bryan 1977).
d) It is a function of particle size, the content of organic matter and of certain chemical compounds (Bryan 1977).
e) Hjulstrom (1935) showed relationships between *soil texture*, flow velocity and particle entrainment (Bryan 1977).
f) Entrainment resistance depends, apart from particle size, also on submerged weight and shape, because of the very shallow depth of *overland flow* (Bryan 1977).
g) Entrainment is strongly increased under *splash*, which causes increased turbulence by eddies from *raindrop* impacts, .The effect depends on the flow depth and the *raindrop* size. The critical raindrop size is a diameter equal to the water depth, deeper and shallower flows showing less *splash* entrainment (Bryan 1977).
h) Re-entrainment occurs after temporary *deposition* of material in transport. The force needed for re-entrainment is much less than for dislodging a particle and mobilising it the first time. *Saltation* plays an important role in re-entrainment (Rose, pers.com.1987).
i) Entrainment by flow is discussed in Thornes 1980:151-152.

**ephemeral gully**
A gully recurring in the same landscape position, but sometimes easily removed by normal tillage operations.
a) Two types of ephemeral gullies are mentioned in Poesen & Govers (1990). One has a width many times its depth and is therefore most likely identical with a *braid*, like the example shown by

photo (p.526). In this case the name gully is less appropriate.
Another type is described as having banks, and a depth that prevents it being removed easily. This feature is thus a *gully*. In this case the name ephemeral does not indicate the great effort needed to remove it.

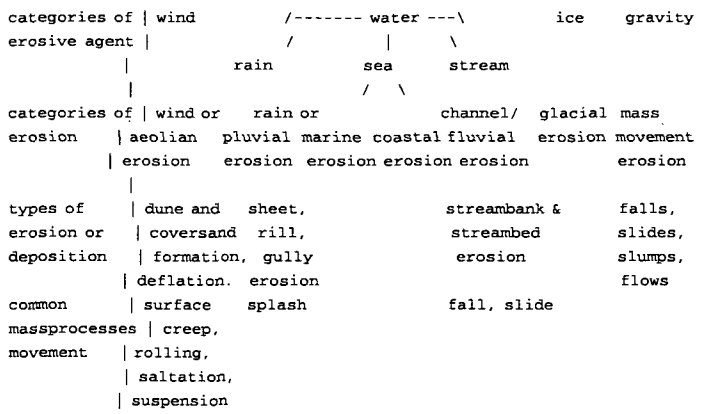
**erode**
To wear away or remove the land surface by wind, water, mass movement or other agents.

**erodibility**, see soil erodibility, gully erodibility

**erodible**
Susceptible to erosion, easily eroded.

**erosion**
The wearing away of the land by running water, rainfall, wind, ice or other geological agents, including such processes as detachment, entrainment, suspension, transportation and mass movement.
a) It does not include weathering.
b) Several categories of erosion exist (Toy 1977:7; Moldenhauer 1989).

DIAGRAMOFEROSIONCATEGORIES




**erosion classes = soil erosion classes**
Degrees of erosion intensity, based on soil profile characteristics such as degree of truncation, and patterns of erosion features in the field applied to accelerated erosion, not to normal, natural, or *geological erosion*.
a) Classes of *accelerated erosion* are established and *eroded soil phases* mapped primarily because of their significance to soil use and management, and since a given amount of *erosion* has a different meaning on different soil types and in different regions, erosion classes can not be defined in precise physical terms applicable to all *soils* (Soil Survey Staff 1951).
b) The number of erosion classes to be recognised and their definitions depend on the objectives of the survey and the *mapping* scale, the significance of the *erosion* to present agriculture, and the dominant plant *cover* (Soil Survey Staff 1951).
c) For some immediate objective (say next year), it may be possible and useful to map existing conditions resulting from *erosion* in great detail, whereas on a published map, only the more permanent conditions should be shown (Soil Survey Staff 1951). The recording of temporary, and often local unrepresentative *erosion features*, with a distribution depending strongly on the *land use*, seasonal management, gives only some indication of present *erosion* processes or present hazard. For a systematic complete record of permanent value, significant permanent *erosion features* should be supplemented with information about other erosion hazard *factors*, with a conclusion about the potential as well as the *actual erosion hazard* shown on a map.
d) Example of erosion class description:
Classes of erosion by water, to distinguish *soils* having suffered different degrees of water erosion (Soil Survey Staff 1951:261-265).

Class 1: The soil has a few rills or places with thin A-horizons that give evidence of accelerated erosion, but not to an extent to alter greatly the thickness and character of the A-horizon. Up to about 25 percent of the original A-horizon, or original ploughed layer in soils with thin A-horizons, may have been removed from most of the area.
In most soils, areas with this class of erosion are not significantly different in use, capabilities and management requirements from the uneroded soil.

Class 2: The soil has been eroded to the extent that ordinary tillage implements reach through the remaining A-horizon, or well below the depth of the original ploughed layer in soils with thin A-horizons. Generally the plough layer consists of a mixture of the orginal A-horizon and underlying horizons.
Shallow gullies may be present.
Approximately 25 to 75 percent of the original A-horizon or surface soil may have been lost from most of the area.

Class 3: The soil has been eroded to the extent that all or practically all of the original surface soil, or A-horizon, has been removed. The plough layer consists essentially of materials from the B or other underlying horizons.
Shallow gullies or a few deep ones are common on some soil types.
More than about 75 percent of the original surface soil, or A-horizon, and commonly part or all of the B horizon or other underlying horizons, have been lost from most of the area.

Class 4: The land has been eroded until it has an intricate pattern of moderately deep or deep gullies. Soil profiles have been destroyed except in small areas between gullies. Such land is not useful for crops in its present condition. Reclamation for crop production or for improved pasture is difficult but may be practicable if the other characteristics of the soil are favourable and erosion can be controlled.

This erosion class description shows that the planning of improvement measures depends on land qualities, apart from the *erosion susceptibility* and the resulting hazard under a certain *land utilisation type*. *Land qualities* are for instance availability of water, of oxygen, or possibilities for mechanisation.

e) For an example of erosion classes in grazing-land, see Biamah (1989: 295-299). The effect of grazing intensities is studied in Heathwaite, Burt & Trudgill (1990).

**erosion control,** see soil conservation or soil conservation practices

**erosion features,** see rain erosion features

**erosion hazard**
~ rain erosion hazard
The sensitivity of the land to the prevailing agents of erosion, or the rate of soil loss expected in the near future.

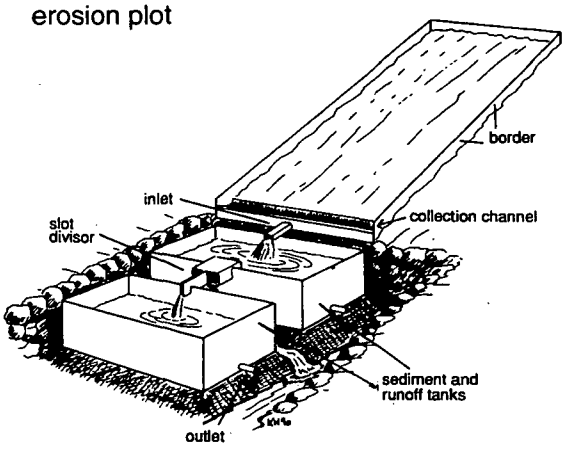
**erosion mapping,** see rain erosion mapping

**erosion phase**
A substantial, defined, modification of a soil by decapitation, of importance for its use, and used in soil mapping and soil classification.

**erosion plot**
Uniform small parcels of land from which runoff and soil loss can be measured under natural or artificial rainfall.

a) The size of an erosion plot is mostly a few metres wide, and some tens of metres long. Larger plots may reach the size of a very small *watershed* (Moldenhauer & Foster 1981:13).
b) Erosion plots may be exposed to natural rain or to simulated rain.
c) *Overland flow* may be caught in one tank for small showers, while larger showers fill a second tank with part of the overflow from the first, selected by a multi-slot divisor (Moldenhauer & Foster 1981:14). For larger plots a third tank is put behind the second to deal with the largest storms.
d) The length may or may not allow rills to be formed.
e) The reference plots for the *USLE* are 22 metres long and 2 metres wide, on a 9% slope.

erosion plot






*Layout of large experimental erosion plots for agro-forestry trials of erosion and production, Northern Thailand (photo H. Hurni).*



*Erosion plots, sediment and runoff collection, Northern Thailand (photo H. Hurni).*

**erosion slope,** see erosion slope length

**erosion slope length**
The distance along a slope subject to uninterrupted overland flow, from the beginning of overland flow to where deposition starts, or where flow enters well defined channels, such as gullies.

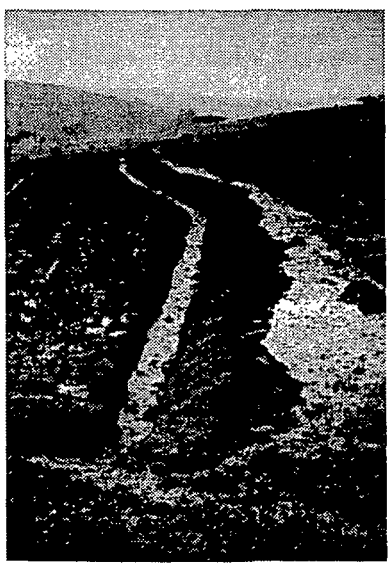
**erosion susceptibility,** see rain erosion susceptibility

**erosion toposequence,** see soil erosion toposequence

**erosive**
Tending to produce erosion
a) The term refers to active agents of erosion, such as rainfall (Houghton & Charman 1986:51), not the material being eroded.

**erosivity,** see rain erosivity

**ethno-ecology**
The ecologically combined weighing of both the intellectual and practical activities that a certain human group executes during its appropriation of natural resources.
a) The concept has been introduced during a study of the Hanunoo in the Philippines (Conklin 1954). Sources of the concept are (Toledo 1992):
   1) anthropology,
   2) investigations about the interaction between human beings and their plant, animal and fungi environment,
   3) agro-ecology, the study of the knowledge and practices of the farmers (example Bellon 1990),
   4) environmental geography, the study of systems of traditional management of resources.



*Graded Fanya juu conservation bund during a storm runoff, Gojam, Ethiopia (photo H. Hurni).*

b) Modern ecology conceives the view that a production process can only be done appropriately if the ecosystems equilibrium can be maintained. In most traditional rural cultures this subjectivity has an ecological significance that directs productive behaviour not by scientific evidence but by reference or ideal values. Knowledge can never replace respect as a guiding principle in our ecosystemic relations (Rappaport 1979:100-101).
c) It is closely related to indigenous knowledge (IK, Vol.1, nr 1,1993), which may provide a scientific path to the heart of the land user, more understanding by the adviser, and more cooperation between them.

**evapotranspiration**
Removal of moisture from soil by evaporation from the soil surface plus transpiration by plants growing in that soil.
a) It is measured at a specific site over a specific period of time (Houghton & Charman 1986:52).
b) Potential evapotranspiration is the amount of water that will be lost by evaporation and transpiration from a surface that is completely covered with vegetation and there is sufficient water in the *soil* at all times for the use of the vegetation.
c) Penman found that evaporation from a free water surface approximated the potential evapotranspiration (Baver a.o. 1972:264, 386-391).
d) Soil moisture shortage or excessive drying conditions may cause the actual evaporation to be less than the potential.

**exfiltration,** see seepage flow

**exposition,** see slope exposition

**exposure (in orographic rainfall)**
Degree of openness to wind, sun and weather:
a) The term is used in quantifying the influence of orographic rainfall. It is the sum of the sectors around a site measured in degrees, where no barrier exists within a given range (Spreen 1947; Ven Te Chow 1964).

**factors of rain erosion**
Categories of influence on the erosion process, named after their dominant relation to climate, relief, soil profile, plant cover of natural vegetation and cultivated plants, and land management practices.
a) In some estimations of *soil loss*, they have the function of single factors. In other estimations, interactions between the factors receive emphasis.
b) The factors of rain erosion are similar to the factors of soil formation, which lead to a soil profile.

**fallow, fallowing**
~ bare fallow:
The management practice of leaving land in an uncropped state, either tilled or untilled, for a period of time prior to sowing another crop.
a) Fallowing may not necessarily involve tillage, but in Australia the term is usually understood to do so (Houghton & Charman 1986:53).
b) Weeds are usually killed either by tillage or by chemicals.
c) Some experiments indicate that weeds which protect the *soil* may contribute to fertility and are generally beneficial if left to grow in combination with strong natural varieties of food crops (Stevens 1988).

**fan,** see alluvial fan

**Fanya juu**
~ colluviation terrace
A system of terracing in which the terrace channel is below the terrace bund, and colluviation resulting from erosion and cultivation above the bund is allowed to form each terrace into a colluvial step.
a) Fanya juu is Swahili language meaning throw upwards, because excavated soil is thrown uphill to form a ridge. The *channel* is dug firstly to form the ridge, secondly to discharge overtopping water, if any (Wenner 1988:198). If not maintained, the terrace channel will be filled with *sediment* and becomes part of the colluvial slope. The terrace is built up gradually by erosion and cultivation of the area above each ridge.
b) Vegetation is planted on the edge of the bank and the downhill face to stabilise the bank and increase *deposition* on the uphill side. Periodically, the process of throwing up more *soil* onto the bank is repeated.
c) The *channel* of the Fanya juu can be level (Hurni 1986:44) in which case *tied ridging* is usual, or it can be graded (Hurni 1986:46), with a lateral gradient up to 1 %. In this case a system of *lock and spill drain* is usual.



*Traditional cultivation of a steep slope in an ox-plough system, Wello, Ethiopia (photo M. Coendet).*

d) A useful variation that speeds up the process of colluviation and spreads the labor requirements is to put in Fanya juu terraces in two stages. First terraces are put in with a *vertical interval* of 2 metres; then, at a later stage, additional lines are put in between. In Kenya, use of this system has resulted in nearly *level terraces* in as little as seven years (Hudson 1988b:121).
e) It has been widely practiced on small, labour intensive farms in Kenya. The concept is clarified and the design is discussed in Thomas & Biamah (1991).

**farming system**
The total of production and consumption decisions of the farm-household including the choice of crop, livestock and off-farm enterprises and food consumed.

**fast geological erosion**
Erosion much more rapid than geological erosion, intensified by natural events, such as a tectonic movement, river capture, or denudation by natural mass movements.
a) The rates are comparable to the high rates of *accelerated erosion* that are caused by the influence of man through agriculture, road construction, *urbanisation*, etc.

**feasibility of improvement**
The possibility for implementing practices of soil and land improvement, as related to removing or reducing the limiting factors for required use, which may relate to soil and land, management capability or labour and/or capital, always defined for a certain land utilisation type.

**field boundary gully**
A gully developed in the land on the boundary between two fields.
a) The field boundary area is sensitive to gullying when both bordering fields are made to drain towards the boundary.
b) The area of the field boundary receives sometimes less careful management when the field boundary separates land of different landusers or owners.

**field capacity = water holding capacity**
~ rain storage capacity
Amount of water held in a soil after gravitational water has drained away (UNESCO 1992:107).
Gravitational water: water in the unsaturated zone which moves under the influence of gravity (UNESCO 1992:131).
a) It is measured after a period of drainage from saturation, when the rate of downward movement has materially decreased (Chorley 1978). As a general rule, soils are considered to be at field capacity after draining for 48 hours (Houghton & Charman 1986:53).

b) Storage of water in *soil* is by different forces and at different tensions (Dunne & Leopold 1978:173-177).

**fill**
Material used to raise the surface of an area to a desired level by earth moving operations.
a) Usually made up of *soil* and rock material, but may also be solid waste (Houghton & Charman 1986:54).

**filter dam**
~ sediment trap.
A barrier, embankment or other similar structure, built of pervious material such as stones or gabions, and located in drainage lines to filter out and store the sediment carried in passing flows.

**filter strip**
~ buffer strip
~ desilting area.
A strip or area of vegetation for removing sediment, organic material, organisms, nutrients and chemicals from runoff or waste water.

**floodbraidwash**
Type of rain erosion with very wide braids caused by strong overland flow.
a) Occurs in cases of heavy *runoff* and moderate to gentle slopes. The width of the feature is greater than about 3 metres; occurs in footslope areas (Richter 1965).

**floodway**
A long low section in a road which allows flood waters to flow across it.

**flow competence**
The maximum size of particles of given specific gravity, which, at a given velocity, a stream will move.
a) Three controlling factors are mentioned by Gilbert (1914): water discharge ,bed slope, and sediment grain size.
b) It is quantified by the critical stress needed for grain movement. Leopold a.o. 1964:172.
c) Flow competence has been used as a forward method: the largest grain observed to be entrained by a flow , Dmax, is used as an estimate of the largest grain that flow can move and, therefore, as a measure of the competence of that flow.
Flow competence has also been used in an inverse form: to estimate the magnitude of a flow event from the calibre of the sediment moved. Relations have been developed for flow velocity and bed shear stress as a function of Dmax (Wilcock 1992).
d) Because the estimates are based on an extreme value of the transport grain-size distribution, however, they are subject to large errors and are sensitive to the effect of sample size.
It is possible to define a single flow competence for the entire mixture, based on a central value, or median size, of the grain-size distribution. Such a measure is relatively stable, does not require between fraction scaling, and appears to be well supported by observation (Wilcock 1992).
e) A small rapid stream can move a relatively large particle, and has a great competence, but the amount of material transported is small. Conversely, a large slow-moving stream may carry in suspension a great quantity of small particles, its competence being small but its capacity great (Dict.Geol.Terms 1962:97).
f) Rill flow generated during moderate rainfall events in the Belgian loam region has a competence almost 10 times that of interrill flow (Poesen 1987:52).

**flume**
A hydraulic structure, incorporating an inlet, chute and outlet, to convey water to a lower level without causing erosion.
a) It may also apply to an entire canal that is elevated above natural ground for its entire length (Soil Cons.Soc.Am. 1982:64).
b) Flumes are usually used at the head or side of a *gully* (Houghton & Charman 1986:55).
c) Sometimes used to support calibrated devices used to measure the flow of water, or *sediment* discharge (Houghton & Charman 1986:55), and in open conduits (Soil Cons.Soc.Am. 1982:64).

**flute, fluting = pipe shaft erosion**
Vertically elongated grooves, generally tapering towards the top, that furrow into the wall of a gully or other steep slope, such as those of roadcuts when overland flow is rather evenly distributed over the slope.
a) Term introduced by Veness (1980).
b) Flutes result predominantly from the action of *rill flow* (Blong 1985).
c) It is one of the processes of lateral extension of gully walls (Blong 1985).
d) Photo in Blong 1985 p.578.

**fluvial erosion**
Erosion produced by concentrated flowing water, typically as by a stream or river.

**folial cover**
~ canopy cover
The cover provided by the aerial parts of plants, dominantly the leaves.
a) It is usually expressed as percentage *cover* of the ground surface area directly below (Soil Cons. Soc.Am. 1982:58).

**freeboard**
The vertical distance between the top water level and

the crest of a bank, dam or similar structure.

**friable**
A consistence of soil structure in which the soil breaks into finer elements but not primary grains, allows some deformation before breaking, is not brittle and coheres again when separate parts are pressed together.
a) The consistence is observed at a moisture content approximately halfway between air dry and *field capacity* (Soil Survey Staff 1951:233).

**Froude number**
Dimensionless number expressing the ratio of inertia forces to gravity forces. In open channels, flow is sub-critical , critical or supercritical if its Froude number in less than, equal to or greater than unit respectively (UNESCO 1992:127).
a) For uniform thin flow it is: (Houghton & Charman 1986:59):

$$F = \frac{v^2}{g.d}, \text{ where}$$

F = *Froude* number
v = velocity
g = acceleration due to gravity
d = depth.
b) It characterises the change over from tranquil to rapid flow (Carson & Kirkby 1972:37).
c) It is one of the determinants of *sediment concentration* of overland- flow (Renard 1977:35).
d) When *overland flow* has very low *Froude* numbers, it is better not considered as *laminar flow*, but as disturbed flow when there is the effect of *raindrop* impact (Morgan 1980:280). The subdivided flow of Horton describes the turbulence due to small obstructions of clods, gravel, plants, etc.
e) *Overland flow* has typically low *Froude* numbers, as indicated by field studies giving *Froude* numbers of less than 0.05 (Morgan 1981:518).
f) *Rills* may be formed when the critical *Froude* number exceeds > 1 + 0.0035 D where D is the median grain size in mu (Boon & Savat 1981:314).

**furrow**
A narrow, shallow, channel made by a plough or grader.

**gabion**, see stone mattress

**geological erosion = natural erosion**
~ fast geological erosion
The normal or natural erosion caused by geological processes acting over long geological periods and resulting in the wearing away of mountains, the building up of floodplains and coastal plains.

**gorge**
~ ravine
A narrow passage, with precipitous, rocky, sides, enclosed among mountains.
a) It develops by *geological erosion*.
b) The walls are nearly vertical, as in the case of a retreating waterfall (Dict.Geol.Terms 1962:213) this means that the top width is not much wider than the width of the bed below.
c) A ravine need not be enclosed (Dict.Geol.Terms 1962:213)

**grade**, see gradient

**graded bank/terrace = diversion terrace:**
A terrace/bank built with a design fall along the channel.
a) Primarily used on arable land.
b) Design grades normally range from 0.1 to 0.5 percent.
c) Some very long terraces/banks would be progressively increased in capacity, in order to handle the large flows which develop towards the *outlet* end.

**graded bund**
~ bund
~ level bund
~ diversion terrace
An low embankment roughly along the contour, made of soil and/or stones, with a basin at its upper side to reduce the velocity of overland flow and to divert it on a slight gradient towards a waterway or river.
(Hurni 1986:46):
a) The height is about 50-75 cm and the bottom width is 100-150 cm.
b) They often have a water retention basin at their upper side, usually with a system of lock and spill drains.

**graded stream**
Stream that apparently has achieved an approximate state of equilibrium between the rate of sediment transport and the rate of sediment supply (UNESCO 1992:130).

**gradient**
The degree of slope of a constructed or excavated surface or the longitudinal fall of a channel.

**grassed waterway**
A drainageway, designed to carry runoff downslope, put in grass to slow down the flow and protect the bed from scour.
a) A grassed waterway should have a dense and vigorous *cover* of about 15 cm long grass. It should therefore be fertilised and have good *grazing*

*management* or mowing (Houghton & Charman 1986:144).

b) It is not always practical to establish and maintain grass-lined *channels* when the rainfall is low or erratic, or when long dry periods are common.

c) Grassed waterways are not really practical on slopes steeper than about 10 percent. To keep the flow rate down to a non-*scouring* velocity, requires a low hydraulic gradient, which means a broad shallow section.

d) Mechanical works to control *surface runoff* are not practical on small holdings of 1 or 2 hectares which need to have a separate *cutoff* or disposal *channel* for each farm unit (Hudson 1988b:126).

**grazing**, see grazing management, rangeland

**grazing capacity**

~ carrying capacity
~ stocking rate

The maximum number of animal units which can graze each year on a given area of range, for a specific number of days, without inducing a downward trend in forage production, forage or soil quality.

**grazing management, grazing land management**

~ grazing capacity
~ rangeland

The science and art of optimising the returns from rangelands in those combinations most desired by and suitable to society, through the manipulation of range ecosystems.

a) It is a biological, physical and social science (Stoddart a.o.1975:3)

b) Grassland improvement includes (Hurni 1986:58):
- introducing better forage species by seeding, or planting of sods
- control of grazing, by rotational grazing, or fencing
- removing unpalatable species, and use for composting
- cutting shrubs, and use for fuelwood
- use of mineral or organic fertilising materials

b) An integrated management approach is called for (Muhia 1989).

**greenness**

~ leave area index
~ soil brightness
~ soil line:

Deviations of spectral data from the bare soil line, in an appropriate direction, which may be attributed to the presence of green biomass.

a) The emergence of green vegetation over a soil causes composite red radiance to decrease because of chlorophyll absorption, and overall infrared response to increase as a result of leaf mesophyll structure. Thus, deviations of spectral data from the bare *soil line*, in an appropriate direction, may be attributed to the presence of green biomass (Huete a.o. 1984).

**green manure**

Plants that are cultivated and ploughed in while green or soon after maturity to improve the soil, especially its content of organic matter.

a) It is normally incorporated into the *soil* by mechanical means, thereby, upon breakdown, providing a source of organic nutrients for subsequent field crops or existing row crops (Houghton & Charman 1986:63).

b) They are incorporated when flowering, or on light *soil*, before they have utilised excessive amounts of soil moisture (Houghton & Charman 1986:63).

c) Green manure crops are typically leguminous, for example lupins, vetches or peas (Houghton & Charman 1986:63).

**ground cover**, see soil cover

**groundwater runoff**

The part of the discharge from a catchment area which is supplied from the groundwater as spring or seepage water.

a) It is distinct from *surface runoff*, which together with groundwater runoff make the total *runoff* from an area.

b) It is fed by *seepage* from groundwater at the sites where the drainage system intersects with the water table, which may be temporary or rather permanent. In this way the groundwater runoff is the main part of the *baseflow* of streams.

**gully**, see also Central Concept of Gully Erosion

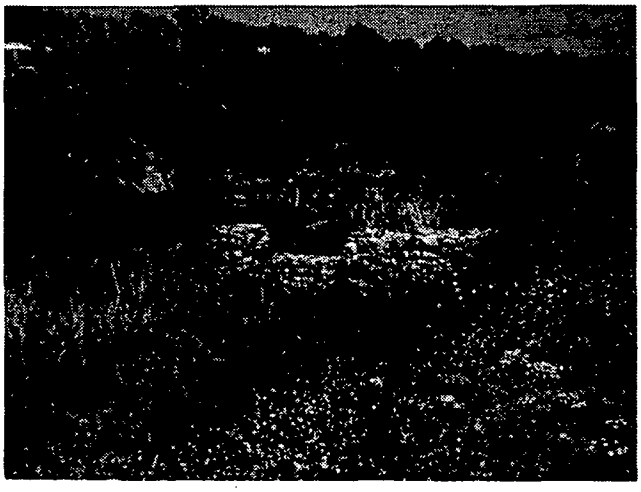
An incised channel or miniature valley cut by concentrated but intermittent runoff flow, usually during and immediately following heavy rain, or during the melting of snow. It is deep enough to interfere with, and not to be obliterated by, normal tillage operations.

a) Gullies are characterised by moderately to very gently inclined floors and precipitous walls. They are formed through a complex series of processes dominated by concentrated surface water flow and hence are frequently found in drainage lines.

b) Major flows in gullies only occur during or immediately after periods of heavy rainfall (Houghton & Charman 1986:63).

c) There may be continuous flow at the gully bottom as a result of *interflow*. This flow is usually of too low a velocity to *erode*, but the saturated bottom is much more subject to *erosion* when high *runoff* rates occur. Interflow seepage may cause collapse of gully(head)walls.

**gully checkdam**
~ gully plug
A small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, minimise channel scour, and promote deposition of sediment.
a) It is often advisable to build a series of checkdams for increased effect and safety in dealing with peakflows.
b) The vertical interval between checkdams is the height of the dam. For loose stone checkdams it is one metre (Hurni 1986:74).
c) They are easily built by hand labour in all gullies less than 2 metres deep and 5 metres wide (Hurni 1986:74).
b) In the loess area of China gully check dams are used (Fang Huarong 1987).
They serve as:
- controls on *soil*- and water losses
- silt-arresters (after *silting*, dams are height ened or new dams are built)
- producers of new fertile *land* on the silt behind the dams



*Gully checkdam, made of stone mattresses, Spain (photo E. Bergsma).*

**gully classification,** see also Central Concept of Gully Erosion.
Useful groupings of gullies based on one or more of their characteristics.

**gully control**
The execution of measures that prevent the lateral or headward extension of a gully and its branches into productive land or towards valuable constructions, and stabilise its course.
a) Relative priority for control is determined in certain cases by considering gully stream order, number of tributaries, stage of development, expected treatment returns for the total gully network, and the potential for vegetation growth which may replace costly mechanical measures especially in semi-arid and arid regions (Heede 1982).
b) For.more descriptive aspects, see Central Concept of Gully Erosion.

**gully erodibility**
The sensitivity to scour from concentrated channel flow in a gully bed, together with the sensitivity to splash and wash of the gully walls and shoulders.

**gully erosion,** see also as Central Concept.
The erosion process whereby water concentrates in narrow flow paths and periodically removes the soil resulting in deep incised channels, ranging from about 30 cm to 30 metres in depth.



*Land degradation by gullying (photo J. Bennema).*

**gully fan**
~ alluvial fan
The cone-shaped area consisting of deposited sediment at the mouth of a gully.
a) It occurs where the gully channel is becoming less confined, or where the bed gradient flattens strongly, or where the gully flow is absorbed by the substratum or previous sediment.

**gully filling**
Placing material in a gully to raise its floor and subsequently shaping it to a uniform cross-section and stabilising it.
a) The aim is to revert the area lost through channel incision back to its original productive capability.
b) It is usually performed by mechanical means.
c) The fill may include *soil* and rock materials but should exclude material that will rot, rust or create voids that form a nucleus for *tunnel erosion* or for subsidence (Houghton & Charman 1986:64).

**gully head**
The upstream end of a gully where overland flow from the catchment above enters or falls into the gully.
a) In case a plungepool is present, *headward erosion* takes place by repeated soil fall from the gully head scarp.

**gully head sill**
A short terrace/bank, with a bund as barrier at each end, used above gully heads to reduce the energy of inflow.

**gully plug**
~ gully checkdam
A small, simple transverse obstruction to flow, built in a gully.
a) They are constructed with sacks, sods, sticks, living plants, etc. (Arledge 1988:170).

**gully re-entry**
Provision made for runoff, diverted from a gully head in a scheme of erosion control, to be brought back into the gully, by way of a flume or drop structure, at a point lower down the flowline, without creating a further erosion hazard.

**gully shaping**
Physical reorientation of the sides of a gully, usually by mechanical means, to create a uniform cross-section, that will carry expected flows, without substantially raising the level of the gully floor.
a) It includes *topsoiling* and *revegetation*.

**gully trimming**
The removal of the upper edge of a gully side, by mechanical means, to decrease the potential for lateral erosion by creating a stable gradient along the gully side.
a) It should include *topsoiling* and *revegetation* (Houghton & Charman 1986:64).
b) It is not intended to raise or alter the gully floor, and it is typically undertaken on deep gullies having stable floors (Houghton & Charman 1986:64).

**gully wash**
The process of gully erosion affecting the whole of a hillslope over time.

**hardpan = duripan**
~ soil pan
A soil pan that is very hard when dry, caused by cementation of soil particles with organic matter and iron, or with materials such as silica (duripan), sesquioxides or calcium carbonate.:
a) The hardness does not change appreciably with changes in moisture content, and pieces of the hard layer do not slake in water (Soil Cons. Soc. Am.1982: 73).

**hardsetting**
~ compaction
~ sealing
Hardsetting results from alternating dry and wet conditions during a long period. There is each time a temporary saturation of a surface layer. It is evident in a relatively deep layer, 10-20 cm.
a) The amount of sodium ions adsorbed on the clay complex influences the degree of hardsetting of a sediment, and therefore its structural stability (Dexter & Chan 1991:219; Bergsma & Valenzuela 1981:318). More sodium causes a denser compaction of the sediment drying from a peptised state.

**headward erosion**
Gully enlargement in an upstream direction.
a) There are two types of uphill erosion of *gully heads*: by *overland flow* causing plungepool action leading to undercutting of the gully head scarp; or by *seepage*, protruding at the foot of the *gully head* face, causing retreat by repeated collapse.
b) The process may be accentuated by the effects of interrill and *splash erosion*, and subsurface *seepage* (Houghton & Charman 1986:49,64).

**hillside ditch**
A ditch or trench running along the contour, made to cut off the runon to lower agricultural land.

**hillside terrace**
A strip of land along the contour which has been levelled for tree planting. (Hurni 1986:66):
a) It may be one metre wide and constructed at about 2-5 metres intervals.
b) It is only used when there is a strong need for erosion protection, for instance in reclamation of badlands and in areas with low rainfall.

**horizontal interval**
The horizontal distance from one soil conservation structure to another.
a) For structures not normally used on steep slopes, it is taken as equal to the distance along the ground (Houghton & Charman 1986:67).

**hydraulic conductivity**
The volume of water which will pass through a unit of cross-sectional area of a soil in unit time, given a unit difference in water potential. (Landon 1984:71):
a) The symbol of notation is K, the dimensions are cm/h or m/day
b) At *field capacity*, K commonly ranges from 1 % to 0.1 %. of its value at saturation.
c) The rapid draining of the larger pores causes a rapid decrease in K with a decrease in water content.
c) It is a measure that is of great importance in surface irrigation by *ponding* water. It less meaningful in *erosion* studies on bare land because here surface porosity is strongly influenced by *splash*, and soil saturation is less frequent and less deep during heavy rainfall.

**hydraulic roughness**

~ hydraulic roughness coefficient

The roughness of a channel bed or banks (including vegetation) causing retardance of flow, or flow resistance.

a) The water movement in an open *channel* is affected by the hydraulic roughness or *soil surface roughness* of *channel* bed and sides.

b) Factors which increase retardance include (Houghton & Charman 1986:104):
   - surface irregularities in the *channel* bed and walls
   - vegetation on the *channel* bed and walls
   - abrupt changes in cross-section
   - sharp curves in the *channel* alignment
   - *erosion* and *sedimentation* in the *channel*
   - obstructions to flow

**hydraulic roughness coefficient**

A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water; Manning's "n" is a commonly used roughness coefficient.

a) It is a measure of retardance to flow in a *channel*.

b) It is computed to assist in the prediction of flow velocities for design purposes, calculating *channel* size or discharge capacity.

c) The *hydraulic roughness* is often expressed by the *Manning's* roughness coefficient (the "n" in the *Manning's* equation) and may be obtained from standard tables (Walker 1983 , Morgan & Morgan 1981:329).

d) Factors which affect retardance include:
   - physical *roughness* of the material forming the *channel*, e.g. surface irregularities in the lining of the *channel* increase n.
   - vegetation, e.g. height, density, type.
   - cross-section, e.g. abrupt changes in section along the *channel* increase n, as does an increase in depth of flow.
   - *channel* alignment, e.g.severe meandering with curves having relatively small radii increase n.
   - *erosion* and *sedimentation*, e.g. active *erosion* increases n.
   - obstructions, e.g. number, type, size.

e) Values of *Manning's* n for *overland flow* are in the range of 0.2 - 0.5 (Morgan 1981:518).
A determination of the Manning's roughness factor can be made by assessing the surface irregularity, the obstructions to overland flow, the proportion of basal ground cover, and the type and height of the vegetation (Phillips 1989:229).

f) The value of n in a natural or constructed vegetated *channel* varies with the season and from year to year and hence is not a fixed value. Thus, all the factors influencing the retardance to flow should be evaluated with respect to the kind of *channel*, the degree of maintenance, the seasonal requirements, and the season of the year when the design storm normally occurs, as a basis for selecting the value of the roughness coefficient (Houghton & Charman 1986:104).

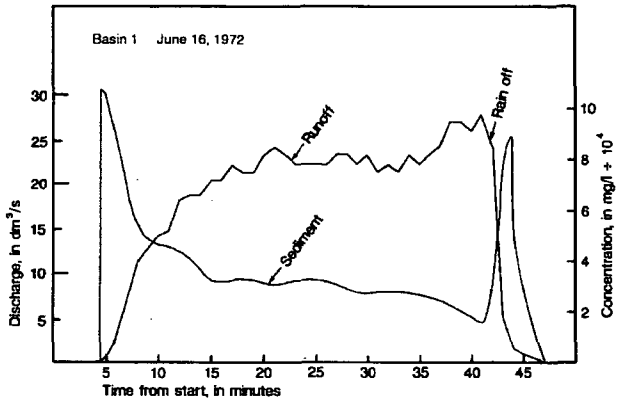
g) For overland flow conditions an estimation of the Manning's roughness factor can be made by

FACTORS THAT DETERMINE THE MANNING ROUGHNESS COEFFICIENT (n = n1 + n2 +v3n4)

| | | |
|---|---|---|
| Degree of irregularity of the surface (n1) | | |
| Minor | 0.001 - 0.013 | Minor irregularities; a few rises and dips |
| Moderate | 0.014 - 0.025 | Frequent rises and dips; significant depressions and small ridges may exist |
| Severe | 0.026 - 0.050 | Very irregular. Many rises, dips, small depressions and ridges; or furrows perpendicular to flow |
| Obstructions (n2) | | |
| Negligible | 0.000 - 0.010 | A few scattered (debris, stumps, exposed roots, logs, isolated boulders); occupy < 5 % of area |
| Minor | 0.011 - 0.048 | Occupy 5 - 15 % of area |
| Appreciable | 0.049 - 0.076 | Occupy 15 - 50 % of area |
| Vegetation cover (v3) | | |
| Proportion | 0.000 - 1.000 | Proportion of ground vegetated |
| Height and characteristics of vegetation (n4) | | |
| Small | 0.001 - 0.025 | Flexible, supple vegetation; flow depth 2 to 3 times plant height |
| Medium | 0.026 - 0.063 | Flow depth 1 to 2 times plant height; or 2 to 3 times for dense woody or stemmy plants |
| Large | 0.064 - 0.126 | Depth of flow more than half plant height, or forest if hydraulic radius > 0.6 metre |
| Very large | 0.127 - 0.252 | Depth of flow less than half plant height; heavy timber stand with flow below branches |
| Extreme | 0.253 - 0.504 | Dense vegetation with heavy litter in fullfoliage; maximum flow contact with branches and foliage |

evaluating the irregularity of the surface, the presence of obstructions to overland flow, the type and density and height of vegetation cover (Phillips 1989). The values obtained can be used in models.

**hydrograph**
A graph showing variation in depth or discharge of a stream of water over a period of time.
a) An example of a runoff hydrograph:




*Runoff hydrograph and sediment concentration curve showing typical characteristics (Lusby 1977:24).*

**hydrologic depth, hydrologic soil depth**
The limited depth of topsoil that is readily permeable to rainfall and throughflow above a relatively impermeable layer or soil horizon.
a) The term is coined by Hewlett and Hibbert (Carson & Kirkby 1972:63).
b) It is an important concept in the *Topsoil Saturation Overland Flow*, where rainfall combines with *seepage* flow and *antecedent* moisture to largely saturate the hydrologic depth, leading to *overland flow* in certain areas of the landscape. These areas occur especially in hollow slopes and concave footslopes. They vary in size with the rainfall season, and more so when the hydrologic depth is shallow.
3) The term is not widely used in Australia and the USA.

**hydromulching**
A procedure whereby a mixture of seed and fertiliser and/or mulching material is applied in a water slurry to exposed soil surfaces for revegetation purposes.
a) The *mulching* material is applied at heavier rates than in hydroseeding, in order to provide a layer of *mulch* to protect the soil surface and create a suitable micro-environment for germinating seeds (Houghton & Charman 1986:67).

**hydroseeding**
A procedure whereby a mixture of seed and fertiliser is applied in a water slurry to exposed soil surfaces for revegetation purposes.

**hypsometric curve = area-elevation curve**
Curve showing which part of the area of a river basin is situated above an indicated elevation (UNESCO 1992:16).

**impact block**
A solid block of concrete or similar material which is located in the path of flowing water to function as an energy dissipator.

**incision rill**, see also Central Concept of Rill Erosion
~ rill
~ braid (braided rill)
A type of rill that is narrow and in which incision dominates over transport and deposition.
a) The term serves to indicate a type of *rill* which is different from a *braid* or braided *rill*. A braid involves accumulation and transport, but little or no incision.
b) It occurs dominantly on the steeper convex and upper concave slopes (see Central Concept of rain erosion features).

**infiltration**
~ runoff coefficient
The downward entry of water into the soil surface.
a) It depends on rainfall intensity, macroporosity of the *soil* profile and its stability, steepness, soil surface sensitivity to *sealing*, *residue management*, *antecedent* soil moisture, turbidity of the water, and viscosity of the water (affected by temperature) (Moldenhauer & Foster 1981:16).
b) Any practice that detains *overland flow* allows more time for infiltration and exposes greater parts of the surface to deeper *overland flow* accumulation (Meyer 1981:36).
c) *Overland flow* in *rainulator* experiments always start at rainfall intensities 5 - 10 times lower than the *infiltration capacities* of the soils as determined from ring infiltrometer tests under *ponding*. The explanation must be in the *sealing* by *rainsplash* (Boon & Savat 1981:313).
d) The initial high *infiltration velocity* of Alfisols are often greatly reduced during the early rainy season by *surface sealing* (Pathak a.o. 1985:354).
e) Infiltration is usually increased by tillage which increases soil *macroporosity*. This effect wears off with time elapsed since the tillage, and it depends also on the *soil structural stability* (Boon & Savat 1981:306).

**infiltration basin**
An excavation in highly permeable soils to temporarily store runoff directed into it.
a) The stored water drains by infiltrating into the *soil*, thereby reducing *runoff* from the adjacent site (Houghton & Charman 1986:70).b) Such *basins* are normally excavated at or very near the source of the *runoff*, and are typically used on individual residential, commercial or industrial allotments (Houghton & Charman 1986:70).

**infiltration capacity**, see infiltration rate

**infiltration rate**
~ basic infiltration rate
~ infiltration velocity
A soil characteristic describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.
a) It has the dimensions of velocity.
b) The *infiltration velocity* decreases with time because of the reduction in the gradient of the total of the driving forces over the infiltration depth: capillary suction, osmotic suction, adsorption forces, and gravity. After some time a more or less constant rate is attained: the *infiltration rate*.

**infiltration velocity = instantaneous intake rate**
The actual rate at which water is entering the soil at a given time.
a) During most rainshower periods the velocity curve is always decreasing, and a steady lowest rate is seldom reached.
b) In some *soils* the *sealing* of the surface is so rapid that a very low steady rate is reached during one storm (Chorley 1978).
c) The rate may be less than the maximum, the *infiltration rate*, because of a limited supply of water from rainfall or irrigation (Soil Cons.Soc.Am. 1982:80).

**inlet**
The entrance of any structure through which water may flow.
a) It may be a simple grate at the entrance to a pipe, a complete entrance structure such as a *drop* inlet culvert, or merely an entry point at which water flows into a *channel* (Houghton & Charman 1986:70).

**inputs**
The material inputs, such as seed, fertilisers, fuel, chemical sprays, and other inputs, such as labour hours, *management* knowledge, capital and machinery, applied to the use of land.

**interception**, see rainfall interception

**intercropping**
The cultivation of two or more crops simultaneously on the same field, with or without a row arrangement.
a) There can be row intercropping or mixed intercropping (Fresco a.o.1989).
b) Relay intercropping is the cultivation of two or more crops on the same field with only partially overlapping growth periods (Fresco a.o.1989).

**interflow**
~ seepage
~ subsurface flow
~ throughflow
~ translatory flow
An intermediate component of runoff, between overland flow and groundwater flow;
a subsurface flow which returns to form surface runoff or is intercepted by a stream channel, without reaching the water table before arriving at the watershed outlet.

**interrill erosion**
~ rill erosion
Formerly called sheet erosion.
The removal of a fairly uniform layer of soil by splash and microchannels, shallower than about 3 cm (prerills), on land where no rills occur or on interfluves between rills.
a) Occurs in cases of low *runoff*. Flow occurs in micro*channels*, which are continuous but shift in position. Such *channels* at this stage are numerous, close together and only a few cm deep when it forms prerills, and supplies in this way most of the *sediment* that is translocated. This results over time in the removal of a fairly uniform layer of soil from the surface of the *land* (Soil Science Society of America 1978).
b) *Overland flow* in combination with rain impact produces much of the *erosion* (Richter 1965). Rainsplash causes the main detachment and overland flow causes the main transport.
c) It appears that the term sheet erosion is not satisfactory bacause it gives the impression that a sheet of water is acting, while in reality this is rarely the case. Much more often *splash* and very shallow local flow act over time to remove a more or less uniform layer from the surface of the *land*. This also happens between *rills: interrill erosion*. This newer term has as a disadvantage that in situations where no *rills* occur, one still recognises the *"interrill erosion"*.
d) *Interrill erosion* rates vary greatly, depending upon soil type, rain intensity and *surface cover*. The rates are affected to a lesser extent by slope steepness, prior *land use* and amount of rainfall (Meyer 1985:175).
e) It is much less sensitive to slope steepness than is

*rill erosion*. In a case study, *erosion* increased 50% between slopes of 2 and 8%, and increased 100% between 2 and 20%. In flatter areas *rill erosion* is insignificant, while *interrill erosion* may be considerable (Meyer 1985:169).

f) The particle size distribution of material *eroded* by *interrill-erosion* shows maxima between 16 and 63 mu, and between about 250 and 800 mu (Meyer 1985:171). The coarse fraction may consist of primary particles or small stable aggregates. The gap between the two maxima can probably be explained by the wearing away of these particle sizes, as these sizes are particularly sensitive to *saltation*.

g) The combination of interrill and *rill erosion* is covered by the term *surface (rain)erosion*, in contrast to *linear erosion*.

h) When rills exist, the transport off a field is often strongly accelerated, because of numerous small channels with turbulent flow of high transport capacity.

**kinetic energy of rainfall**, see rainfall energy

**laminar erosion**

The removal of a more or less horizontal layer of soil material from the surface of the land by erosion.

a) It is similar to surface erosion.

**laminar flow**

Flow of a fluid in which the viscous forces are predominant. In channel flow the fluid particles move approximately in definit, relatively smooth paths, with no significant transverse mixing. The Reynolds number is smaller than 500-2000 in flow channels and smaller than 1-10 in flow through porous media (UNESCO 1992:175).

a) A type of flow that is determined by the viscosity of the liquid (Hooghart 1986)

b) The *Reynolds number*, equal to velocity x hydraulic radius divided by kinematic viscosity, would be lower than about 500 (Hooghart 1986).

c) It is rare in open *conduits*, but common in groundwater flow and in *afterflow* on the land (Hooghart 1986).

**land**

The surface of the earth's outer crust not covered by bodies of water.

a) The term is also used in a comprehensive, integrating sense to encompass the physical environment within a profile from the atmosphere above the earth's surface down to some metres below the surface. Land therefore includes climate, landform, *soils*, hydrology and vegetation, to the extent that these influence the potential for *land use* (Houghton & Charman 1986:73).

**landslide**

~ avalanche
~ block glide
~ landslip
~ mass movement
~ mud flow

A type of mass movement in which the mass remains in contact with the plane of failure and is relatively little disturbed itself.

a) The movement is relatively rapid. It may be parallel with the slope, along a more concave plain or along a number of rather parallel, steeper failures.
It may occur in single, multiple or successive arrangements (Embleton & Thornes1979:161-173). It may result in a backward tilt of the resulting mass (*slump*).

b) The type of material may be specified by the name: earth slide, debris slide, rock slide.

c) Shallow, planar, translational slides may be called *slips*.

**land appraisal = land resource evaluation**

The determination of the extent of one or more land resource attributes, the assessment of the various potential land uses to which the resources could be or should be put, and the effect upon the land if the resources are used for the particular purposes.

a) In a *soil conservation* context, land resource evaluation relates to the assessment of the possible uses of the *land*, with respect to the prevention and control of *soil erosion* (Houghton & Charman 1986:73).

**land attribute**

A property of land related to its use.

**land characteristic**

An attribute of land that can be measured or estimated, and which can be employed as a means of describing land qualities or distinguishing between land units of differing suitabilities for use.

**land classification**

~ land evaluation

The systematic arrangement of land into various categories based on selected properties of the *land* or its potential for some particular purpose.

a) Land classification may be done in different ways, varying from the genetic approach, where *land* is subdivided into natural regions on the basis of environmental factors, to the parametric approach where *land* is subdivided by mapping key attributes, such as slope and terrain component, in quantitative terms (Houghton & Charman 1986:73).
Physiographic *mapping* units, well created, will coincide with most of the important differences in

key land attributes. The parametric approach neglects the landscape units first, and may conclude on similar units later. A combination of physiographic *mapping* and parametric distinction produces the best results.

**land degradation**

~ soil degradation
~ potential land degradation
~ actual land degradation

The decline in quality of natural land resources, commonly caused through improper use of the land by humans.

a) Land degradation encompasses *soil degradation* and the deterioration of natural landscapes and vegetation. It includes the adverse effects of *overgrazing*, excessive tillage,overclearing, *erosion* and *sediment deposition*, extractive industries, *urbanisation*, disposal of industrial wastes, road construction, decline of plant communities and the effects of noxious plants and animals (Houghton & Charman 1986:73,74) and pollution of the air with its effect on land.
b) The measures necessary to arrest and reverse land degradation are the concern of both rural and urban communities. It is a national and international problem of concern to all governments and planners as well asfarmers (Hauck 1985:719).
c) *Degradation* appears by a decline in hydrologic balance, crop production, suitability for settlement and socio-economic viability (Suwardjo & Sofijah Abujamin 1985:607).
d) Land degradation in the tropics arises when the *land* is bare for tillage operations. *Degradation* is accelerated by intense rainfall and tropical temperatures. All of these factors contribute to *erosion* and low *productivity*, especially on *soils* of non-volcanic origin (Suwardjo & Sofijah Abujamin 1985:607).
e) It is used frequently as synonymous with denudation, which however refers more specifically to processes which wear away the earth surface, including weathering, *erosion*, mass wasting and transportation of *soil* and rock



*Land degradation by wide-spread gullying, Sidamo, Southern Ethiopia (photo M. Coendet).*

materials (Toy 1977:15) and which have less qualitative implication.
f) The main causes of land degradation and *soil erosion* stem from indiscriminate human interference in the ecological balance, from abuse and mismanagement of soil and water resources, and from trying to farm land beyond its capability (Hauck 1985:720). This may be done through ignorance, as a consequence of indifference, or as a result of favouring short-term gains (Hauck 1985:721).
g) *Degradation* may be due to chemical, physical and biological changes in the *soil*, for example by *soil loss*, dissection, salinisation, burning, pollution, etc. (FAO 1979). For *land evaluation* the major *land quality* to consider is not the expected *erosion* rate, but the *degradation* due to this *erosion* rate (Bennema & de Meester 1981:80, 534,535).
h) Some specific causes of *soil erosion* and land degradation are (Hauck 1985:721-722):
   - arable farming
   - attitudes
   - forestry operations
   - grazing
   - lack of data
   - land ownership and tenure
   - population pressure
   - shifting cultivation with too short a *fallow* period
   - shortage of trained staff
i) Land degradation as evident from *degradation* of the vegetation or *land use* can come about by (FAO 1979):
   - *erosion*, such as *surface erosion* and gullying, *mass movement*
   - salinisation
   - burning
   - deforestation, leading to *erosion* and deteriorating hydrological conditions locally and possibly in the *catchment* as a whole
   - pollution
j) For assessing land degradation two procedures are open (Dudal 1981:8):
   - direct observation and measurement
   - interpretation of environmental factors, such as *erosion hazard*
k) The effects of land degradation can be evaluated either by a loss of *productivity* or by the cost of corrective measures to retain production at its original level (Dudal 1981:8).
l) Critical soil properties differ for different types of *degradation*: soil depth for *erosion*, present salinity for salinisation, etc. (FAO 1979 :x).
m) *Erosion* is one of the causes of land degradation, but it may however,in certain conditions, have a favourable influence on the suitability of the *soil profile*. This is the case of farming in the loess

area in the South of Holland, where the calcareous B horizon gives better yields (*seedbed* quality) than the original A-horizons (FAO 1983 ; Bennema & de Meester 1981).

**land evaluation**
(FAO 1983):
- compound land utilisation type
- conservation requirements
- crop requirements
- farming system
- inputs (of land use)
- land
- land attribute
- land characteristic
- land classification
- land evaluation unit
- land facet
- land improvement
- land quality
- land suitability
- land system
- land unit
- land use limitation
- land use requirement
- land use system
- land utilisation type
- limitation, see land use limitation
- major land improvement
- minor land improvement
- multiple land utilisation type
- outputs (of land use)
- resistance to erosion as a land quality
- sustained use
- two stage approach of land evaluation.

The process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms of the objectives of the evaluation.

**land evaluation unit**
~ land evaluation
Mapping unit or group of land mapping units which are supposed to act in the same manner in relation to a specific land utilisation type.
a) The unit may be created on the basis of soil survey, physiographic geomorphological survey, land-use or ecological survey.

**land facet = land unit**
A land unit which for most practical purposes has uniform characteristics of climate, landform, soils and vegetation.
a) It is a subdivision of a land system.

**land husbandry = land stewardship**
~ conservation ethic
Treatment of land, and policy of land use, based on motives of care.
a) It is common to find that successful *conservation* in the third world countries utilises the concepts of land husbandry which are more akin to traditional ideas of balance with nature. Is it not us, the non-farmers, who have to rebuild an ethic which earlier was discarded because it did not match our economic demands on the *land* ? Crop husbandry, animal husbandry and land husbandry can be seen as parts of a biological *conservation* continuum (Shaxson 1981:356,357).
b) An ethic relevant to *soil conservation* is an ethic of good husbandry, which gives recognition to limits of *soil* as a resource and accepts responsibility for *conservation* of this resource for future generations (Rose 1985:782; Stocking 1981; McCormack & Young 1981).
c) It can come about from local traditions, by selecting for conservation work the persons who have this attitude, and by a change in attitude which is based on inner conviction and faith (Bergsma 1988).
d) The role of land husbandry is shown for instance in Moldenhauer & Hudson 1988, especially p.60-62 and p.275-279; Shaxson a.o. 1989, especially p.19-23.

**land improvement**
~ major land improvement
~ minor land improvement
An alteration in the qualities of land which enhance its potential for land use.

**land information system**
A computerised mapping and land information data base designed for interactive use by land managers.

**land productivity**, see also as Central Concept
~ soil productivity
The productive capacity of land, normally expressed in terms of sustainable crop or pasture yields.
a) It is assumed that the production takes place through economic practices (Houghton & Charman 1986; Purnell 1984).
b) Losses in land productivity from *erosion* are related to a change in replaceable and non-replaceable soil attributes. Replaceable soil attributes are principally plant nutrients. Replacement, of course, involves a cost. Irreplaceable attributes are principally reductions in available waterholding capacity and plant rooting depth (Larson a.o.1985).
c) *Rain erosion* affects land productivity by *surface erosion, linear erosion*, and their deposition. *Surface erosion* affects land productivity by:

reducing crop production by
- reducing fertility (in *topsoil*)
- deteriorating soil tilth, water *infiltration* and air infiltration
- causing irregular surface microrelief (Mannering 1981:341; National Planning Committee 1981).

This has negative implications for fertiliser use, tillage timing and effect, weeding, crop growth and harvesting (National Planning Committee 1981).
Erosion affects the cost of water control structures by (McCormack & Young 1981:367):
- increasing maintenance
- decreasing effectiveness
  - causing loss of harvestable crops by *erosion* and *deposition*
  - causing loss of fertilisers
  - reducing soil recovery potential (National Planning Committee 1981)

*Linear erosion* affects land productivity increasingly by interfering with:
- tillage
- communications across fields
- lowering the groundwater table of a wide area around.

Deposition affects land productivity by:
- covering crops
- damaging roads and drainage systems

**land quality**
A usually complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use.
a) Common main land qualities are availability of nutrients, availability of oxygen, availability of water, resistance against erosion, possibility for mechanisation, and size,shape and access of the land unit (FAO 1983).

**land resource evaluation**, see land appraisal

**land suitability**
The fitness of a given type of land for a specified kind of land use on a sustained basis, for a specified level of technology and inputs.
a) A complete land suitability evaluation involves a multidisciplinary approach to *land evaluation* and includes a basic inventory of land resource data; an understanding of the ecological requirements of the planned *land use*; basic data on the economics of *land use*, *land improvement*, new technologies, marketing and transport, and a knowledge of the attitudes and goals of people affected by the proposed changes (Houghton & Charman 1986:75).
b) There are forms of *land use* which appear to be highly profitable in the short run but lead to serious *land degradation* in the long run. Such consequences would outweigh short term profitability and cause the *land* to be classed as not suitable for such purposes (Dudal 1981:7).
c) Crops differ widely in the vegetation *cover* which they provide at various times of the year, they may be annual or *perennial*, they may require different treatments which influence *degradation* (Dudal 1981:7).
d) In a wider sense, regarding the damage by *erosion* to the suitability of the *land*, effects of the loss of nutrients by *erosion* should also be taken into account (Shaxson 1981:390).
e) The use of fertilisers and plant protection may markedly improve vegetative cover. Drainage will increase salinity hazards. *Contour farming* may be possible when mechanical equipment is available but may not be feasible with hand labour only. The intensity of tillage has a bearing on *erosion hazards* (Dudal 1981:7).
f) In conservation planning, the need for *conservation* expressed by the expected rate of *soil loss* minus the *soil loss tolerance*, is combined with the land suitability for a range of alternative land utilisation types, to determine the priority for *conservation* (Bergsma 1983).

Schematic diagram of steps from erosion surveys to conservation planning (modified from Bergsma 1983).

**land suitability classification**
~ land suitability
A classification based on the suitability of land for a specified use.
Current: in its present condition, without major *land improvements*.
Potential: after specified major *land improvements*.

**land system**
An area, or group of areas, delineated on a map, throughout which there is a recurring pattern of topography, soils and vegetation.

**land unit**
An area of land with common landforms, and frequently with common geology, soils and vegetation types, occurring repeatedly at similar points in the landscape over a defined region.
a) An area of land possessing specified land qualities and land characteristics and which can be demarcated on a map (Houghton & Charman 1986:75).
b) It is a constituent part of a land system (FAO 1983; Fresco a.o.1989).

**land use**
A general term indicating the type of activity for which the land is used by man or the natural ecology that prevails.

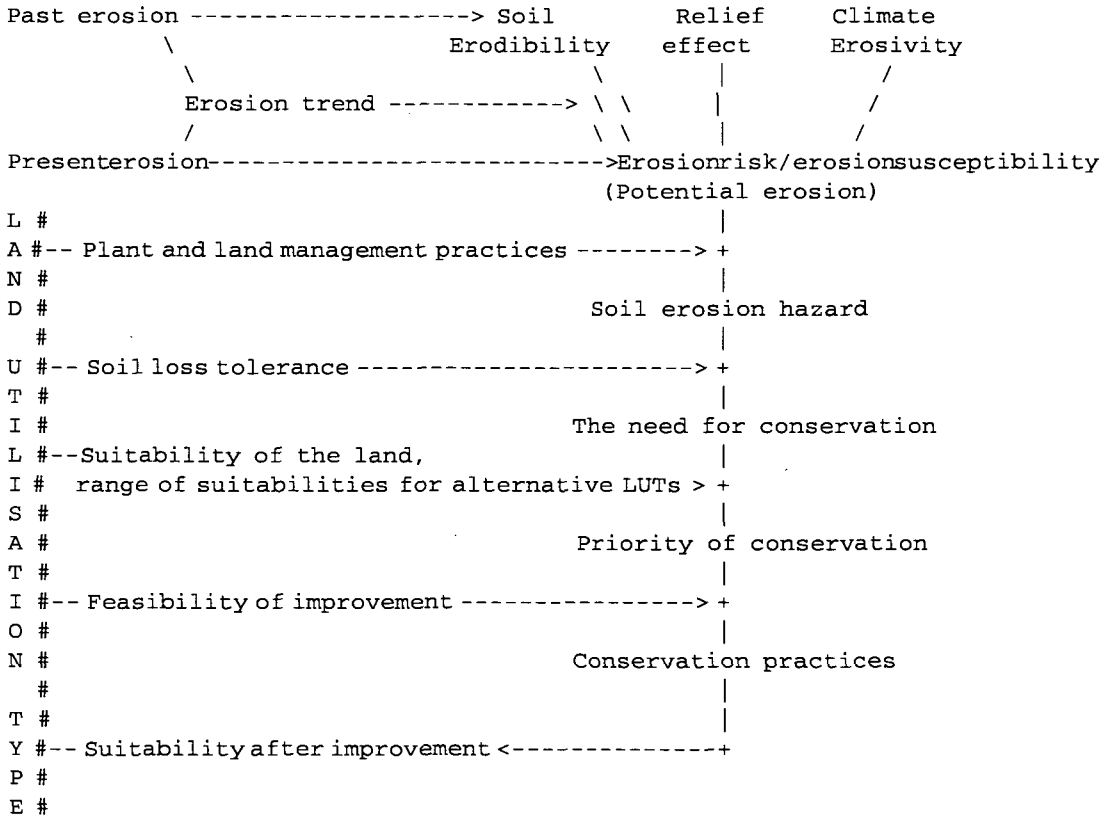
**land use limitation**
A land quality or land characteristic which adversely affects the potential of land for a specified kind of use.

**land use system**
A specified land utilisation type practised on a given land unit and associated with inputs, outputs, and possibly land improvements such as terracing, irrigation, drainage, etc.

**land use requirement**
The needed inputs necessary or desirable for the successful and sustained practice of a given land utilisation type.

**land utilisation type**
~ compound land utilisation type
~ multiple land utilisation type
A kind of land use described or defined in a degree of detail greater than that of a major kind of land use.
a) In the context of rainfed farming, it defines a crop or combination of crops or cropping system within a specified technical and socio-economic setting (FAO 1983:228).
b) Three levels of detail in the description of land utilisation types are given in FAO 1983:26. Examples of descriptions are in FAO 1983:197.

**landslide**
~ blockglide
~ debris
~ landslip
~ rotational slide, slumpsoil slip
A general term indicating *erosion* processes in which gravity is the primary force acting to dislodge and transport land surface materials.
a) It is a function of the gravitational stress acting on a possible plane of weakness and the resistance of the materials to dislodgement. When the gravitational stress exceeds this resistance, *mass movements* occur.
b) The occurrence of mass movement depends on the interaction of various factors including landform, lithology, soil type, rainfall intensity and duration, drainage characteristics, vegetative *cover*, and human intervention.
c) There are various ways to classify mass movements, including age, cause and degree of disruption of the displaced mass, but the preferred classification is based on the type of material - bedrock, *debris* and earth - and the type of movement - fall, topple, lateral spread, flow and slide (Houghton & Charman 1986:80).
d) Related terms are described separately, for instance in Varnes (1978).



**landslip**
A superficial landslide occurring over only a short distance and which is composed mainly of debris or earth materials.
a) In many instances conventional *soil conservation measures*, such as tree planting, can be applied for their control. In other cases more complex measures are needed such as drainage (Varnes 1984).

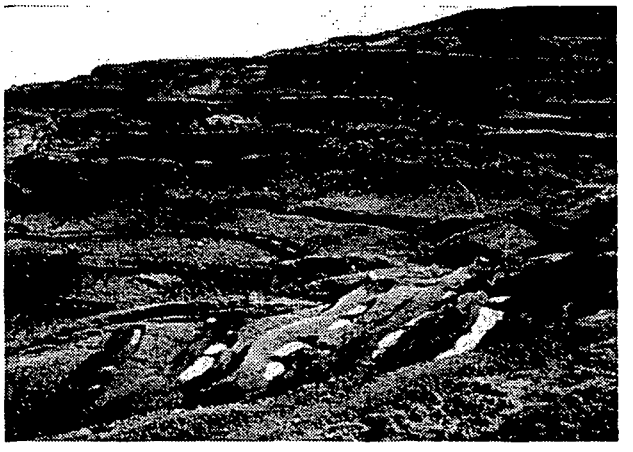
**lateral erosion**
Erosion of the sides of a channel by streamflow.

**lavaka**
A ravine incising a slope or a mountain crest, the upper end being abrupt, the lower part can end in steep fans of sand and debris.
a) Name used in Madagaskar for a certain type of *gully* or *ravine*.

**leaf area index, LAI**
A canopy parameter defined as leaf surface area (one side of the leaves only) per unit of ground area.
(Baret a.o. 1988; Clevers 1988; Huete 1988):
a) It is used to describe canopy structure.
b) It varies from 0.0 for bare soil to 10 for annual crops and more than 15 for very dense perennial forest.
c) Canopy spectral responses depend not only on vegetation parameters but also on soil background and other factors. Vegetation indices were developed to distinguish the influence of vegetation from that of soil background and irradiance geometry, which create noise around the relationship of canopy parameters and reflectance.
d) The Normalised Difference Vegetation Index, NDVI, is a vegetation index that enhances the contrast between soil and vegetation reflectance or radiance in the red and near-infrared space. It is determined as:
NDVI = (Rnir - Rred) divided by (Rnir + Rred)
d) Percentage ground cover plotted against LAI gives a convex up curve, with a rather linear part from no cover up to 80 % cover (Stoner, Baumgardner & Swain 1972).
e) The index has a linear relationship with the ratio of channels 0.82/0.65 mu (Stoner, Baumgardner & Cipra 1972), channels 1.20/0.65 mu (Stoner, Baumgardner & Cipra 1972) and normalised bands 1.65/2.22 mu (Elvidge & Lyon 1985), except for full ground cover.
f) As example: the ratio for Juniperus was about 3.2, independent of seed source or crown height. A strong relationship between the ratio and the weight or volume of the trees exists, but it is dependent on the seed source and the crown height (Cregg 1992).

**level bank/terrace**
~ retention terrace
A bank/terrace that is constructed along the true contour, its channel being level, and which discharges at either or both ends depending on design requirements.
a) Typically used on *grazing land* to reduce or prevent erosion.

**level bund**
~ bund
~ graded bund
~ retention terrace
An embankment along the contour, made of soil and/or stones, with a basin at its upper side to reduce or stop overland flow and its effect in causing erosion.
(Hurni 1986:42):
a) The height is about 50-75 cm and the bottom width is 100-150 cm.
b) They often have a water retention basin on their upper side, usually with tied ridges placed in the basin every ten metres.



*Level bunds with lock and spill drains to retain soil and runoff on cropland; intended to develop into terraces, Shewa, Ethiopia (photo H. Hurni).*

**limitation, see land use limitation**

**linear erosion**
~ surface erosion
~ gully erosion
Rain erosion in the lines of concentrated flow, such as in master-rills, gullies and ravines.

**liquefaction**
The sudden large decrease of the shearing resistance of a soil caused by a collaps of the structure from shock or other type of strain, and associated with a sudden but temporary increase in the pore-fluid pressure; a temporary transformation of the material into a fluid mass.
a) The process may be inhibited by a high clay content (de Ploey 1981:147 and de Ploey 1985:529) or a high content of organic matter (de Ploey 1985:529).
b) Thin sections show the collapse of microstructure,

the reduction of original pores and the absence of new matrix orientation (de Ploey 1985:529).

c) Unstable clods are flattened by *raindrop* impact and merge in a fluid state, indicating the start of *sealing* (de Ploey 1985:529).

**listing**:
Ploughing by lister: a type of ploughing that throws up ridges and excavate furrows useful in erosion control and surface water storage

a) The implement is a double plough, the shares of which throw the *soil* in opposite directions, leaving the field with a series of alternate ridges and *furrows* which can be used for *erosion control*, water storage or drainage depending on whether they are on the *contour* or up and down slope (Soil.Cons. Soc.Am. 1982:92, Houghton & Charman 1986:78).
b) Row crops may be seeded in the bottoms of the *plough furrows*, or on top of the *plough ridges* (Soil.Cons.Soc.Am. 1982:92).

**litter**
A surface layer of loose organic debris in forests, consisting of freshly fallen or slightly decomposed organic materials which have accumulated at the ground surface.

**live barrier**
~ grass strip
A band of growing plants across the slope, to slow runoff, increase infiltration, and cause sediment to be deposited.

**lock and spill drain**
A small ditch along the contour designed to retain overland flow, but allowing excess to flow off laterally along a gentle grade, overtopping low barriers left at intervals in the channel.

a) The practice is common in the Kandy area of Sri Lanka.
b) Dimensions are for instance: depth 50cm, width 50 cm, height of locks 30 cm.

**macropores = non capillary pores**
The soil pores that drain freely in one day, given a low enough groundwater table.

a) They are wide enough to accept rain quickly during a rainshower.
b) They are air-filled at the moisture content of *field capacity*, if they are accessible and continuous. They store water only temporarily, and do not contribute to the more permanent storage of rain water in *soils*, the *rain storage capacity* (Dunne &Leopold 1978:173).
c) Their volume varies between 5 and 40%, mostly 15 and 30% (Hall a.o. 1977:29,34,37) of total soil volume. A variation between 6 and 25 % is found to correlate with the *hydraulic* conductivity (Baver 1963:267).
d) In severely cracking *soils*, having a high macroporosity in the dry state, *surface runoff* may be limited, unless fine *soil structural* elements in the Ap horizon or swelling prevents easy access of rainwater to these large volumes of macroporosity (Chisci & Zanchi 1981:214).
e) Factors constructive for macroporosity are: shrinkage on drying, solution *piping*, freezing, *mole drainage* and *subsoiling*, plant roots and soil fauna (White 1985:96).
f) A porosity factor for macroporosity is quoted by Baver (1963:269) as the sum of:
% pores drained at 10 cm water suction
% pores drained between 10 and 40 cm water suction / 4
% pores drained between 40 and 100 cm water suction / 10
g) Macropores allow transport of dissolved and suspended matter through the *soil* (White 1985:96).

**major land improvement**
A large non-recurrent input in land improvement which causes a substantial and reasonably permanent change in the suitability of the land, and which cannot normally be financed or executed by an individual farmer or other land user.

**management**, see crop residue management, soil management

**Manning's formula**
A formula used to predict the velocity of uniform water flow in an open channel or pipe.

a) The formula is as follows:

$$V = \frac{1}{n} \times R^{2/3} \cdot S^{1/2}$$

V = mean velocity of flow (m/s)
n = *Manning's roughness coefficient* of the *channel* lining
R = hydraulic radius (m)
S = channel slope (m/m)

**Manning's roughness factor**, see hydraulic roughness coefficient

**mapping of rain erosion**, see rain erosion mapping

**mass movement**
~ avalanche
~ blockglide
~ creep
~ landslide
~ landslip
~ mud avalanche
~ mud flow
~ slump
~ soil slip
~ solifluction
~ terracettes

Those processes that involve a transfer of slope materials from higher to lower ground under the influence of gravity, without the primary assistance of a fluid transporting agent.
(Embleton & Thornes 1979:130-149):

a) In the context of rain erosion, the scars of the mass movements leave the surface exposed to rain erosion processes, which may be intensive because of available loose material, slope steepness, and absence of plant cover.
b) The movements may be slow or rapid, shallow or deep and include one or more of the processes of *creep* , flow, *slide* or *fall*.
c) The slope material may be earth/soil, rock, debris and even snow.
d) Instability may appear as a slope base failure or a failure of part of the upslope area.
e) Mass movement occurs by increase of the shear stress, or a decrease in internal friction. External changes often cause internal changes as well.
f) Common causes are: undercutting of a hillslope (river action, road construction), unloading (excavation, rapid drawdown of the phreatic level), loading (deposition, rapid rise of the phreatic level), shocks and vibrations (earthquakes, construction machinery), and internal changes such as: liquefaction, progressive weathering, remoulding under overburden, lubrication, seepage action.

**master rill**
A large rill grown from smaller individual rills by processes of *micropiracy* and *cross grading*

**microbasin**
A small basin with the shape of a half circle or full circle, excavated for planting a tree or crop plants in areas where rainfall is a limitation for plant growth.

a) They have to be carefully aligned on a slope, with intermittent placement for runoff control and proper spacing (Hurni 1986:65).
b) It is also called a micro-catchment. Drawings of its form and results of application are presented by Mutai (1989:250, 251).

**micropiracy**
The wearing away of a microdivide between two rills, resulting in a fusion of the rills.

a) After micropiracy the combined flow develops a deeper *rill*, and the process of micropiracy may be repeated when tillage does not intervene. By collecting flow from several smaller *rills*, a bigger rill develops into a *master rill* (Leopold a.o. 1964:411-416).

**microrilling, erosion by prerills**
~ prerills
The process of rain erosion by very shallow rills, up to about 3 cm deep, as part of the interrill erosion process, and often preceding rill erosion.

**minimum tillage**
~ no-tillage
The minimum soil manipulation necessary for crop production or meeting tillage requirements under the existing soil and climatic conditions.

a) Herbicides and *residue* conserving tillage may be used for weed control during both the cropping and *fallow* periods. *Grazing* may be helpful during the *fallow* period (Houghton & Charman 1986:82).

**minor land improvement**
A land improvement which has relatively small effects on the suitability of the land, or is non-permanent, and which normally lies within the capacity of an individual farmer or other land user.

**models of rain erosion and conservation,** see also as Central Concept
Description of erosion by mathematical equations, more or less simplified, using as input the information about erosion factors and their components and having as output the soil loss and/or the overland flow, for a field or hillslope, or the sediment yield and discharge for a catchment area.
In the Central Concept several categories of models are included:
I = models of rain erosion subprocesses
II = models of total, on-site, surface rain erosion
III = models for roadway erosion
IV = models of sediment yield
V = models of the cost of erosion and conservation

**mole drain**
An unlined drain used for draining clay soils, of which the channel is formed by pulling a torpedo-shaped cylinder through the subsoil.

a) It only lasts as long as the clay material surrounding the hole remains stable (Houghton & Charman 1986:41).

**monoculture**
A cropping system where only one type of crop is grown year after year on the same land.

**mulch**
~ dust mulch
~ hydromulching
~ stubble mulching
Soil surface cover of plant residue, loose soil, stones, etc. as protection against rainsplash and to keep a favorable soil microclimate by reducing evaporation of soil moisture.

a) Like all *surface cover* , mulch is very effective against *rain erosion* , mainly by reducing soil *splash* , and also by slowing down *overland flow*, when the mulch is in contact with the soil surface and is not washed away.
b) The mulch effect is one of the three effects of plant *cover* on *erosion* that are recognised in the USLE (Wischmeier & Smith 1978), the others being the *canopy* effect and the *residual effect* .
c) Mulch reduces *erosion* more than buried *residue*, and much more than burned *residue* (Valentin & Roose 1981:242).
d) Placing large amounts of crop *residues* as a mulch on large fields is not possible because of the limited supplies and high costs, except possibly for some high value crops (Stewart a.o. 1985:330).
e) *Residue cover* is more effective on no-till than on tilled treatments (Norton a.o. 1985:605).
f) *Crop residue* mulch applied at a rate of about 10 t/ha/yr reduced *soil loss* on slopes up to 15 percent. The mulch also helped to maintain organic matter content, improve soil physical properties, and maintain *soil productivity* (Suwardjo & Sofijah Abujamin 1985:613).
g) In the hot savanna region of Ghana, straw mulch improves the effectiveness of manures in minimising *erosion* and increasing crop yields. Poultry manure and wood shavings can be used. Mulching alone can minimise *soil erosion* , and wheat straw mulch has been reported to more than double grain sorghum yield and water use efficiency. Therefore, a combination of manure and straw mulching may have a promising future in *soil management* in the dry, humid tropics. During the dry season however, termites generally attack the straw mulch, so mulch and manure must be applied every year (Bonsu 1985:620).
h) The USLE defines the mulch factor for surface *residue* as the ratio of *soil loss* with *crop residue* to *soil loss* with no *cover* , other *factors* being the same (Norton a.o. 1985:598).

**mud avalanch**e or **lahar**, see avalanche, mud flow

**mud flow**
Rather rapid mass flow of mud. (Cotton 1947:13):
a) They often extend far when following gullies and river valleys.
b) They are slower than mud *avalanches* , and occur on more gentle slopes, for instance in semi-arid regions where the surface is not bound and protected by vegetation.
c) Mudflows characterise some phases of vulcanic activity.
d) They produce unstratified and unsorted deposits, which may contain very large boulders.

**multiple land utilisation type**
A land utilisation type consisting of more than one kind of use or purpose simultaneously undertaken on the same land, each with its own inputs, land use requirements and produce or other benefits.

**MUSLE** Abbreviation of: Modified Universal Soil Loss Equation
A soil loss prediction model developed from the USLE by replacing the erosivity factor R by a runoff factor.

**nappe**
A sheet or curtain of free-falling water flowing from a structure such as a weir.

**narrow-based terrace**
~ broad-based terrace
~ soil conservation terrace
A conservation terrace/bank with a limited width of channel and riser, the storage capacity increased by greater height and therefore not passable by machinery and not included as part of the crop field, as is the broad-based terrace.

**natural erosion**, see geological erosion

**natural resources**
The elements of supply inherent to an area that can be used to satisfy man's needs, including air, soil, water, native vegetation, minerals, wildlife, etc.
a) A subdivision can be made into reneweable and non-renewable natural resources (Soil Cons.Soc.Am. 1982:108).
b) Though soil is renewable on a geological timescale, for conservation purposes accelerated erosion destroys the soil and it should therefore be regarded as an example of a non-renewable resource (Houghton & Charman 1986:83).

**netting**
Coarse mesh material usually placed on top of a mulch to prevent its displacement and thus provide protection to the soil surface from erosion during the early stages of revegetation.
a) Common materials are wire, plastic, paper, cotton or other woven or synthetic fibrous materials (Houghton & Charman 1986:83).
b) The netting should be pinned firmly to the ground surface and not traversed by vehicles (Houghton & Charman 1986:83).

**normal erosion**
The gradual erosion of land used by man that does not greatly exceed natural erosion.
a) A rather vague concept.

**no-tillage = zero-tillage.**
~ minimum tillage
A minimum tillage practice in which the crop is sown directly into a soil not tilled since the harvest of the previous crop; this usually involves opening a small slit or punching a hole into the soil; weed control is achieved by the use of herbicides, and stubble is retained for erosion control.
a) Its initial use in the USA was in areas where *fallowing* is important, but it has been spreading to non-fallow areas where *mulch* is important, because of microclimate and protection from erosive forces.

**open drain,** see retention furrow

**orographic precipitation**
Precipitation caused by the ascent of moist air over orographic barriers (UNESCO 1992:208).

**overfall**
Abrupt change in stream channel elevation; the part of a dam or weir over which the water flows.
a) For *soil conservation* purposes it usually applies to the rim of a *gully head* over which *runoff* falls (Houghton & Charman 1986:86).

**overflow channel**
A channel used by a stream when the flow exceeds bankfull discharge.

**overgrazing**
~ overstocking
~ carrying capacity
~ grazing capacity
Repeatedly overstocking an area, resulting in adverse effects on the grazing animals, the edible plant composition and growth, and on the soil.
a) It leads to a reduced capacity to produce forage, deterioration in pasture or range condition and increased *erosion hazard* (Houghton & Charman 1986:86).
b) Effects of overgrazing in the Sahelian zone may appear as a reduction of soil organic matter content in the area around watering places, while there is an increase in the immediate vicinity. The bulk density of the *topsoil* may increase towards the watering place (Valentin 1985:57-58).
c) The effect of *grazing* intensities is studied in Heathwaite, Burt and Trudgill (1990).

**overland flow,** see also as Central Concept.
~ surface runoff.
The part of the rainfall that flows off the surface of the land in non-concentrated flow or in temporary very shallow channels, including rills.
a) Overland flow includes the flow causing interrill and *rill erosion* , it does not include gully or permanent *channel* flow. *Surface runoff* includes the overland flow, as well as surface *channel* flow such as in gullies.

**overstocking**
~ overgrazing
The placement of a number of grazing animals on a given area of pasture or rangeland that will adver-sely affect its plant components by the end of the grazing period.
a) The effect may be only temporary, and in this respect the practice differs from *overgrazing* . However continued overstocking will lead to *overgrazing* (Houghton & Charman 1986:87).
b) An area may be overstocked for a short period with-out decreasing rangeland condition (FAO 58:137).

**outlet**
Point at which water discharges from a river, creek or other flowline; lake, tidal basin or drainage depression; pipe, channel, dam or other hydrologic structure.

**output (of land use)**
The products, services or other benefits resulting from the use of land.
a) In case of agriculture the products are derived from the cultivated plants, for services one may think of water supply or recreational facilities, for other benefits one may think of wildlife/ecosystem conservation.

**partial area**
The part of a catchment which produces runoff, usually as small to very small part of the total area. (Campbell 1985:132).
a) The size of the *runoff* producing area may change with variations in precipitation, but the change normally is not great.
b) The linkage between the partial area concept and *sediment* source areas has not been investigated very much.
c) The dynamic expansion and contraction of the partial area and its effect on *overland flow* may be referred to as "variable *runoff* contributing area", also called the "variable source area" (of peak flow).
d) The difference between the partial area and the total catchment area is of great significance. Usually, *runoff* volumes, stream discharges, *sediment -yields* and *erosion* rates are calculated for the total *basin* area. *Sediment delivery ratios* may vary between 3 and 90%.

**pasture renovation**
~ pitting
The upgrading of a pasture by sod seeding or mechanical treatment using such implements as an aerator, pasture harrows or a special disc plough for forming discontinuous pits or furrows.

**ped**
A naturally formed soil aggregate.

**pedestal**
Remnant of the former soil surface in an *eroded* area, protected from splash erosion and with a surface in the shape of the protecting body (leaf, twig, gravel, etc), often bordered by steep sides.

**perennial**
Describes a plant or crop whose life cycle extends for more than two years.

**permeability,** see soil permeability

**permissable soil loss,** see soil loss tolerance

**pipe shaft erosion,** see fluting

**pipe flow = tunnel flow**
~ tunnel erosion
Concentrated subsurface flow of water in natural pipes.

**piping,** see tunnel erosion

**pitting**
Making shallow pits of suitable capacity and distribution to retain water from rainfall or snowmelt on rangeland or pasture.
a) Can be used in combination with reseeding.
b) Normally carried out using special mechanical equipement.

**plant cover,** see soil cover.

**planting basin**
Shallow hole cut into the topsoil, with a diameter of 30 - 80 cm and a depth of 10 - 15 cm, in which a plant (or plants) is established.
(Some & Quattara 1990):
a) A *conservation practice* called "Zai" used in the northeast of Burkina Fasso.
b) A handful of manure is put into the hole for the *seedbed*.
c) More rain will infiltrate in these places.
d) Research of the method is strongly recommended, to improve the technical efficiency and amount of labour needed.

**plough-furrow**
~ plough-ridge
~ plough-rill erosion
The shallow linear incision left behind by the tillage operation of ploughing.
a) It provides retention storage for rain when made along the contour on slopes less than about 7%.

**plough-layer**
The upper part of a soil profile that is affected by the recurrent ploughing and tillage operations of the farmer.
a) It is often darker than the *subsoil* because of the organic matter content that is mixed in this layer by the ploughing.
b) It has often a poorer structure than an untilled *topsoil*, because of lower organic matter content, and a reduced soil biological activity.
c) Though its properties are somewhat poorer than those of the original untilled *topsoil*, it is often the most fertile part of the *soil*, and its loss through *erosion* often leads to a great reduction in soil productive potential.

**plough-pan**
~ soil pan
A compacted soil layer, caused by repeated ploughing to a certain depth.

**plough-ridge**
~ plough-furrow
Low, linear soil elevation made by the passage of a plough.

**plough-rill erosion**
Erosion of the plough-furrows which may act as preformed rills.

**ponding,** see surface ponding

**potential erosion,** see rain erosion susceptibility

**potential land degradation**
~ actual land degradation
The theoretical loss of agricultural *productivity* which would result from the influence of four main physical factors: climate, relief, soil profile and present active erosion, without actual interference of human factors and without protection by natural vegetation.
a) The definition of potential *land degradation*(Dudal 1981) conforms to that of *potential erosion*, except that in *degradation* other agents than *erosion* can play a part such as: chemical pollution, salinisation, etc.

**potential rain erosion = potential rain erosion hazard,** see rain erosion susceptibility

**prerill**
~ rill
Very shallow rills or shallow microchannels, up to about 3 cm deep.
1) They have a low storage capacity for water and *sediment*, *erodible* material is easily available, the flow is very effective in removing material per unit of water volume, more so than *interrill erosion* or *rill erosion* (Roels 1984).
2) Prerills grow from incision of flow paths in *interrill erosion* (Roels 1984).
3) By deepening and extending in length, they change into *rills* (Roels 1984).
4) In the formation of prerills the reduction of *shear strength* in conditions of wetness may play a role (Luk 1988).

**productivity,** see soil productivity, land productivity

**rain erosion**
Erosion caused by rainfall and the resulting runoff
a) A term to describe the combined effect of all types of rain erosion: *surface rain erosion* (*interrill* and *rill erosion* ) as well aslinear *rain erosion* (*gully erosion* ).

**rain erosion classes**
~ erosion classes
Defined degrees of the effect of rain erosion on the soil profile and the land.

**rain erosion control practices,** see soil conservation practices

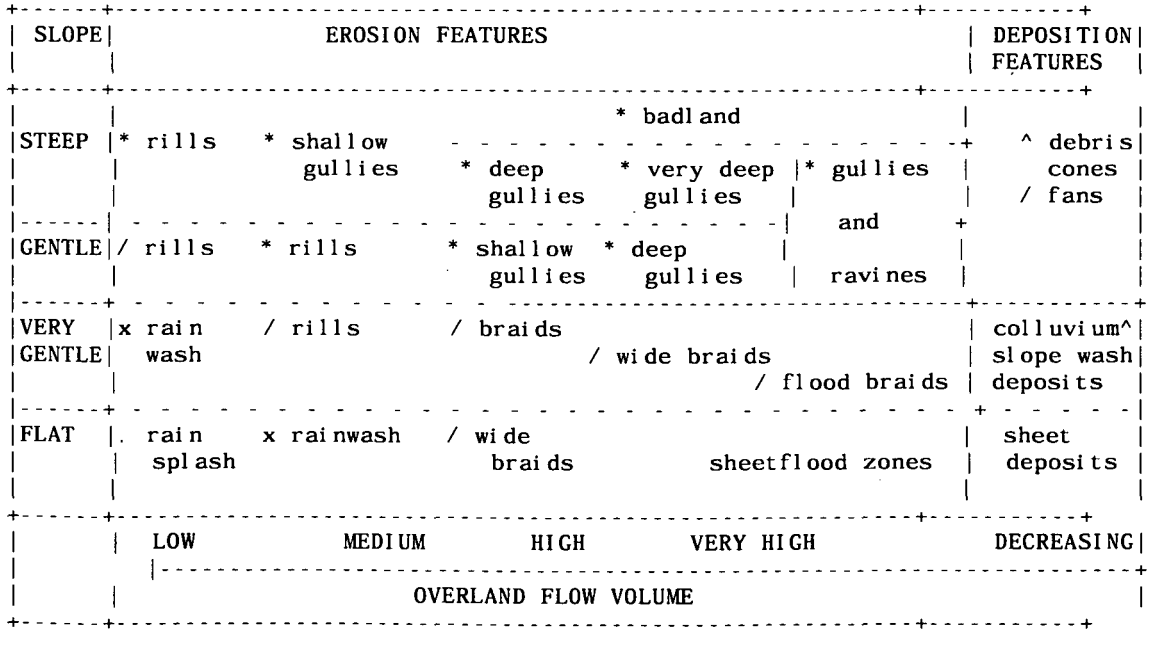
**rain erosion features,** see also as Central Concept
Rain erosion features included in the list of definitions are the following. They have been grouped here more or less in a sequence of processes:

- rainsplash
- pedestal
- rainwash
- prerill
- rillwash
- gullies
- gully wash
- ravines
- lavaka
- badland
- braid
- braidwash
- floodbraidwash
- sheetflooding
- arroyo
- colluvium
- rill fan
- gully fan
- sheetflood deposit

Modifications of the soil surface by rain erosion.
a) Includes features of soil removal, its transport and sediment *deposition* .
b) The common features of rain erosion can be grouped in a diagram in a general way, according to slope steepness and the amount of *overland flow* .

Adapted from: Richter 1965; Carson & Kirkby 1972; Bergsma 1974.
Legend: . = dominantly splash, flow in discontinuous microdepressions
x = dominantly flow in discontinuous microchannels
/ = dominantly flow in continuous but temporary channels
* = dominantly flow in permanent channels
^ = deposition by gravity and wash.

FEATURES OF RAIN EROSION
(schematic diagram of main features)



c) The erosion processes depend on rainfall, material, position, slope form, land use and time. This may sometimes result in regular sequences of features along hillslopes.

Deposition is mainly determined by slope shape, basal plant cover, surface depression storage, and overland flow infiltration. Deposition is often very local but can be very damaging when it occurs in thick deposits on arable crops. It is the accumulation of material received from large areas, even in cases of low erosion rates upslope.

**rain erosion hazard = soil erosion hazard**, see also as Central Concept
~ actual land degradation
The rate of soil loss expected in the near future, due to rain erosion, depending on the combined and interactive effects of all erosion hazard factors: climate, relief, soil profile, present erosion, land use, vegetation and cultivation system.

**rain erosion hazard classes**, see Central Concept of Rain Erosion Hazard

**rain erosion hazard factors** - see factors of rain erosion

**rain erosion mapping**, see also as Central Concept
The representation of the areal distribution of *erosion* on a map, possibly showing information about types, total effect and expected rates of erosion, respectively called an "erosion feature map", an "erosion degree map", and an "erosion hazard map".

a) Erosion maps do not always show the same kind of information. There are three categories of erosion maps, which may also occur as mixed categories:
   - "erosion feature map" showing the active (and fossile) *erosion features* due to *interrill erosion* , *rill erosion* and *gully erosion* , and in a wider sense the processes of *riverbank erosion* , flooding and *mass movement* .
     By showing the active features, the map gives a picture of the present distribution of the processes, which often depends strongly on the protection by *land use* at the time.
   - the "erosion degree map", showing the degree to which *erosion* has affected the soil profile. This is similar to an "erosion damage map", showing the analysis of the changes in the soil profile (Hurni 1981:187).
   - the "erosion hazard map", showing the expected rates of soil loss in the near future, qualitatively or in quantitative classes (Bergsma 1983).

**rain erosion models**, see models of rain erosion and conservation.

**rain erosion risk**, see rain erosion susceptibility

a) It is sometimes used as an indication of the effect of permanent erosion *factors* (Stocking 1981:377-384).
b) It is defined by Riquier (1977) in the sense of: the *potential erosion* rate under the influence of the relative permanent *factors* of climate, *relief* and soil profile.
c) "erosion risk" relates to the more permanent *factors* , and is a defined term: "The intrinsic susceptibility of a parcel of *land* to erosion caused by rainfall" (Houghton & Charman 1986:51).
d) In other languages it comes close to terms meaning rain erosion hazard.
e) Another term which is used is: "*potential erosion* ". This term suggests a maximum, while the erosion under faulty management practices such as overuse of sprinkling can be higher than erosion on bare land, ploughed up and down the slope, under natural rain.
f) Preference for terms: *rain erosion susceptibility* > *potential rain erosion* > rain erosion risk.

**rain erosion susceptibility**
~ erosion hazard
~ resistance to erosion, as a land quality
~ potential land degradation
Erosion susceptibility is the expected rate of *erosion* when there is no plant cover and no conservation practice and tillage is done up and down the slope; in other words: the expected rate of soil loss caused by the relatively permanent erosion factors of climate, relief, soil profile and present conditions of erosion.

a) The erosion susceptibility is a characteristic of an area. It describes the *erosion* to be expected without protection by plants and in the absence of *conservation practices* (Beek a.o. 1965; Bennema & de Meester 1981:79-80).
   The relative permanent erosion risk has been called soil erosion susceptibility (Brinkman & Smith 1973).
b) It is a useful concept for planning land development, when alternative *land utilisation types* are considered. Each alternative may result in a different *erosion hazard* for one unit of *land* which has a certain erosion susceptibility.
c) Effects of present *erosion* are taken into account because the development of *erosion* towards a new natural equilibrium usually takes many years, and therefore the present *erosion* is a rather permanent condition of the *land* . The different stages of gully development, as well as stages of *interrill erosion* and *rill erosion* often take

several years to develop, the time span which is also taken for the *erosion hazard*.

d) In most cases the *erosion hazard* is much lower than the erosion susceptibility, both expressed as the expected rate of soil loss. The effect of surface *cover* is dominant over the effect of rainfall, slope, or soil profile, which is fortunate for mankind. Plant *cover* often strongly reduces *erosion*, while in many cases *conservation practices* may also cause a great reduction in *erosion* rates.

e) Different types of *land use* may interact in a different way with the soil profile, and one can say therefore, that the influence of the erosion susceptibility is not constant, but varies with the type of previous *land use*.
It seems preferable, however, to consider the effect of interaction between certain plants and the soil as part of the plant effect. The enduring part of this interaction has been called the *residual effect* (Wischmeier & Smith, 1978) indicating that changes in the soil (structure, porosity, organic matter, litter) remain present for some time after the causal plant *cover* has left. It occurs for example in *crop rotations*, or following conversion of forest or grassland into arable cropping land.

f) Because the concept of erosion susceptibility is a (rather) permanent characteristic of a piece of *land*, or *mapping* unit, it is a *land quality*.
The concept is in fact opposite to that of the *land quality* called "*resistance to erosion*". A low *resistance* to *erosion* is equal to a high erosion susceptibility.

g) In rating the erosion by classes the class numbers are identical for both. Low susceptibility is rated 1 and a high *resistance to erosion* is rated 1, both being the most favourable rate. When five classes are used, a susceptibility class 4, high, is similar to a resistance class 4, low (Bergsma 1986).

h) The term "*rain erosion susceptibility*" is preferred to "potential (rain) erosion", because the term suggests a maximum (which however may be passed under faulty irrigation management), and it is preferred to the term "rain-erosion-risk" because this is too close to the Spanish and French translation of erosion hazard.

**rain erosivity**, see also as Central Concept
Potential ability of rain to cause erosion due to its kinetic energy and volume.

a) The erosivity will vary with the type of shower, characterised by the rain amount per rain intensity class, duration of periods of high intensity, variability of the intensity, and the drying spells between rains.

b) The *erosive* potential of a rainstorm and its associated *runoff* is a function of the *rainfall energy*, the maximum prolonged intensity and their interaction (Wischmeier 1977:47).

c) For flat lands (slopes 1% or less) a correction to the effect of rain is made because ponding surface water during rainfall is deeper and protects more against splash (Mutchler & Murphree 1981:322).

d) Rain erosivity can be expressed by an index, several have been developed.The erosivity index in the USLE is the product of the *rainfall energy* and its maximum 30 minute sustained intensity (Wischmeier 1977:47).

**rain erosivity distribution**
The average long term rain erosivity for small time intervals of for instance one month, covering a period of one year.

a) It is usually shown in a histogram or a cumulative curve for a one year period and the interval values are most practically expressed as percentages of the annual total.

**raindrop impact**, see rainsplash

**raindrop erosion**, see rainsplash erosion

**rainfall acceptance**
- sorptivity
- rain storage capacity
- macropores

The amount of rain the soil can hold before overland flow takes place.

a) It includes the storage by *surface ponding* as well as infiltration.

b) *Surface ponding* in arable land depends strongly on tillage practices.

c) Whether rain water can be stored in the soil profile depends on the amount of soil surface *sealing*.

d) If sealing is unimportant, the soil stores rain water during the rain mainly in the non-capillary pores or macropores. The macroporosity may change with the degree of wetness of the soil profile in the case of swelling clays, and in general its availability for storage will depend also on the *antecedent* moisture content.

**rainfall energy = rain energy = kinetic energy of rainfall**
The energy contained in falling drops of rain, expressed in units of kinetic energy, per unit volume of rainfall.

a) The kinetic energy per unit of rain varies as the square of the terminal velocity of the drops (Wischmeier 1977:47).

b) The terminal velocity increases with drop size (Hudson 1981:57-58).

c) The median drop size tends to increase as rain intensity increases, untill it levels off at about 4 mm for rain intensities of about 75 mm/h (Hudson 1981:57-58).

c) It can be computed from recording rain gauge data, by a relationship between rainfall energy and intensity (Wischmeier 1977:47).

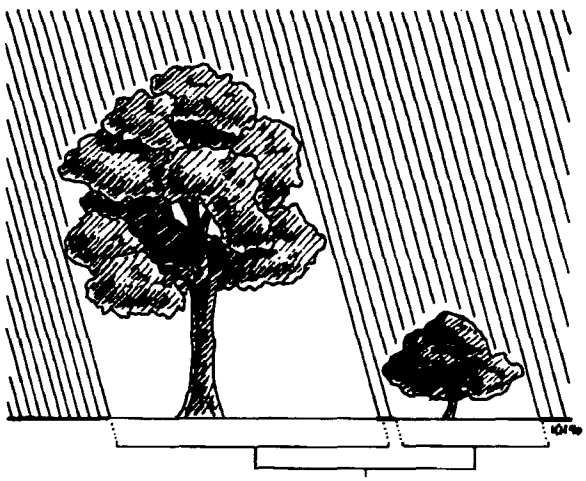
**rainfall interception**

~ soil cover

The interception and temporary holding of precipitation by vegetation or other materials.

a) In forest the interception can amount to 10 to 15 mm, while in crops it may be only 0.5 mm to 1 mm (Houghton & Charman 1986:70).

b) The rate of interception is initially high during the rain, but the available capacity is rapidly filled, so that its ability to reduce *runoff* rates within a given *catchment* is relatively small (Houghton & Charman 1986:70).



Rainfall interception

**rainfall simulation**

~ rain erosivity

The controlled application of water drops or artificial rain to experimental plots, using some type of drop former.

a) The equipment is called a *rainfall simulator* when it is relatively small, mostly mobile, portable, or mounted on a car, covering a small plot area, for instance one square metre.
It is called a rainulator when the equipment is large, mostly installed in a fixed position outside or in a laboratory. It could also be called a drop applicator if the drops produced are of the same size, which is not the case in real rain. The largest, fixed site rainulators, cover a permanent plot, or they may move on rails.
Small portable rainfall simulators are easy to bring to any site, but they still use amounts of water that are not easily provided at remote sites.
Larger simulators, mounted on trucks, cannot reach all sites, water supply is easier.

b) In many cases drops of certain size are applied, formed by nozzles, yarn, small tubes, or other drop formers (Moldenhauer 1981:16). Drops of unequal size may be produced by a nozzle, as in *sprinkler irrigation*, or by capillaries which dis-charge drops, or by dropping or spraying water on a *drip* screen, from where the water drips down.

c) In some cases the purpose is to simulate natural rain as far as possible (Houghton & Charman 1986:97). The artificial rainfall is meant to resemble natural rain in drop diameter distri-bution and intensity, and to generate *erosion* on soils under laboratory or field conditions. In this way experimental data are produced about *rainfall erosion* in a shorter time than would be possible under natural rain (Lusby 1977).

d) Simulated rain is not exactly the same as natural rain (Moldenhauer & Foster 1981:16). Entirely satisfactory *simulation* of natural rain with its intensity-drop size-energy relationships is claimed only for certain elaborate and expensive rainulators. It is achieved by replacing continuous with intermittent rainfall. Most rainulators are designed to provide uniform rain over the test plot, while natural rain varies in intensity and drop size. Comparability of results only applies for rainulators of the same design. Natural conditions and rainulators of different design will, in general, produce different results (Bryan 1981).

e) Even when rainulator use is standardised, resulting *runoff* and soil loss show strong variation. This can only be overcome by considerable test replication (Bryan 1981).

f) Variation in soil loss production by rainulator relates strongly to rainfall intensity, rain volume, *surface sealing* and *infiltration*. Also *antecedent* moisture and tillage conditions cause variation in test results (Bryan 1981).
Perhaps an overall explanation of variation lies in the varying depth of the water layer on clods of different size and stability, interacting with varying drop sizes (Bryan 1981). Duration of the test, drainage conditions of the soil and *sealing* interact to produce the effect of rain on soil loss. Very sandy soils and well aggregated soils are sensitive to drainage differences and test procedure (Bryan & de Ploey 1983).

g) Plots for rainfall *simulation* should not be too small for *rill erosion* to occur, and should have enough length to evaluate the effect of *steepness* , plant *cover* and *management* (Moldenhauer & Foster 1981:22).
Larger field plots (700 m2) under sprinklers simulate *natural erosion* conditions better, as *subsurface flow* and *rills* may form, and rain is varying somewhat in intensity and drop size, as in nature. Slope length however is still small (30 m) relative to many field situations.

h) In the laboratory, small experimental soil surfaces (80 x 300 cm for instance, often smaller) are used,

while outside areas are about 1 m2 in case of small, portable simulators, or about 5 x 10 metres in the case of larger rainulators that stand fixed or move on rails.

**rainfall simulator,** see rainfall simulation
Device to apply water in a form and at a rate comparable with natural rainfall (UNESCO 1992:236).

**rainsplash**
The spattering of small soil particles caused by the impact of raindrops on wet soil; the loosened and spattered particles may or may not be subsequently removed by surface runoff.
a) Rainsplash is the most critical process in *rain erosion* , it is the main provider of *erodible* material, by disintegrating soil surface structural elements into transportable fragments. Preventing splash is one of the most effective means of reducing *erosion* and *erosion hazard* . Crop and *residue management* offer great possibilities for splash prevention in most conditions.
b) It often leads to *sealing* of the soil surface pores by the fine material it produces through detachment and slaking.
c) *Rainfall kinetic energy* is highly dominant over *overland* flow kinetic energy (Hudson 1981:64-66).
d) When raindrops fall on thin *overland flow* , splash increases the *detachment* capacity because it increases turbulence.
e) When falling on a water layer deeper than three times the *raindrop* diameter, splash becomes ineffective for detachment by raindrops.
f) Rainsplash causes some transport on a slope through the dominance of displacement in a downward direction.
g) The more than proportional reduction of *surface erosion* by small amounts of *soil cover* is explained by the direct *interception* of splash by vegetation and the extensive additional *interception* of secondary splash drops (Meyer 1981:36).
h) In situations of grass tussock *cover* , splash causes an accumulation of soil amongst the tussocks, changing microrelief. It should not be confused with evidence of removal of soil between the tussocks by *interrill erosion.*

**rainsplash erosion**
~ detachment
~ rainsplash
Primary soil particles and small soil aggregates that are detached and transported by splashing water drops as a result of raindrop impact on the soil.
a) Typical features are *pedestals* .
b) It is an important process in *interrill erosion* (Houghton & Charman 1986:49).
c) The effect of rainsplash varies with rain intensity and raining time (Luk 1983:283-295).
d) Although *raindrop* impact and surface water flow can be considered to have separate potentials to cause soil loss, interactions between them may influence their combined effect (see *rainsplash*).

**rain storage capacity**
~ field capacity
~ rainfall acceptance
~ water-holding capacity
The amount of rain that can be stored in the soil profile during a rainshower, largely in *macropores,* that allows rapid access of water.
a) It is a limitation to the total volume of rain that can infiltrate.
b) It depends strongly on the *sealing* of the soil surface, the macropore volume, the *antecedent moisture* , and therefore also the drainage condition of the site.
a) It is not the same as *water holding capacity* , which is the amount of water held in the soil at a pF of about 2, after 24 hours free drainage from saturation (Bryan 1977:68).

**rainulator,** see rainfall simulation

**rainwash**
Erosion by rain on sloping land in which the effect of rainsplash and that of overland flow act together on the whole of a hillside.
a) Occurs in cases of low *runoff* . Flow occurs in shallow micro-*channels* which are continuous but shift in position. Flow in combination with rain impact produces much of the *erosion* . *Channels* at this stage are numerous, close together and only a few cm deep (micro-*channels* ) (Richter 1965).

**rangeland**
Land currently used for grazing by livestock or wildlife, where natural vegetation is the main forage source.

**rating curve**
A graphic representation of the discharge of a structure or channel as a function of depth of flow.
a) A tabular presentation of the same data is known as a rating table.

**rating table,** see rating curve

**rational formula**
~ rational method
A formula for estimating peak discharge of runoff from a catchment above a specific point:

$$Q = \frac{CIA}{360}$$, where:

Q = peak discharge ($m^3/s$)
C = runoff coefficient
I = rainfall intensity (mm/h) for the selected return period (years) with storm duration equal to the time of concentration for the catchment (minutes).
A = catchment area (ha)
a) The rational formula is based on the following assumptions:
- rainfall is of uniform intensity over the whole *catchment* for the duration of the design storm.
- the rainfall duration is equal to the catchment's *time of concentration*.
- the *return period* of the peak discharge is equal to that of the rainfall intensity.

b) The formula can be used for *catchments* up to 100 ha. For *catchments* of a size between 100 and 1200 ha a correction factor is possible to reduce an overestimation of the peak discharge. For larger *catchments*, the formula should not be used.

**rational method**
~ rational formula
A method used in the design of terraces and drainageways to estimate the maximum rate of runoff that the system should accomodate.
(Hudson 1988b:124-125):
a) The method requires estimates of the *time of concentration* for each of the parts of the *catchment* area and estimates of the probable maximum rainfall intensity for these times.
b) Few countries have sufficient data to construct reliable and accurate tables or design charts.

**ravine**
~ gorge
A narrow, steep-sided incision, larger than a gully but smaller than a valley and usually formed by running water.

**recurrence interval**, see return period

**reforestation**
Planting of forest to replace old or declined forest or to replace degraded vegetation that followed deforestation.
a) Depending on the existing climate and soil conditions a decision must be made on suitable tree species to be planted (Agricultural Compendium 456).

**relief factor (of rain erosion) = topographic factor (of erosion)**, see also as Central Concept
The influence of topography on rain erosion, including steepness, slope form, length of uninterrupted non-depositional overland flow, and slope exposition.
a) Steeper slopes show less *infiltration* and more *runoff* (Toy 1977:10) because faster flow gives less time for *infiltration*, assuming a certain *soil permeability*. However it remains difficult to compare steepnesses, without introducing soil differences (Lal 1981).

**remote sensing = teledetection**, see also as Central Concept
~ greenness
~ leaf area index
~ soil brightness
~ soil line
The collection of information about an object or phenomenon by the use of sensing devices not in physical or close contact with the investigated object.
Descriptive aspects: see Central Concept.
They have been subdivided into the following parts:
a) general
b) radiation from soil
c) radiation from sparse vegetation
d) radiation from cultivated plants as a yield parameter
e) geo information systems to handle the satellite data
f) satellite data interpretation and mapping in erosion studies

**Reno mattress**
~ gabion
A shaped mattress made of wire mesh, filled with loose rocks and stones, used to protect earth surfaces from the erosive action of flowing water.
a) It is similar to a *gabion*, but thinner and used for instance in lining stream and riverbanks (Houghton & Charman 1986:101).

**residual effect (of plant cover)**
The effect of former cultivated plants or natural vegetation on current soil erodibility.
a) It strongly depends on the type of the previous vegetation or crop and the farm management of the *residues* (Wischmeier & Smith 1978:20).
b) A strong residual effect is well known for forest and for *perennial* pasture, due largely to the addition of organic matter to the soil.

**residual suitability**
The ability of the land to produce certain crops, that remains after some erosion or other land degradation has taken place.

a) It is used in combination with soil attributes such as soil depth to calculate the *permissible soil loss* (Biot 1990).
b) The permitted soil loss calculated in such a way does not take into account a change of market, an increase in cost of fertiliser, the exponential character of the *erosion* process, and limitations to the development of new seed varieties. It fits in poorly with the concept of *land husbandry*.

**residue,** see crop residue

**residue management,** see crop residue management

**resistance to erosion**
~ erosion susceptibility
A land quality indicating the land use limitation due to erosion posed by the combined effects of climate, relief, soil profile and present erosion, in the absence of plant cover and in conditions of tillage up-and-down the slope.
a) It is the reciprocal of *soil erosion susceptibility*.
b) It is a *land quality*, that is rated 1 for very high and 5 for very low.

**retaining wall**
A barrier, usually of uniform thickness and constructed of masonry materials, designed and installed to hold back unconsolidated rock and/or soil.
a) Its aim is to counter the gravitational force of the material it is withholding and prevent *mass movement*. Small holes or gaps may be incorporated in the wall to permit *seepage* (Houghton & Charman 1986:101).
b) It is designed to sustain lateral earth and pore water pressure. It should have good drainage. In Taiwan old tyres around reinforced concrete columns are used for small *retaining* walls as they can bear small unequal *settling* (Tuan 1987).

**retarding measure**
Any measure to delay storm runoff and thereby reduce peak discharge.
a) Such measures may include grassed drains, *retention furrows*, constricted pipe *outlets* and detention structures (Houghton & Charman 1986:102).

**retention**
That part of the precipitation falling on a drainage area which does not escape as surface streamflow during a given period (UNESCO 1992:248).

**retention furrow or open drain**
~ furrow
A furrow for surface storage of overland flow.
a) A shallow incision made by a plough, on the *contour*, to increase *surface storage* of water; the excavated *soil* is spread thinly on the uphill side (Hudson 1988:124).
b) If *runoff* exceeds storage, the surplus can spill uniformly over the downhill edge of the drain (Hudson 1988b:124) but most likely the spilling will not be uniform. Only on good *grazing land* will the *erosion hazard* caused by unequal spill be acceptable.
c) In Zambia these are called "pasture furrows" on *grazing land* and "*contour seepage furrows*" on arable land (Hudson 1988b:124).

**retention terrace/bank**
~ diversion terrace
A terrace/bank that retains the overland flow in a contour channel, and therefore should have a designed storage capacity in relation to the expected overland flow volume.

**retention storage**
The amount of water which can be stored by a retention structure.

**return flow**
~ seepage flow
That part of the water diverted from a stream that finds its way back to the stream channel either as surface or underground flow.

**return period = recurrence interval**
The average period in years between the occurrence of an event and one of equal or greater magnitude.
a) Used, for instance, for a storm of specified magnitude.
b) It is an average figure, not an interval. For example, a storm with a return period of five years does not occur regularly every five years but would probably occur ten times in fifty years.
c) It is a design variable associated with estimates of maximum rates of rain intensity and *runoff*. The normal concept in engineering design is that the safety factor should be related to the damage that would occur in the event of failure. Most design manuals favour a return period of 10 years for soil conservation structures, but from the farmer's point of view the period could probably be shorter to avoid over-design while accepting a slightly higher risk of failure (Hudson 1988b:126).

**revegetation**
The re-establishment of plants, such as grass, legumes and selected trees and bushes in order to provide forage, protection against erosion, or improvement of the landscape.

**revetment**
A protective layer of loose stones and rocks or other erosion resistant material either permanent or temporary, placed along the edge of a stream channel, to stabilise the bank and to protect it from the erosive action of the stream.

**Reynold's number**
The dimensionless number expressing the ratio of inertia forces to viscous forces (UNESCO 1992:249).
a) Field studies indicate that *overland flow* typically has low Reynold's numbers, less than 100 (Morgan 1981:518) unless *raindrops* are falling into it, then shallow flow will be turbulent around these spots. As the flow becomes deeper, *raindrops* will have less and less effect.
b) When viscous forces predominate, the flow is laminar, and the Reynold's number has values less than about 500. When the Reynold's number is greater than 2000, the flow is turbulent (Carson & Kirkby 1972:37).
c) The Reynold's number is 4q/v in which q = the unit discharge, and v = mean flow velocity (Boon & Savat 1981:314).
d) An uneven surface will concentrate flow and resistance at the edges of the flow will cause turbulence across the flow.

**ridging**
Land management practice of making bunds by tillage for water management and soil conservation.
~ contour ridging
~ tied ridging
a) *Erosion* by drop impact can be very strong on the side slopes of the ridges (Foster 1981:276).

**rill,** see also Central Concept of Rill Erosion
~ incision rill
~ braid or braided rill
~ rill fan
Shallow rain erosion channel, not more than 20 to 30 cm deep, through which water flows during and immediately after rain and which can be obliterated by normal tillage operations.
a) When recently formed, the walls may be steep.
b) They mostly occur in dendritic or parallel patterns. Control is by slope form, or by tillage direction.
c) When *erosion* develops further, there are two series of erosion features possible: towards the *gully* and towards the *braid*.
d) When the upper depth limit is put at 30 cm, as is usually done (Soil Cons.Soc.Am. 1982; Houghton & Charman 1986:102) deep rills will certainly be an obstacle to normal tillage operations. On simple *management* levels, with animal or human traction, deep rills will form a *land management* limitation.
It will take a large disc plough (55 cm) to obliterate 30 cm rills. With a disc, mouldboard or chisel plough, it will take several passes to obliterate 30 cm rills.
Therefore the upper depth limit is better put at 20 cm so that the criterion of no obstacle to normal tillage can be kept.
e) The lower depth limit is some 3 centimetres, thus excluding the *prerills*.



*Single incision rill in arable land (auger is 120 cm long), the rill followes partly the slope, partly the plough direction, Spain (photo E. Bergsma).*

**rill erodibility**
~ soil erodibility
The sensitivity of a soil or site to the formation of erosion rills.
a) Important determining factors are:
- the *overland flow* volume
- the erosive capacity of the *overland flow*, in turn depending on the velocity, influenced by slope steepness, basal plant cover (hydraulic roughness) and depth of flow
- the *scour* sensitivity of the surface material
b) The governing factors have been summarised by Boon & Savat (1981):
- slope steepness
- soil texture
- volume of overland flow
b) The amount of overland flow depends strongly on concentrations of surface flow and *subsurface flow* in hollow slopes and concave lower slopes, and in level areas where *topsoil saturation overland flow* is dominant.

**rill erosion,** see also as Central Concept
An erosion process in which numerous small channels of several centimetres up to about 30 cm deep are formed.
a) It occurs mainly on recently cultivated soils (Soil Science Society of America 1978) and/or recent *cut and fills* (Soil Cons.Soc.Am. 1982:55) and recent *mass movement* scars.
b) On arable land it always occurs together with *interrill erosion* , which provides much of the *sediment* (80% in some experiments) transported by the *rills* off the field.
c) Rill erosion is much more damaging than *interrill erosion* .
d) It covers only a small part of the land surface, but is very damaging to regular plant growth, especially of annuals (Meyer 1981:33).
e) The *channels* should be less deep than 30 cm, the commonly used depth limit, to present no obstacle to normal tillage operations, especially for tillage using animal or human traction, but also for mechanised tillage.

**rill fan**
Small, cone-shaped depositional feature, comprising sediment at the foot of a rill.
a) Most pronounced below single *incision rills* in grassland.
b) In arable land which is tilled up-and-down the slope, rill fans often join together laterally into a zone of *colluvium* at the lower concave slope, where individual fans are obliterated by tillage.

**rillwash**
~ rill erosion
The erosion by rills on sloping land, in which the rills change position periodically and so over time act on the whole of a hillside.
Occurs in cases of moderate *runoff* (Richter 1965).

**rip-rap**
Loose rock or stone used to protect earth surfaces against *erosion* by flowing water or wave action.

**riser**
A: The downslope facing batter or bank of a terrace.
B: A vertical length of pipe used in an hydraulic structure specifically to control the level of water in the structure. Typically used as the inlet of a pipe spillway.

**risk of erosion,** see rain erosion susceptibility

**riverbank erosion = lateral stream erosion**
Erosion of river or stream banks by the action of flowing water.
a) *Lateral erosion* in rivers is one way by which *channels* respond to environmental stresses. Other ways include changes of *channel* width, depth, stream velocity, *surface roughness* and *sediment* transport (Hey 1978).
b) Flow characteristics of bends result in changing ability of the stream to transport and deposit sediment. As a result of this alternate shift of the flow profile, riversbeds are eroded laterally to form meandering *channels* (Krhoda 1986).

**rotational slide**
~ slump
A landslide where the material is not greatly deformed and the surface of separation is concave, with backward inclination of the material in the new position.

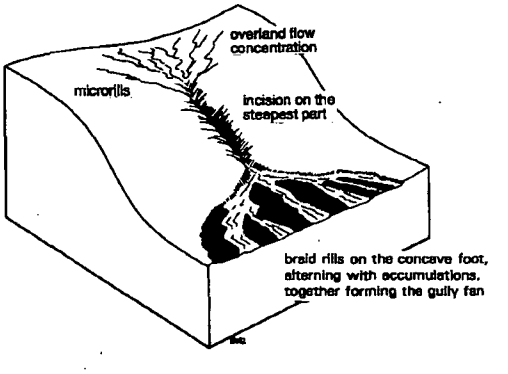
**roughness,** see hydraulic roughness or surface roughness

**roughness coefficient,** see hydraulic roughness coefficient

**routing of surface runoff**
The pathways of surface runoff through a catchment, from its origin as overland flow to the place of discharge as channel flow.

**runoff**
~ base flow
~ groundwater runoff
~ overland flow
~ surface runoff
That portion of the precipitation on an area which is not immediately absorbed by the soil but runs over the land surface, then is discharged from the area through stream channels.
a) The part which is flowing over the land is called *surface runoff* and that which enters the soil before reaching the stream is called groundwater runoff or *seepage flow* from groundwater.
b) In soil science runoff usually refers to surface flow; in geology and hydraulics runoff usually includes supply to the drainage *channels* by *surface runoff* and by *subsurface flow* , or *seepage flow* (Soil Science Soc. of America 1978).

rain erosion features on a slope



**runoff coefficient = runoff percentage**
The runoff as a proportion of the precipitation input in an area for a given period.
a) It indicates the proportion of the rainfall rate that is actually contributing to the *runoff* rate and as such the coefficient is always less than 1 (Houghton & Charman 1986:104).
b) It depends on (Houghton & Charman 1986:104).
   - *rainfall* intensity
   - *interception*
   - *topography*
   - *depression storage*
   - *infiltration*
c) The C-factor in the *rational formula* equals the ratio of the rate of *runoff* to the rate of rainfall (Houghton & Charman 1986:104).
d) For its estimation, numerical values are alloca-ted to various *runoff* producing characteristics, the sum of which gives the *runoff coefficient* . This assessment is subjective and represents one of the main problems in the application of the "rational-formula" for calculating *runoff* rates (Houghton & Charman 1986:104).

**runoff curve method**
A method to predict the quantity of runoff developed for the USA. (Hudson 1988b:124-125):
a) It requires a great deal of accumulated knowledge that is seldom available outside the USA. The method was really designed to predict the quantity of *runoff* . Using it to estimate maximum rates of *runoff* requires assumptions about the shape of the *hydrograph* .
b) It is designed for small *watersheds* of mixed use on gentle slopes

**runoff hydrograph**, see hydrograph

**runoff plot**
~ erosion plot
An area of land, usually small, arranged so that the portion of rainfall or other precipitation flowing off, and perhaps carrying soluble materials and soil, may be measured; usually the flow from runoff plots includes only surface flow.

**runon = topwater**
Surface water flowing onto an area as a result of *runoff* occurring higher up the slope.

**saltation**
The movement of small grains or particles in water (or wind) with rebound along a firm stream bed (or land surface).
a) The bouncing may set other particles into motion.
b) The process needs a certain distance to develop fully, depending on the diameter, weight, and shape of the particles.
c) The size of sand susceptible to saltation is 100-400 mu.

**saturated infiltration rate**, see basic infiltration rate

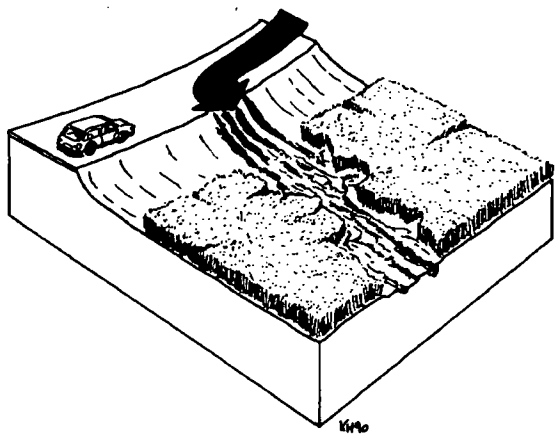
**saturation overland flow**, see also Central Concept of Overland Flow
~ overland flow
Shallow widespread surface runoff caused by reduced infiltration of rain during saturation by a rising groundwater table.

**saturation wedge**
The wet zone between a pseudo groundwater table on a hillslope and a relatively impermeable soil horizon or layer below.
a) At its upslope point it may intersect with the land surface, leading to *overland flow* of the type *topsoil saturation overland flow* .

**scour**
The process of mobilisation and removal of soil materials by the shear force from flow and turbulence of flowing water.
a) It is one of the main processes in rain erosion.
b) In the case of dam lakes scouring may be accelerated in the channel below the damsite. Above the dam, deposited material causes aggradation of the *channel* , reduces local stream gradient, increases *channel* width, and changes *sediment* size distribution.
c) *Sediment yield* rate decreases until a dam fills, but downstream scour tends to offset the benefit of storage of deposits (Liu Chiun-Ming 1985:547).

**sealing**, see soil sealing

runon from a road to a field downslope



**sediment**
~ bedload
Material of varying size, both mineral and organic that is being or has been moved from its site of origin by the action of wind, water, gravity or ice, and come to rest on the earth's surface either above or below a water level
a) Cropland is (in the USA) the source of about 40% of the sediment delivered to the nation's waterways. *Streambank erosion* is responsible for about a quarter of the sediment delivered , pastureland and rangeland for a little more than 10%, and forest land, urban land and land used for means of transportation for most of the rest (Crosson 1985:232).

**sediment basin**
Basin or pond at the upper end of a channel or reservoir to store sediment-laden water for a sufficient length of time for the sediment to be deposited (Soil Cons.Soc.Am. 1982:142).

**sediment concentation curve**
~ hydrograph, with figure
A graph showing the sediment concentration of a transporting medium, such as runoff, against time.
a) The *sediment load* of a stream consists of *bedload* material and suspended load (Houghton & Charman 1986:109).
b) Sediment concentration of a stream depends on its *transport capacity* and is determined by:
   - velocity, cross-section and turbulence.
   - the texture of the *sediment*
   - ionic composition of dissolved salts in the water
c) For the case of *overland flow*, a typical curve shows a concentration peak in the first few minutes of flow, and another concentration peak in the last few minutes of the flow, after the rain has stopped (Lusby 1977:24).
d) Tillage operations frequently lead to high sediment concentrations in *surface runoff*, while it declines with time after tillage (Bottcher a.o. 1985:625).

**sediment delivery ratio**
~ sediment yield
A measure of the sediment actually reaching a stream or lake expressed as the quantity of material reaching a specific point in a drainage system divided by the quantity actually eroded in the catchment above the same point.
a) The reduction of the total *eroded* volume by *deposition* within the *watershed* is described by the sediment-delivery-ratio (Wischmeier 1977:54).
b) Delivery ratios are extremely variable and quite often site-specific for field areas (Moldenhauer 1981:24).
c) The origin of the *sediment yield* is the total *sediment* leaving the upslope lands through *erosion* , minus the volume deposited in *terrace channels* , in *grass strips*, sod *waterways* , ditches, at field boundaries, at the toe of field slopes, in depressional areas (Mutchler & Murphree 1981:324) and along the path travelled by the *runoff* on its way from a field to the stream system: the *routing* of the *sediment* .
d) It is affected by climate, *land use* , local environment and general physiographic position (Toy 1977:16), texture of *eroded* material and flow velocity (Meyer 1981:40).
e) *Sediment* may be produced by *surface erosion* and gullying, but also by *streambank* - and *channel erosion* (Wischmeier 1977:54).
f) The *routing* of the *sediment* through a drainage *basin* is a question far from solved (Hadley 1977:73). The *routing* of erosion *sediment* through the flow system and evaluating *sediment yield* is much influenced by the potential for *sediment deposition* (Meyer 1981:35; also Walling 1990).
g) Flatland (slopes below 4%) has many *depositional* opportunities (Mutchler & Murphree 1981:321).
h) The *sediment* yield data for the discharge point have little meaning in terms of *soil erosion* and tell nothing of the soil relocation within the *catchment* (Blandford 1981:117).

**sediment load**
The amount of material carried by a stream per unit volume of water.
a) It includes suspended load and *bedload* (Soil Cons.Soc.Am. 1982:109).

**sediment routing**
~ routing of surface runoff
The pathways of sediment transport from its site of mobilisation, through the drainage basin to its deposition or exit from the catchment.
a) Much is still unknown about the transport paths of *sediment* through a drainage *basin* (Hadley 1977:73).

**sediment storage**
Material eroded from the land and not delivered to the stream system in a catchment but accumulated in depositional slopes and sites.
a) The concept is used in sediment budget studies (Sutherland & Bryan 1989:93-94).
b) The assumption of a steady state in *catchment* denudation studies is often incorrect. *Sediment yield* is only a measure of fluvially-transported material from a *catchment* , and does not account for *deposition* of colluvial and alluvial material *eroded* from upland slopes (Trimble 1972). Basin *sediment yield* may be quite small (5-7% for instance) compared to *erosion* or *sediment* storage (Trimble 1983)

c) Quantitative studies of *sediment* storage in *channels* in forested areas indicate that the volume of temporarily stored *alluvium* is commonly more than 10 times larger than the ave-rage annual export of *sediment* (Swanson 1982).
Present *sediment yields* may be controlled by remobilisation of stored material, rather than supplied by variation in hillslope *erosion* processes (Trimble 1983).
d) A change in *sediment* storage may result from a change in *land use* or a change in *conservation* strategies.
e) Denudation rates calculated exclusively from *sediment yields* are poor indicators of hillslope *erosion* , unless the basin is in a "steady-state" condition.

**sediment trap**
A structure, usually relatively small, designed specifically to collect sedimentary material in a drainage line.
a) They should be regularly cleaned out to maintain their efficiency (Houghton & Charman 1986:109).

**sediment yield = sediment discharge**
The quantity of sediment transported through a channel cross-section in a given time, measured in dry weight or by volume.
a) It is obtained by multiplying the *sediment concentration* by the stream discharge.
b) It is usually expressed as volume or weight per unit of area, per unit of time.
c) *Sediment* discharge consists of both suspended load and *bedload* (Soil Cons.Soc.Am. 1982:142).
d) Sediment yield per unit area decreases with increasing drainage area, because of:
- absorption of streamflow by the *channel* , especially in dry *channels* of ephemeral streams, resulting in *deposition* of *sediment load* .
- topography in larger *basins* includes more flatter slopes in the downstream part providing sites for *deposition* of *colluvium* at footslopes and *alluvium* on valley floors and floodplains.
- limited areal extent of rainstorms relative to increasing size of *catchments* : only a part of the *catchment* area contributes to *erosion* when the *basin* is large.Temporary *deposition* is common.

Therefore the *sediment delivery ratio* for large *basins* is lower (for instance 0.1) than for small *basins* (for instance 0.9) (Dunne & Leopold 1978:664,678; Walling 1990).
e) Several parameters have been used for its assessment:
- average stream gradient
- change in elevation across and along the *basin* (Hudson 1981:84).
- discharge, peak discharge, and a soil/*relief*/*cover* /practice factor (Williams 1975).

f) The origin of the sediment yield is the total *sediment* leaving the upslope land through *erosion* , minus the volume deposited in *terrace channels* , in sod *waterways* , at field boundaries, at the toe of field slopes, in depressional areas, and along the path travelled by the *runoff* on its way from a field to the stream system: the *routing* of the *overland flow* carrying the *sediment* .
*Sediment* may be produced by *surface erosion* and gullying, but also by *streambank* - and *channel erosion* (Wischmeier 1977:54).
f) A curve showing the *sediment* concentration of the *runoff* against time is called the *sediment concentration curve* .
g) Sediment yield is best determined by a survey of deposits in a reservoir. Alternatively, it can be computed by integration from a *hydrograph* of flow and a *function* of discharge. Note that separate *sediment rating curves* must be developed by field measurement for suspended load and for bedload (Dunne & Leopold 1978:678).
h) It is only of limited usefulness for the prediction of soilloss, but data are adequate for the design of water storages (Blair Rains 1981:59). Although sediment yields from river *catchments* can provide useful information on denudation rates over the *catchment* , knowing the *delivery ratio* for different parent materials, land uses, and topographics is a major constraint (Lal 1988a:45).

**sedimentation**
The process of deposition of sediment by water.
a) In agriculture it affects small parts of fields, but it is very damaging to crops, especially annuals; as such it is a major concern.
b) In urban areas common problems are muddy streets, clogged storm drains and dirty office corridors. Storm water management is needed to avoid flooding, often caused by sedimentation (Krhoda 1989:115-122).

**seedbed**
The layer of topsoil prepared to promote the germination of seed and the growth of seedlings.

**seepage**
A: flow into
B: flow from = exfiltration
~ interflow
~ subsurface flow
~ throughflow
~ translatory flow
DEFINITION A:
The slow movement of gravitational water through the soil.
DEFINITION B:
Subsurface water emerging at the land surface from lateral throughflow.

a) The emergence is forced by a rising water table or by progressive saturation of soil above a relatively impermeable *soil layer* or horizon.
b) After emerging at the land surface the water contributes to overland flow.
c) Its place in the hydrological cycle has been discussed in Dunne (1978) and Dunne & Leopold (1978:255-278) Chapter 9, Runoff Processes.
d) It is important in extending and maintaining first order *channels* (Dunne 1980, 1988).
e) It occurs for instance at a scarp face, on the downstream face of an earth dam, on the lower part of an alluvial fan or colluvial slope.

**settling**
The deposition of suspended material from a transporting medium like water; or the increase in bulk density of the soil by the pressure of its own weight.
a) A freshly ploughed surface has a bulk density which increases with time through the progressive collaps of the open soil structure. In this way contour furrows loose part of their storage capacity over the season.

**shear**
~ shear strength
A process of distortion, strain or failure produced by a force acting at right angles to the direction of movement over the shearing plane.

**shear strength = shearing resistance**
The maximum resistance of a soil to shearing stresses.
a) It is derived from an interplay of:
   - plane friction ) together called the internal friction
   - interlocking of particles ) of the material
   - the effective normal stress: the force that acts to push the particles together
   - the cohesion: a force that makes tiny particles stick or cohere (Carson & Kirkby 1972:66-67).
b) It depends on inter-granular friction, cohesion, and pore water pressure patterns (Bryan 1977:69).
c) For coherent soils, under grass or natural vegetation and not in arable use, *entrainment* resistance is determined by *shear strength* (Bryan 1977:70).
d) It can best be measured by the direct shear test, adapted for thin samples and small variations in load (Carson & Kirkby 1972:67).

**sheet deposit**
A more or less even layer of deposition from sedimentation, occurring by stream flooding or overland flow.

**sheet erosion,** see interrill erosion

**sheetflooding**
Type of rain erosion caused by wide, continuous and deep overland flow.
a) Occurs in cases of heavy *runoff* on gentle to nearly level slopes.
b) *Erosion* and *deposition* may alternate in place and time.
c) Subsidence of the water flow may leave behind a *floodbraid* pattern.
d) Aggrading sheetflooding is more common than the erosive type (Richter 1965).

**sheetwash**
~ interrill erosion
~ surface wash
The process of interrill erosion, stressing the extension of the process in time over a hill slope which loses a shallow layer of soil, more or less uniformly.
a) Sheetwash, in sandy *sediments*, is maintained by widespread *liquefaction* of the topsoil, induced by *raindrop* impact and positive porewater pressure (de Ploey 1981:147).



*Sheet-flood entering a gully, Eritrea (photo N. Grunder).*

**sill**
A horizontal section at the outlet of a conservation or a hydrologic structure which spreads water flowing from the structure, hence preventing it from causing erosion or concentrating and forming gullies.

**silt trap,** see sediment trap

**silting (up)**
The filling of a channel or a reservoir by the settling of transported sediment.

**slaking**
The loss of soil structure under the influence of wetting, not necessarily involving dispersion.
a) Wetting causes structure breakdown by swelling of clays, reduction of pore water suction, dissolving of cementing agents, and air explosion in sandy materials.
b) It does not include the effect of *soil dispersion*. It is a component, along with *soil dispersion* and other factors including soil *detachment*, of the process whereby *soil structure* is broken down in the field (Houghton & Charman 1986:112).
c) It may be used for a classification of the stability of the surface soil structure on sudden wetting (Loveday & Pyle 1973).

**slide**, see landslide

**slip**, see landslip

**slope aspect**, see slope exposition

**slope effect (on rain erosion)**, see relief effect

**slope exposition = slope aspect**
The direction towards which a slope faces, as designated by the points of the compass.
a) An equivalent term, slope aspect, may be misunderstood to mean a matter which is related to slope.

**slope length**, see erosion slope length

**slope wash**
~ interrill erosion
~ surface wash
~ rainwash
A grouping of processes in which surface runoff acts on the whole of a hillside with the dominant influences of splash ( rainwash), interrill-erosion (soil wash or sheetwash), rills (rillwash) or gullies changing position over the slope periodically (gully-wash), and so lowering the slope more or less evenly.
a) The term *surface wash* (Carson & Kirkby 1972:190,226) indicates the combined effect of *rillwash* and soil wash, as the term *surface erosion* indicates the combined effect of *rill-* and *interrill erosion* .

**slump**
~ rotational slide
A slide where the material in motion is not greatly deformed but has backward rotation on a more or less horizontal axis, and displacement along a concave surface of separation, resulting in a mass with an inward sloping surface.
a) In Selby (1985) and Thornes & Embleton (1979), discussing *mass movement*, the term is not used.

**sod planting**
A method of planting in sod with little or no tillage; herbicides are used to kill or retard the existing vegetation.

**sod seeding**
The sowing of seed, with or without fertiliser, directly into pasture.

**solum**
The part of the soil profile consisting of the A and B horizons.

**soil**
~ soil profile
The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.
a) It may have *soil horizons* (Soil Survey Staff 1951).
b) It has a thickness that is determined by the depth of common rooting of native *perennial* plants (Soil Survey Staff 1951).

**soil aggregate = ped**
~ crumb: a certain type of natural aggregate, typically formed by animal activity (Soil Survey Staff 1951:228).
~ clod: a volume of soil, or lump, formed artificially by human disturbance (Soil Survey Staff 1951:225).
A natural unit of soil structure, consisting of soil textural particles which may be combined with organic matter or other cementing agents, separated from adjoining aggregates by surfaces of weakness.
a) On investigation, an aggregate may be broken into other, smaller aggregates, or into parts of aggregates called soil fragments (Baver).
b) Many soils have a compound soil structure consisting of one or more sets of smaller *peds* held together as larger *peds* (Soil Survey Staff 1951:230).
c) Mere breakage into fragments larger than the soil grains without some orderly shape and size should not be confused with soil structure (Soil Survey Staff 1951:230).
d) Soil structural element are units of soil structure, including aggregates, peds, clods, crumbs and fragments of aggregates (Soil Survey Staff 1951).

**soil aggregate stability**
The resistance of soil aggregates to breakdown under wetting, splash and tillage, or other mechanical pressure.
a) It is not exactly the same as soil "structural" stability, because aggregates are formed in the soil at least partly by biological activity, while other soil structural elements exist in many soils (Baver a.o. 1972:182).

b) Factors affecting *soil aggregate stability* are:
- soil texture
- soil structure
- type of clay mineral
- organic matter content and type
- cementing agents and
- cropping history (Troeh a.o. 1980:104-107).

c) Indices of aggregate stability are several:
- *dispersion ratio*,
- *water stable aggregation*,
- *soil aggregation index* (Bryan 1969)
- the Emerson aggregate test (Emerson 1967; Loveday & Pyle 1973).

d) Applications of different organic material have over time a different influence on aggregation (Baver a.o. 1972:168).

**soil aggregation**

The way natural structural elements in a soil bind primary particles together into aggregates which are separated from adjoining aggregates by surfaces of weakness.

a) Aggregation is described by strength of expression, and the size and form of aggregates.

**soil aggregation index (Henin)**

~ soil aggregate stability

A parameter expressing soil structural stability resulting from a standardised test of shaking soil aggregates in water after prewetting one part of the soil aggregates in water, one part in benzene and one part in alcohol.

a) The soil aggregation index,S,is calculated as the largest of the three fractions < 20mu in *suspension* after shaking, divided by the sum of % stable aggregates in the three samples divided by three, and subtracting 0.9 fraction of coarse sand (Renard 1977; Henin 1960: 134-136).

b) The index S varies between 0.1 for soils rich in organic matter and 100 for soils on marl and soils rich in adsorbed sodium (Henin 1960:134-136).

c) The index S is combined with a measure of the *permeability* of the soil (K). When plotted, the log S and the log K values give a grouping of soils according to a line: 3 log k + 2.5 log S - 7.5 = 0. The combination of the value S and the value K provide a global index of soil stability (Henin 1960: 134-136).

**soil brightness**

In four-dimensional Landsat MSS signal space the soil brightness vector describes the maximum variations in soil spectral response.

a) Attribute of visual perception in accordance with which an area appears to emit more or less light.

b) Most of the variability of bare soil signals is attributed to soil brightness (Kauth & Thomas 1976; Kauth a.o.1979).

c) Soil spectra vary with surface moisture content, organic matter content, particle size distribution, soil mineralogy, soil structure, surface roughness, crusting and presence of shadow (Huete a.o. 1984).

**soil compaction**

A: the result of various natural and man-made processes in the soil causing a high density in some layer, with lower permeability for air and water.

B: a process of mechanical engineering affecting construction material.

A: DEFINITION:

The undesirable increase in the bulk density of a soil by tillage, stock trampling, and/or vehicular traffic, often resulting in the formation of pans such as plough-pans.

a) It decreases soil *permeability* and *infiltration* and increases *surface runoff* (Houghton & Charman 1986:30).

b) It reduces soil aeration with resultant lower plant production (Houghton & Charman 1986:30).

c) Trampling causes *soil compaction*. It results from *overstocking* and *overgrazing* (Valentin 1985:57,61).

d) Deep ripping and *conservation tillage* are used to alleviate the condition (Houghton & Charman 1986:30).

B: DEFINITION:

Intentionally increasing the soil bulk density and decreasing porosity by the application of mechanial forces to the soil; firming is a process of achieving a desirable degree of compaction.

a) Compaction may be achieved by rolling, tamping, or other mechanical means (Houghton & Charman 1986:30).

b) Optimum compaction of earthworks depends on the moisture content of the material and is particularly important in the control of *seepage* and earthwork tunnelling (Houghton & Charman 1986:30).

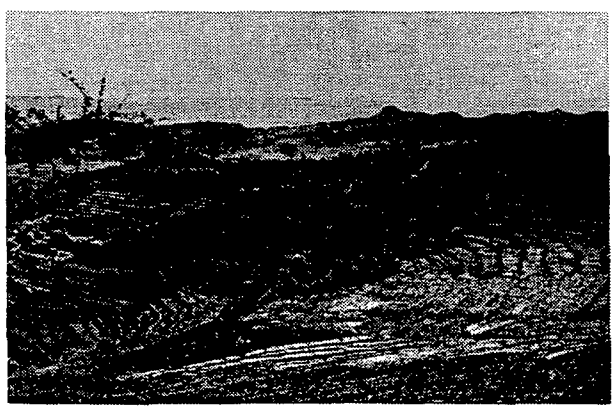
**soil conditioner**

Any material added to a soil for the purpose of improving its physical condition.

a) See for instance Pla, Florentino & Lobo 1987 for asphalt *mulch*.

**soil conservation,** see also as Central Concept
~ land degradation
The use of land, within the limits of economic practicability, according to its capabilities and the need to keep it permanently productive.

a) It is in fact the whole programme of connected studies, investigations, projects, methods and techniques for remedying, preventing or reducing *soil degradation* in a particular locality or under defined circumstances.
b) Many known technologies and practices for conserving soil and water resources enhance crop *productivity*, at least in the short term. However, long term actions, such as policy reform and institutional adjustments, coupled with long term funding commitments, are the key to resolving many of the world's problems of resource *management* and agricultural *productivity*. Such policies include the promotion of smallholder agriculture through the provision of product incentives, rural credit, reasonable food crop prices, adequate market and transport systems, strong agricultural research and extension programs, and the promotion of *farming systems* that do not degrade *land* and water resources (Mohammed T. El-Ashry 1988:x).
c) "Soil Conservation" as a term may not be the most appropriate name. An alternative is "conservation farming" which changes the emphasis from *conservation* to farming (Hudson 1988a:3).
d) Cover-management is very often the most important influence on *erosion hazard*, and often it can be used to some degree for *soil conservation*.
e) Proposals that are most effective and most readily acceptable in controlling *erosion* are those that are (Shaxson 1985:671):
   1. site specific, to take account of the unique combinations of physical characteristics of each individual property, and
   2. person-specific, to take account of the unique complex of wishes, resources, and abilities of each individual farmer.



*Narrow contour terraces for water conservation in a hoe agricultural system, Ethiopia (photo H. Hurni).*

f) Recommendations have a better chance of being adopted if they are seen to assist rather than hinder the overall aims of the land user. Four examples are given (Shaxson 1985:670):
   1. Tea estate owners in Malawi readily adopted the layout of tea fields on the *contour*, along with interrow micro-*catchments*, strip *mulching*, and roads aligned along crests and shallow gradients on a *catchment* pattern, when it was shown that the cost of production per kilogram of tea could be cut by a signifi-cant amount. Cost reductions resulted from less maintenance on roads and *contour banks* and reduced costs of repairing erosion damage, compared with traditional square layouts.
   2. Tobacco farmers in central African countries adopted a closer-than- essential spacing of *graded terraces* in *contour planted* fields because the arrangement allowed more effective and precise management of the crop at all stages. It also provided added erosion protection in a cropping system that otherwise suffers serious *soil degradation*.
   3. Direct planting of soya and wheat has been adopted by many farmers in southern Brasil because they found that such a system allowed more flexibility in planting dates. The conventional system requires time-consuming *cultivations* that often delay planting beyond optimum dates. Farmers also noticed marked reduction in *erosion*.
   4. Small farmers in central India enthusiastically adopted recommendations for more productive cropping practices, based on using improved seed, optimising planting dates, and fertilisers. Extension agents were delighted with the response to their efforts, farmers were pleased with better production, and conservationists were gratified at the reduced *erosion* that followed the significant increases in crop *canopy* and *rainfall* energy interception.

**soil conservation measures,** see soil conservation practices

**soil conservation practices**
~ conservation
~ soil conservation
Practices of plant management, cultivation system, land management and small construction works for correcting, preventing or reducing soil degradation.

a) Practices include "erosion control measures", which are those activities based on vegetation management, tillage operations, structural works and/or other farm *management* options designed primarily to achieve control of *soil erosion* (Houghton & Charman 1986:51). But they also include preventive practices.

b) *Practices* are subdivided as follows (Gibbons, pers.com. 1988):

b1) PLANT MANAGEMENT PRACTICES: using the plant and cover influence. These practices against *erosion* may be very effective, relatively simple and cheap, difficult to detect on airphotos, the first to be tried against *erosion* .
Examples are: fertilisation, *crop rotations* , *revegetation* , *stubble mulching*.

b2) *LAND MANAGEMENT* PRACTICES: using the land layout and soil management. These practices are used in addition to plant management practices, they involve some movement of soil, they are easy to recognise on airphotos by the layout of the land when the principle of *contour farming* is applied, they may reduce *erosion* effectively to very low levels. Examples: *contour tillage*, *contour strip cropping* , *minimum tillage*, land layout (for example Suwardjo & Sofijah Abujamin 1985).

b3) STRUCTURAL PRACTICES: using small construction works. This category of practices may be split into "land forming practices" using earth as material and other "small works" made of other materials. The practices are usually recommended only when more simple measures do not suffice; moving soil is involved, often by *cut and fill*; recognition on airphotos is not difficult because contour farming is involved; a very effective control of erosion can be achieved.
As in the case of land management practices, if retention of runoff takes place, though the actual erosion hazard can be much reduced, the potential erosion hazard increases strongly, because on failing of the structures by overtopping, great damage may result. Examples are: *contour terraces/banks* , *gully filling*, constructed *flumes* (Hudson 1975).

c) Intercropping can be an effective practice. An example of a cropping system that reduces erosion hazard is the interseeding of grass or a legume affecting the growth and yield of corn (Baldwin 1989:473-480).

d) A parameter for the effect of practices is P of the USLE, being the ratio of erosion with and without practices.

| Practices | P-value (Lewis 1988) |
|---|---|
| cut-off trench | 0.25 |
| terrace | 0.25 |
| terrace with cut-off trench | 0.20 |
| mulching | 0.15 |
| mulching with cut-off trench | 0.15 |
| mulching and terrace | 0.15 |
| mulching, cut-off trench and terrace | 0.10 |
| Practices | P-value (Roose 1976) |
| Tied-ridging | 0.20 - 0.10 |
| Anti-erosive buffer strips from 2 to 4 metres wide | 0.30 - 0.10 |
| Curasol mulch (60 g/L/m2) | 0.50 - 0.20 |
| Reinforced ridges of earth, or low dry stone walls (ridge elevation 80 cm above channel) + tillage + cultivation and balanced fertilisation | 0.1 |

**soil conservation structure**, see soil conservation practice

**soil conservation terrace/bank**

- absorption terraces
- bench terraces
- broad-based terraces and narrow-based terraces
- colluviation terrace
- contour terraces
- Fanya-juu
- graded terraces
- retention terraces
- terrace spacing

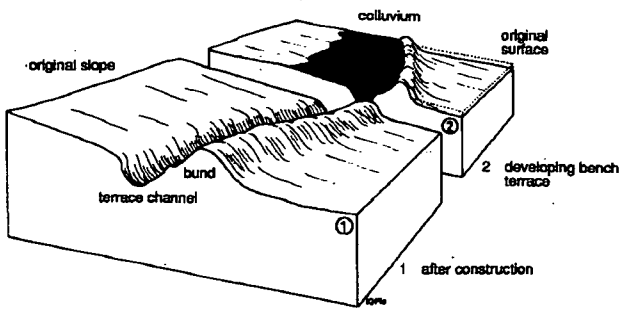
A constructed earth embankment, incorporating a channel on the upslope side, typically traversing a slope to control and/or prevent the erosion of that slope, by intercepting, diverting or storing runoff instead of permitting it to flow uninterruptedly down the slope.

a) The Australian concept of bank is: a longitudinal mound of soil running across a hill slope, as a fairly large bund, interrupting overland flow; a terrace involves restructuring of the whole hill slope, terraces together cover the hill slope as a series of wide level steps.

b) In situations when the plant and land manage-ment practices cannot be sufficiently effective, practices have to be considered that will modify the slope length and steepness, such as *bunds* and *furrows* (Hurni 1981:188) and terraces/banks.

c) Where rainfall is adequate, terrace banks can be used for *perennial* fodder grasses (Jackson 1981:540) or planted in fruit trees as an economic return from *land* that is otherwise lost for production.

Narrow base retention terrace



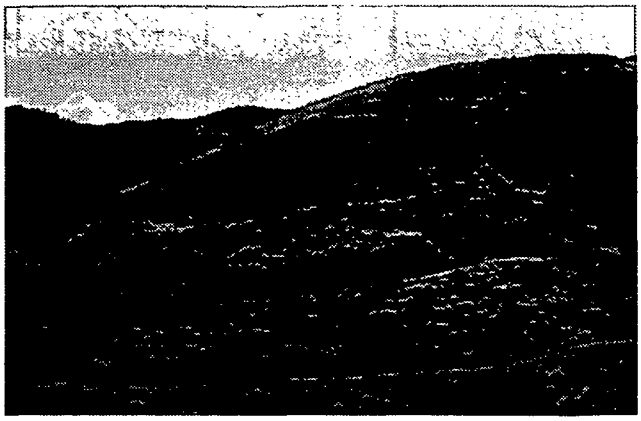
d) Terraces formed in loess at close intervals have a definite risk of *tunnel erosion* by *suffosion* (Pinczes a.o. 1981:100).

**soil consistence**
An expression of the resistance of the soil to deformation, under specified soil moisture conditions.
a) Specific conditions can be: dry, moist and wet (Suarez 1965:290). Terms used are respectively: loose, hard; *friable*, firm; sticky, plastic (Houghton & Charman 1986:116; Soil Survey Staff 1951:231).

**soil cover,** see also as Central Concept
Not included in list of terms:
- crop cover (focus on arable crops)
- ground cover (focus on low cover of the soil)
- land use cover (focus on human land use: arable, grazing)
- plant cover (focus on vegetative cover, planted or natural)
- vegetative cover (focus on plant cover plus *residues*)

Included in list of terms:
- basal cover (cover by plant stems just above soil surface)
- canopy (cover by plant and tree crowns)
- cover crop (cover by a low dense crop)
- folial cover (cover by leaves on plants and trees)
- mulch (cover by material on the ground)
- crop residue (crop remnants)
- soil cover = surface cover = ground cover

DEFINITIONS: There are definitions stressing vegetative aspects (A), stressing protection by cultivated plants against *erosion* (B) and others stres-sing cover of the soil surface by any material (C).
A) Vegetation cover or natural plant cover, from the ecological viewpoint:
All plants of all sizes and species found on an area, irrespective of whether they have forage or other value.
B) Crop cover or cultivated plant cover, from the conservation viewpoint:
The combined aerial and basal parts of plants, covering a proportion of the ground surface over a given area and providing protection against the impact of rain.
C) Basal cover, ground cover, surface cover, soil cover, from the conservation viewpoint:
A vegetative layer of grasses and/or other low-growing plants or plant residues providing protection to the soil against erosive agents.
A
a) Natural vegetation in the humid tropics, especially the evergreen forest, has a tremendous effect on soil formation. Even on very steep slopes and under highly erosive rainfall soil losses are minimal, and very deep soils are found (Bennema & de Meester 1981:83).



*Plant cover, Brazil (photo J. Bennema).*

B
a) Of all hazard factors the cover and cover management for conservation are the most important influence on the rain erosion hazard.
b) Cover is very effective against rain erosion, and even small amounts have a more than proportional effect (Wischmeier & Smith 1978; Shaxson 1981:389-390).
c) The term "aerial cover" used as distinct from *"basal cover"*, is somewhat misleading relative to airphoto-coverage; the term *folial cover*, or *canopy* cover may be more precise.
C
a) A good ground cover is an essential part of the majority of soil *conservation* programmes (Houghton & Charman 1986:63,82).
b) The plant cover close to the surface is the *basal cover*, in contrast to the *canopy* part or folial cover. The basal cover may include the effect of algae covering and binding the surface soil into a resistant crust.
c) The cover factor is the C-factor in the USLE, or similar parameter in erosion models.

**soil crust = (soil) surface crusting = capping ,** see also as Central Concept of Soil Crusting
- soil sealing
- hardsetting

A surface layer on soils, ranging in thickness from a few mm to perhaps as much as 3 cm, that is much more compact, hard and brittle, when dry, than the material immediately beneath it.
a) *Soil crusting* always implies a dried out soil (Houghton & Charman 1986:132).
b) It is often a sign of *actual land degradation* (Dudal 1981:5) caused by deteriorating conditions for plant *cover* and soil structure formation such as are brought about by overcropping, *overgrazing* or overtillage. It can be formed by one rain-shower.

c) For the Sahelian zone, Casenave & Valentin (1989:111) have recognised main types of crusts. They are:
   1) The desiccation crust.
   2) Structural crust, of sandy texture. of loamy or clayey texture
   3) Erosional crust, on material of the A-horizon on material of the B-horizon on a gravelly B-horizon
   4) Crust with coarse fraction
   5) Overland flow crust
   6) Decantation crust
   7) Wind deposit crust
   8) Salt efflorescence crust

   The types of crust are used to describe types of surface for a zone, which have (Casenave & Valentin (1989:127) different hydrological properties. This has implications for agricultural use and the occurrence of *overland flow* and *erosion* .

**soil degradation**
~ land degradation
Decline in soil qualities commonly caused through its improper use by man.
a) *Soil degradation* is one of the major problems confronting agriculture throughout the world. Deforestation, intense *cultivation* of vulnerable land, *overgrazing* , and poor soil and water management all reduce the productive capacity of soils and pose constraints to increased food, forage, and fuel production (Mohammed T. El-Ashry 1988:ix).
b) While *soil degradation* problems are widespread and could have significant impacts on the world's ability to meet future food demands, opportunities exist in both the technical and policy arenas for promoting better resource utilisation and *management* .
c) *Soil degradation* includes physical, chemical and/or biological deterioration Examples are loss of organic matter, decline in soil fertility, decline in structural condition, *erosion* , adverse changes in salinity , acidity or alkalinity, and the effects of toxic chemicals, pollutants or excessive flooding (Houghton & Charman 1986:116).

**soil detachability**
The susceptibility of a soil to the removal of transportable fragments by an erosive agent, such as rainfall, running water or wind.
a) It depends largely on soil texture and structure, and is an important component of *soil erodibility* (Houghton & Charman 1986:116).
b) It can be distinguished from the general availability of *erodible* material, which includes transportable, *erodible* particles that need not be detached to be *eroded* , for instance in loose sandy soils or certain finely structured tropical clay soils.

**soil detachment**
~ soil detachability
The removal of transportable fragments of soil material from a soil mass by an erosive agent, usually falling raindrops, running water, or wind.
a) Through detachment soil particles or aggregates are made ready for transport (Soil Cons.Soc.Am.1982:44).
b) On gentle slopes, in case of *interrill erosion* , detachment is mainly by *rainsplash* while trans-port is by *overland flow* . On steeper slopes, detach-ment is mainly by overland-flow (in *rills* ), while transport by *rainsplash* increases (Meyer 1981:32).
c) Detachment by *overland flow* without rain (*afterflow* ) is very sensitive to grain size, increasing as particle size decreases down to 0.25 mm. Particle cohesiveness increases as particle size decreases to silt and clay size, causing a decline in detachment rate. For short and gentle slopes detachment may increase with particle size (Quansah 1985:419-421). There may be a relationship with sealing, which is more permanent on more gentle slopes (pers.com. Mannaerts and Gabriels 1991).
d) A consolidated clay is virtually undetachable by flow. A newly tilled *soil* will be easily detached, regardless of the size of aggregates. Raindrops can dislodge a wide range of soil particles (Quansah 1985:419-421).
e) When *splash* is falling on thin *overland flow* , it increases the turbulence and thereby its *erosive* capacity. When falling on a water layer deeper than the drop diameter, *splash* becomes less effective (Bryan 1977).

**soil dispersion**
The process whereby soil structural elements break down in water and separate into their constituent particles of sand, clay and silt.

**soil erodibility,** see also as Central Concept
The influence of the soil profile, distinct from that of relief, on the rain erosion process, determined by the availability of material for erosion and the generation of overland flow volume from rain.
a) The rainfall supplies the water, but the soil profile determines how much *overland flow* is generated from a rain. The volume of *overland flow* , and the soil detachability determine the erodibility of the soil profile.
b) The potential *erosive* power of the *overland flow* will depend on the *relief* but the actual *erosive* power of the flow depends also on plant *basal cover* and *conservation practices* .
c) In the K-factor of the USLE the *permeability* of the profile is taken into account.
d) Soil erodibility may vary with the season and *management* .
e) In case of single processes, one can speak of: susceptibility to scour, susceptibility to detachment.

**soil erodibility classes**
Degrees of soil erodibility, sometimes defined by quantified ranges of values.
a) For examples see the Central Concept of Soil Erodibility.

**soil erodibility index**
Numerical value indicating the degree of a soil's erodibility.
a) Originally it was the name for the erodibility factor (K) in the *USLE*.
Later several other indices were developed.

**soil erodibility K-factor**
The soil erodibility index of the Universal Soil Loss Equation, USLE, is the amount of erosion per unit of rainfall erosivity measured from or adjusted to unit plot dimensions and conditions. See the Central Concept of Soil Erodibility.

**soil erodibility nomograph**
Diagram to find the soil erodibility factor K of the USLE, using five parameters. See the Central Concept of Soil Erodibility.

**soil erosion = accelerated rain erosion**
The detachment and movement of soil from the land surface by wind or water in conditions influenced by man.
a) It is the same as *accelerated erosion* , the name stresses the loss of soil as a *natural resource* for agriculture, and the influence of human activity as a causal factor.
b) Although a component of *natural erosion* , it becomes the dominant component of *accelerated erosion* as a result of human activities and includes the removal of chemical materials (Houghton & Charman 1986:48) such as nutrients attached to clay (see *enrichment ratio* ).
c) Nutrient loss is one of the factors which causes *productivity* decline when *erosion* occurs (Gachene 1989:34).

**soil erosion hazard,** see rain erosion hazard
The term gives an emphasis on loss of soil as a *natural resource* , and the influence of man as a causal factor.

**soil erosion susceptibility,** see rain erosion susceptibility

**soil erosion toposequence**
~ rain erosion features
A series of erosion features and corresponding deposition features, defined by type and intensity, occurring from the summit along the slopes down to the drainageway, when it occurs repeatedly along hills of similar shape and erosion conditions.
a) It is a useful concept for erosion mapping, prediction of erosion hazard, and for conservation planning (Bergsma 1974).
b) On aerial photographs it is apparent from the soil surface greytone showing mottles that extend along the contour (Bergsma 1974).

**soil horizon**
A layer of soil, approximately parallel to the land surface, with characteristics produced by soil-forming processes.

**soil layer**
A layer occurring in the soil profile which has characteristics produced by its deposition or weathering from a substratum, which differentiate it from the soil material above and below.

**soil life**
The period a soil can be used for production under present conditions of erosion.
a) It is calculated from the present soil depth minus a minimum depth, divided by the present *erosion* rate in mm soil loss per year.
b) Soil life depends not only on soil loss but also on the types of crops grown (Biot 1990).
c) In low rainfall areas it is important that a soil has sufficient *storage capacity* to accommodate local rainfall for the moisture requirements of the crop (Biot 1990).
d) There are obvious disadvantages to this simple approach:
- the present erosion rate in mm/yr is very difficult to assess unless experimental fields with comparable conditions are close to the site.
- the concept looks at soil as a disposable resource.
Food habits, markets, or other factors may change and cause new interest in deep soils because of desired *cultivation* of deep(deeper) rooting plants.
- off-site effects are not considered, which are often very costly.
e) The permitted soil loss calculated in such a way does not take into account an increase in cost of fertiliser, the exponential character of the *erosion* process, and limitations to the development of new seed varieties. It does not fit very well into the concept of *land husbandry*.
f) The suggestion that surplus soil should be allowed to be *eroded* must be given careful consideration, because most soils have a clear concentration of fertility and good structure in the top few centimetres (Hurni 1989:517, discussion).

**soil line**
The diagonal line in four-dimensional Landsat MSS signal space, describing maximum variations in soil

spectral response, has been named the soil line or soil brightness vector.

a) Kauth and Thomas (1976) and Kauth a.o. (1979), in studies of the distribution of soil spectra in four-dimensional Landsat MSS signal space, found most of the variability of bare soil signals to be attributed to *soil brightness* as nearly all spectral data fell along a line extending from the origin.
b) The emergence of green vegetation over a soil causes composite red radiance to decrease because of chlorophyll absorption, and overall infrared response to increase as a result of leaf mesophyll structure. Thus, deviations of spectral data from the bare soil line, in an appropriate direction, may be attributed to the presence of green biomass (Huete a.o. 1984).
c) The width of the soil line precluded *greenness* assessment below 25 % cover (Huete a.o. 1984).

**soil loss**
The amount of soil removed from a given area due to an erosion event in a given period and including mineral particles, organic matter and nutrients.

a) It is expressed in units of weight per unit of surface area, such as t/ha (Houghton & Charman 1986:118).
b) It does not account for soil that moves within the area, or that which moves onto the area from outside it (Houghton & Charman 1986:118).
c) Average values over even small catchments may be misleading, because of the local variation of erosion and on-site deposition.

**soil loss equation**, see Universal Soil Loss Equation

**soil loss plot**, see erosion plot

**soil loss tolerance**, see also as Central Concept
= **permissible soil loss**
~ actual land degradation
~ soil life
~ soil productivity
~ sustained use
~ vulnerability of productivity to erosion
~ yield sensitivity to erosion
The maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be obtained economically and indefinitely.

a) *Erosion* starts mostly as a slow process and is often unnoticed till it reaches a damaging intensity (National Committee), which is a strong argument for using soil loss tolerance values in land use planning.
b) Inclusion of a soil loss tolerance value in land use planning and policy is a matter of *land husbandry* (Shaxson 1981; McCormack and Young 1981; Stocking 1981).
c) Soil loss tolerance values may be determined relative to soil loss from the profile, affecting plant yield, or it may be determined relative to the silt production, affecting water quality or *sediment concentration* in dam lakes. (Mannering 1981:346; Smith & Stamey 1965)

**soil management**
The total of all tillage operations, cropping practices, fertiliser applications, liming and other treatments conducted on, or applied to, a soil for the production of plants.

**soil pan**
~ clay pan
~ duripan, see hardpan
~ plough-pan
A subsoil horizon or layer that is strongly compacted, indurated, or of very high clay content, and therefore relatively impermeable for water, air and plant roots.

a) Apart from the specified types of pan, cases exist of soil hardening and becoming compact after many cycles of wetting and drying, usually under poor vegetative *cover* .
b) Some pedogenetic processes lead to pan formation such as clay illuviation.
c) A fragipan has a high *bulk* density, a moderate to weak brittleness when moist, low content of organic matter, mottles, and consists of non-calcareous material. In a fragipan relatively high contents of aluminium play a role in the pan character (Soil Cons.Soc.Am. 1982:45).

**soil permeability**
The potential rate at which water (or air) may move through a soil, limited by the least permeable horizon or layer.

a) It depends largely on soil texture, soil structure, the presence of compacted or dense *soil horizons* or soil pans, and the size, distribution and stability of pores in the soil (Houghton & Charman 1986:120).
b) Rates vary widely in the field, from more than 3000 mm/day in sands and gravels, to less than 0.01 mm/day for some heavy plastic clays (Houghton & Charman 1986:120).
c) Large pores above a less permeable layer or horizon, but also coarse pores below a layer with finer porosity, may cause (temporal) stagnation of the *infiltration* at the interface (Baver 4th ed 343-345).

**soil productivity**
~ land productivity
~ vulnerability of productivity to erosion
~ yield sensitivity
The capacity of a soil in its normal environment to produce a specified plant or sequence of plants under a specified system of land management.

a) It is a function of the soil's chemical, physical and biological properties as well as climate, *management*

and other non-inherent factors used to produce crops (Renard & Follett 1985:692).

b) Under good *management*, maximum use is made of a soil's fertility status, whether natural or artificial, and physical properties such as available *water holding capacity*, *bulk* density and *permeability*.

c) *Erosion* on soils with unfavourable *subsoil* and substratum characteristics exhibit drastic reductions in productivity. On other soils, *erosion* does not rapidly damage the rooting medium and growth potential; they are not strongly affected, even though they are being *eroded* at high rates (Renard & Follett 1985:693).

d) Points that receive attention as indicators of soil productivity, and therefore have consequences for crop management and land management in the semi-arid tropics, are (Pathak, Singh & Sudi 1987:533-550): the poor crop stand due to :
   - crusting
   - rapid drying of surface soil
   - high soil temperature poor crop growth due to - unreliable soil moisture supply
   - low soil fertility
   - soil workability problems
   - compact *subsoil* layer
   - crusting,sealing and soil consolidation

**soil profile**

A vertical section of the soil from the surface through all its horizons, including the C horizon.

a) It includes all the genetic horizons, the natural organic layers on the surface, and the parent material or other layers beneath the solum that influence the genesis and behaviour of the soil (Soil Survey Staff 1951:173).

b) The soil forming factors are climate, topography, parent material, vegetation and land use, soil fauna, man and time. These factors are similar to those that determine rain erosion.

**soil scalping = desurfacing**

Accurate removal of the topsoil layer from a soil profile.

a) It is done during construction or excavation to preserve topsoil later to be spread over a new surface.

b) It is also done to simulate *erosion*, removing the topsoil or a soil surface horizon, as part of experiments relating *erosion* to *productivity* (Houghton & Charman 1986).

c) The mechanical removal of soil does not characterise completely the *erosion* process because there is no selective sorting of soil materials, which occurs in the *natural erosion* process, nor is there mixing of soil materials within the tillage zone. Well designed field experiments are possible within a limited range of field conditions (Renard & Follett 1985:695).

d) Desurfacing experiments on a Paleustalf are reported (Lal 1985:239,243). Maize yield is measured for 3 scalping depths and three levels of fertilisation. The yields on scalped soils are much lower than on the original sites, on all levels of fertilisation.

e) Scalping experiments on a Paleustoll in the Central Great Plains with sudangrass and rye showed recovery of *productivity* by fertiliser application (Grab & Smika 1985:326).

**soil sealing = (soil) surface sealing,** see also as Central Concept

~ soil crusting or surface crusting

~ liquefaction

The formation of a thin, dense, platy soil surface structure of fine soil particles under the influence of splash, slaking, swelling or sedimentation, which is relatively impermeable to water and air.

a) It results in a dense thin (about one mm to a few cm) laminar soil packing or thin platy *soil structure* reducing soil surface porosity. When dry it is more compact, hard and brittle than the material immediately beneath it (Soil Science Society of America 1978; Baver a.o.1972:219-220 ; Callebaut a.o. 1986).

b) Soils that are sensitive to sealing are silty and fine sandy soils, swelling clays and dispersible clays. Soils low in organic matter, clay fraction with reduced activity, high silt content, dominance of fine and flat particles in the sand fraction, combined or individually are the main factors inducing sealing (Pla Sentis 1981:136).

c) Unstable clods are flattened by *raindrop* impact and merge in a fluid state, indicating the start of *sealing* (de Ploey 1985:529).

d) Sealing soils often generate more *surface runoff*, and these soils have therefore a greater hazard for *rill erosion* (de Ploey 1981:149-150).

**soil slip**

A shallow landslip where the surface soil is displaced due to a marked change in shear strength between it and the subsoil.

a) Generally soil slips revegetate naturally with time, but they may become a serious problem on thin soils overlying bedrock.

**soil stabiliser**

~ soil conditioner

A substance or material added to soil to improve soil stability, strength or bearing capacity.

**soil strength**, see soil structural stability and shear strength

**soil structure**

~ soil aggregation

~ soil structural stability

The combination or arrangement of primary soil particles into compound elements which are separated from adjoining structural elements by surfaces of

weakness; the compound elements are called peds or aggregates.

a) The structural elements may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern (Baver a.o. 1972:131).
b) The individual elements may originate from natural processes or from human influence (Baver a.o. 1972:131).
c) The soil *aggregation* is caused by natural processes only. Tillage forms clods and causes *fragmentation* of natural *peds* .
d) The structural elements can be distinguished and classified on the basis of size, shape and degree of distinctness into classes, types and grades, respectively (Soil Cons.Soc.Am. 1982:159). Field description is based in addition on distinctness and durability of the visible *peds* (Baver a.o. 1972:131).
e) The size distribution of the aggregates as well as the amount and size distribution of the pore spaces between them and within the aggregates serve as our direct quantitative measure of *soil structure* (Baver a.o. 1972:131-132).
f) *Soil structure* is an important property with respect to the stability, porosity, and *infiltration* characteristics of the soil (Houghton & Charman 1986:122; Luk 1988).
g) Soil structure in arable land is strongly influenced by the tillage operations. When done at the right time, with respect to moisture content and weather, tillage may lead to favorable *soil structure* formation for cropping (Houghton & Charman 1986:120).

**soil structural stability**

~ soil aggregate stability

The resistance of the soil structural elements to the disintegrating influence of water and mechanical manipulation.

a) It is not exactly the same as *soil aggregate stability*, as not all soil structural elements are natural aggregates (Baver a.o. 1972:182).
b) Soil structural stability depends on the degree of cementation of flocculated particles of soil (Baver a.o. 1972:140) in which different substances may play a role such as: humus, sesquioxides, carbonate, and adsorbed ions.
c) It is related to *crusting* and *rainwash erosion* (Luk 1988).
d) It is strongly dependent on soil moisture content (Luk 1988).

**soil structure grade = soil structural strength, strength of structural expression.**

The degree and strength of soil aggregation, determined on moist soil.

a) The grades range from structureless, if there is no observable aggregation, to strong, where more than two-thirds of the soil is aggregated (Houghton & Charman 1986:122).

**soil surface roughness = surface roughness**

The degree of unevenness of the soil surface, related to surface depression storage and resistance to splash and overland flow.

a) It can be easily changed by man (Thornes 1981:267).
b) There is a link between *runoff*, roughness and macropore volume (Thornes 1981:267).
c) The irregular micro-topography of natural, or cultivated land surfaces may ensure that some fine *sediment* is retained, even in the longer term. It prevents the production of a sediment layer which is completely in equilibrium with the entrainment by *overland flow* (Rose a.o. 1988).
d) Roughness elements promote *runoff* by a concentration of rainwater, but opposite effects are the interception and dissipation of *rainfall energy* (de Ploey 1985:531)
e) A decrease of *erodibility* can be caused by a decrease in surface roughness, related to progressive crusting (de Ploey 1981:149).
f) An index of soil surface roughness for *rain storage* on the soil surface is the standard error among logarithms of surface elevations (Norton a.o. 1985:602).
g) The influence of roughness on flow is much greater than is generally appreciated from lab studies. Values of *Manning's* "n" are in the range of 0.2 to 0.5 (Morgan 1981:518).

**soil texture**

The relative proportions of the various size fractions of the mineral matter of a soil or soil horizon, generally expressed in terms of gravel, coarse sand, fine sand, silt and clay

a) By adjectives, the textural class may be modified to the coarse fraction, that is particles coarser than 2mm, when present in substantial amounts (Soil Cons.Soc.Am. 1982:161) such as: slightly gravelly, very stony.
b) Small amounts of coarse fraction on the surface of the land may slow overland flow and protect the soil against splash, resulting in a substantial reduction in soil erodibility (Soil Cons.Soc.Am. 1982:161).

**soil wash**

The proces of surface erosion by splash and over-land flow affecting over time the whole hill slope.

**solifluction**
A slow movement of soil material by gravity, in a saturated state, caused by a relatively impermeable or frozen *subsoil* and resulting in viscous flow.
a) Convolutions of the *soil horizons* and layers are characteristic.
b) In case thawing of frozen ground leads to the required conditions, the term gelifluction is equivalent (Selby 1985:226;405-408).

**sorptivity**
~ rainfall acceptance
The property of a soil surface to absorb water by suction as dominant force, before gravity becomes the dominant force and infiltration slows down and ponding starts.
a) It controls the early part of the infiltration process.
b) It varies with rain intensity and soil surface structure.
c) It is used in *overland* flow research.
d) It is measured by the amount of rainwater the soil can absorb before surface ponding occurs. The cumulative infiltration in the first 10-15 minutes plotted against the square root of time gives a straight line of which the slope is the index of sorptivity.

**spillway**
An open or enclosed channel, or a combination of both, used to convey excess water from a dam or reservoir, gully control structure or detention structure.
(Houghton & Charman 1986:123-124):
a) Location, design and construction of an adequate spillway is essential to prevent overtopping and possibly failure, and provide for safe water disposal without causing *soil erosion* .
b) Each spillway has an *inlet*, control and outlet section. The control section, which conveys the flows, is critical to the succes of the spillway, and must be able to deal with the discharge derived for the design *return period* (Houghton & Charman 1986:124).
c) It may contain gates, either manually or automatically controlled, to regulate the discharge of the excess water (Soil Cons.Soc.Am. 1982:165).
d) The "principal spillway" is the ungated spillway designed to convey the water from the retarding pool at release rates established for the structure.
e) The "emergency spillway" of a dam is the spillway designed to convey water in excess of that impounded for flood control or other beneficial purposes. It is to carry water safely through or around dams should the primary spillway fail to function properly or if larger *runoff* occurs than was assumed for the design of the primary spillway (Soil Cons.Soc.Am. 1982:165).
f) The "retarding pool" is the reservoir space allotted to the temporary impoundment of floodwater. Its upper limit is the elevation of the crest of the emergency spillway.
g) An earth spillway is an unvegetated open *channel* in earth materials.
h) A vegetated spillway is a vegetated open *channel* spillway constructed of earth materials.
i) A "ramp spillway" is a vegetated spillway constructed on the downstream face of an earth dam (also = "overshot spillway").

**splash,** see rainsplash

**splash erosion,** see rainsplash erosion

**sprigging**
The planting of portions of the stem and root of grass to enable a stable cover to establish itself rapidly.

**sprinkler irrigation**
Supply of additional water to growing plants by spraying the water in a rotating jet.
a) The supply rate can be adjusted so as to avoid runoff. This enables its use on slopes, for soils with moderate infiltration rates.

**stemflow**
Rainwater collected on the foliage of plants, flowing down the stem to the ground.
a) The concentration of stemflow water on very localised spots of the soil surface contributed irregularly to *erosion* (Wiersum 1985:83).
b) Stemflow concentrates rainwater at the internodal base (de Ploey 1985:532). In this way *overland flow* may occur at rain intensities well below the general rainfall *infiltration rates* .

**stocking rate**
~ grazing capacity
~ carrying capacity
The actual number of grazing animals expressed in either animal units or animal unit months, on a specified area at a specific time.
a) In Australia one tends to convert all stocking to "dry sheep equivalents" (d.s.e.) which results in: one milking cow = 10 d.s.e. and one dry cow = 8 d.s.e. (Houghton & Charman 1986).
b) The effect of *grazing* intensities is studied in Heathwaite a.o. (1990).

**stone mattress = gabion**
A rectangular wire mesh cage filled with rock, brick or similar material.
a) The components are usually assembled on site, securely tied together, and used in the construction of *retaining walls* and anti-erosion structures (Houghton & Charman 1986:60).

b) It can be constructed in inaccessible sites when local stones are available.
c) They are used for streambank protection. They are also used for *gully checkdams*. Water may flow through, but is slowed and loses its *scouring* power.
d) It is a flexible structure, with good drainage properties. It can bear unequal settlement.
e) Used tyres can be employed to protect the gabion against the full impact of large gravel and boulders (Ching-Hao Tuan 1987:1110).

**stoneline**
A thin layer at some depth below the soil surface, which will be exposed in a soil profile as a line, rich in coarse textured material, in contrast to the material above and below.
a) The coarse material is often left behind and accumulated from selective removal of fine constituents in an earth material, through the action of water and/or wind and/or selective dissolution, and is later covered by other earth material.
b) In some other cases the layer of gravel may result from *creep* downslope of an outcrop which contains resistant rock.
c) The coarse fragments are more often pebbles or cobbles than stones (Soil Cons.Soc.Am. 1982:168).

**storage capacity,** see rain storage capacity (in the soil profile)

**streambank erosion**
~ lateral erosion
The removal of soil from streambanks by the direct action of streamflow and/or wave action.
a) Typically occurs during periods of high flow (Houghton & Charman 1986:50).

**strength of soil structure,** see soil structure grade

**strip cropping**
~ contour strip cropping
Cultivation of crops in bands along the contour, alternating erosion prone with erosion resisting crops in the bands.
a) There are three variations of the system (Houghton & Charman 1986:129):
   - *contour strip cropping*
   Layout and tillage follow the *contour* and only very small deviations of strip boundaries from the exact *contour* are permissible.
   - Field strip cropping = Parallel strip cropping.
   Strips of uniform width are positioned across the general slope, but they may not exactly follow the *contour*.
   - buffer strip cropping
   Permanent pasture strips, often called contour *grass strips*, are utilised between contour planted strips of crops in rotation. Their function is to cause *runoff* to spread out and drop a large part of its suspended *sediment*.
b) The width of strips depends on height of vegetation and *soil erodibility* (Houghton & Charman 1986:129). They may range from 20 to about 110 metres.
   For practical *management* purposes, other factors are considered. This will usually produce a basic strip that is wider than the optimum for *erosion control*. The width is influenced by the following factors:
   - slope of the land
   - soil type and structural stability
   - rainfall intensity
   - management practice, width of farm machinery
   - type of crops
   - *slope length*
   - volume of *runon* entering the strip
   - previous *erosion* history

**stubble**
The basal portion of plants remaining standing or loose after the top portion has been harvested or has been grazed.
a) The straw *residue* that remains after a grain crop has been harvested. It includes standing straw and that which is discharged by the harvester (Houghton & Charman 1986:131).

**stubble mulching**
The practice of leaving stubble of crops or crop residues in place on the land providing a protective surface cover before and during the preparation of a new seedbed and at least partially during the growing of the succeeding crop.
a) It is used primarily to protect the soil against *erosion* but also to help conserve soil moisture (Houghton & Charman 1986:131) and create a favourable microclimate.

**subsoil**
The part of the soil profile below the topsoil.

**subsoiling**
Loosening the subsoil by deep ploughing, to break pans and improve drainage and aeration of the root zone for the plants.

**subsurface erosion,** see tunnel erosion

**subsurface flow**
~ interflow
~ seepage
~ throughflow
~ translatory flow
Water flow through the soil, usually close to and approximately parallel to the land surface.

**suffosion = subsurface eluviation:**
The vertical and lateral removal of fine soil particles by subsurface flow.
a) The distances and volumes of translocation were greater on hollows than on spurs (Embleton & Thornes 1979:193-194).

**surface aggregation ratio**
The ratio between the total surface area of particles larger than 0.05 mm diameter and the quantity of aggregated silt and clay.
a) A variation of Bouyoucos' idea of a ratio between the material bound and the material binding.
b) Aggregated silt and clay is obtained by subtracting dispersed silt and clay from total silt and clay. The surface area is obtained by considering particles as spheres of uniform density and assigning a number of mean diameters (Bryan 1969).
c) Bryan (1976) used the index as one of many in research of soil erodibility indices.

**surface cover,** see soil cover

**surface detention**
~ detention storage
~ retention storage
The depth of water temporarily held on the land surface while moving freely downslope, excluding channel storage.

**surface erosion**
Interrill erosion and rill erosion combined, as they remove a surface layer from the land
a) It stands in contrast to *linear erosion*, where concentrated flow follows linear paths, such as in *gullies*.



*Pattern and position of surface erosion on a convex-concave hillslope, Merida, Spain (photo E. Bergsma).*

**surface gravel**
~ gravel on the surface of the land.
a) It usually results from outwash of fines from a colluvial or alluvial *deposit*, or from an in situ soil profile developed on rock.
b) *Surface* gravel gives protection against *splash*, when otherwise the soil is bare. The effect is rated in Wischmeier & Smith (1978:19). The relation given there between relative *erosion* and *cover* is strongly hyperbolic.
Another, similar, relationship is reported by Figueroa & Valentin (1987). They found that *surface* gravel is more effective than plant material as a protective *mulch*. The gravel remains more firmly in position when slowing down *overland flow*, and the gravel causes less fine material to be available for *erosion*. A percentage of 50% *surface gravel* caused complete protection from *erosion*.
c) Compared to a bare soil, gravel on the soil surface allows a greater *infiltration*, a smaller volume and longer *time of concentration* of the *overland flow* (Poesen 1987).
Removing the fraction coarser than 13 mm caused a decrease in infiltration and an increase in overland flow; a further decrease in infiltration resulted after removal of the fraction coarser than 5 mm. A further removal of the fraction coarser than 2.4 mm did not have a significant effect on infiltration or runoff (Grant & Struchtemeyer 1959).
Surface gravel and stones reduce rainsplash, increase infiltration, make a positive contribution to surface roughness and thereby cause deposition of part of the eroding soil (Jung 1960).
d) When gravel is incorporated in a soil surface which is crusted, *infiltration* is slower and *overland flow* is increased (Poesen 1987; 1990).

e) The effect of *surface gravel* on *infiltration rates* and the production of *overland flow* is found to be directly proportional to the percentage of the gravel (Poesen 1990).
f) In extremely heavy downpours, in a semi-arid to arid environment, *surface* gravel increases *erosion* , because air is trapped below the gravel preventing *infiltration* and *storage* . Therefore the *overland flow* volume increases and soil loss is greater.

**surface ponding**
- rainfall acceptance
- surface retention
- surface storage

Formation of small pools of rain water in excess of infiltration on the surface of the land.

**surface roughness**, see soil surface roughness, hydraulic roughness

**surface runoff**
Discharge of rainwater over the surface of the land.
a) Surface runoff is composed of *overland flow* (unconcentrated) and gully flow (concentrated).

**surface sealing**, see soil sealing

**surface storage = depression storage**
- channel storage
- depression storage
- detention storage
- retention storage

The combined volume of storage of water in basins and depressions on the land surface and the volume of water that flows down the channels of the drainage system of an area at a certain moment.

**surface wash**
The effect of overland flow on the whole of a hillside.
a) It includes processes of unconcentrated and concentrated flow (Carson & Kirkby 1972:190).

**suspension**
The floating of dispersed particles in a medium like water.
a) The particle movement keeps the particles dispersed in water or air by fluid motion in currents, by turbulence and/or by molecular motion of the surrounding medium (Houghton & Charman 1986:132).
b) It is one of the states of particle transport of *eroded sediments* , especially for the smaller and lighter particles such as clay.

**sustained use**
Continuing use of land which restricts land degradation to an insignificant level.
a) The subject of raising and sustaining productivity of smallholder farming systems in the tropics is discussed in Beets (1990:40-41).

**talud = colluviation step = graften** (name used in the Netherlands)
A short steep slope formed gradually at the downslope margin of a field by deposition at the upslope side of a hedge, a stonewall, a grass strip, or other similar barrier.

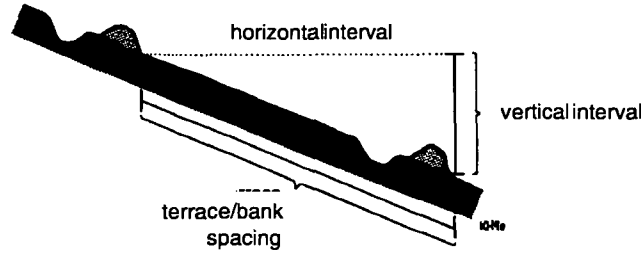
**terrace/bank**, see soil conservation terraces

**terrace/bank interval**
- terrace spacing

The distance, measured either vertically or horizontally, between corresponding points on two adjacent terraces.
a) The terrace intervals for *grass strip* or contour bund terraces have been investigated in Indonesia by Suwardjo a.o.(1987).
b) Several formulas relate spacing to slope, soil and climate (Kirkby & Morgan 1980:264).

**terrace/bank spacing**
- terrace interval

The actual distance along the ground between adjacent soil conservation terraces/banks.




**terracettes**
- solifluction steps

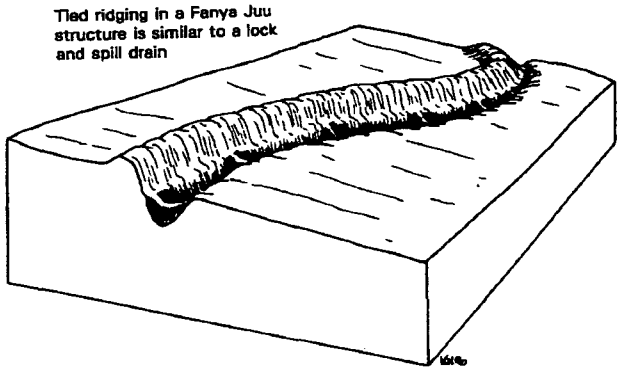
Ledges of earth on steep hillsides, varying from about 10 cm to 1.5 m in height and averaging 0.5 - 1 m in width, formed as a result of the development of slippage planes in, and subsequent slumping of, the soil or mantle.
a) They are slightly rotated, narrow strips, occurring on a shallow instable layer of soil, a type of micro-slumping (Cotton 1957:8).
b) Normal sheep track patterns afford no indication that their formation has led to any appreciable slumping. Naturally, terracettes, where they occur, are used also as paths by animals (Cotton 1957:8, 15-17).

c) The slippage planes develop under conditions of partial saturation of the soil mantle, leading to solifluction processes. This will be restricted when plant roots, reaching a stable substratum, can stabilise the soil; nor will it happen in well drained sites.

**throughfall**
Precipitation falling unhindered through the crowns of forest vegetation or any plant canopy.
a) It excludes *drip*.

**throughflow**
~ interflow
~ seepage
~ subsurface flow
~ translatory flow
A type of subsurface flow which is lateral and occurs in the aeration zone of the soil.

**tied ridging = tied furrows**
Placing bunds or ridges along the contour, connected at intervals by ridges along the slope.
a) It is done to reduce *runoff* and increase *infiltration* and water storage compared to open *ridging* or flat planting (Hulugalle 1989:693).
b) Its aim is to reduce the risk of overtopping of contour ridges by avoiding lateral accumulation of *surface storage* ; also achieves *water conservation* through increased *infiltration*.
c) In West Africa it can be a very effective technique against soil loss (Roose 1976:70). In southern Africa (Nyamudeza 1990) tied furrows are used for water conservation. The use increases and stabilises yield. Row width is an important parameter.
d) The system may be constructed by special machine.




**tile drain**
~ drainmole drain
A lined sub-surface drain formed by placing a pipe along the bottom of an excavated trench and covering it with soil.

**time of concentration**
The shortest time necessary for all points on a *catchment* to contribute simultaneously to flow past a specified point.
a) It is equivalent to the time required for *runoff* to flow from the most remote part of the *catchment* to the specified point, normally the *catchment* outlet (Houghton & Charman 1986:135).
b) The time of concentration is used to calculate the peak discharge for a *catchment* by using the *rational formula* . This formula assumes that the peak discharge will be caused by a storm of duration equal to the time of concentration for the *catchment* (Houghton & Charman 1986:135).

**time to ponding**
The period from the beginning of a rainfall to the moment rain starts forming ponds on the soil surface at a particular site.

**time to runoff**
The period from the beginning of a rainfall to the moment when overland flow occurs or gully flow starts.
a) It is related to the rainfall intensity, *antecedent* moisture, stone and gravel *cover* , tufted grass *cover* , slope steepness, *sealing* and *liquefaction* of the topsoil (de Ploey 1985:535-537).
b) It is also called "runoff threshold time" (de Ploey 1985:535-537).

**tolerable soil loss**, see soil loss tolerance

**topographic factor (of erosion)**, see relief factor

**topsoil**
A general term for the upper part of the soil, often richer in organic matter and of better soil structure, where most plant roots are concentrated.
a) Properties of the topsoil generally determine the value of the soil for growing plants in agriculture. For forestry deeper soil layers are also important.

**topsoil saturation overland flow = return overland flow**, see also Central Concept of Overland Flow
~ overland flow
Overland flow due to the semi-saturation of a permeable topsoil above a relatively impermeable subsoil.
a) It occurs especially in topographic positions of hollows and concave slopes (Gregory a.o. 1973; Zaslavski a.o. 1981).
b) It is supplied by *translatory flow* , the lateral flow in the topsoil occurring by displacement of stored water by water added from later rainshowers.

c) Saturated areas on draining hillslopes (O'Loughlin 1981) are located in relation to the transmissivity of the soils, the hillslope gradient and its wetness state, which are reflected by the base flow discharge from the *catchment*.
The width of the saturated zones depends strongly on the flow line pattern, being diverging or converging. Hill slope gradient is of dominant importance, probably also because the downslope form is of great influence on the moisture status of a soil (Zaslavsky (1981).
In drier conditions a plane slope *seepage* zone may shrink back to the stream edge while the convergence wet zone tends to persist. An undulating hillslope with several minor re-entrant zones can be expected to display more *runoff* contributing areas in dry conditions than a plane hill-slope with the same soil and the same mean gra-dient towards the stream (O'Loughlin 1981:241).
In deep well-structured soils the transmissivity may converge to a value large enough to preclude the occurrence of any *seepage* zone at all (O'Loughlin 1981:242).
On plane hillslopes the relative size of the contributing areas varies (O'Loughlin 1981) in approximate proportion to q/Msq.K where
q = streamflow prior to rain
Msq = (gradient)square
K = saturated hydraulic conductivity.

d) The depth of the relative permeable top part of the soil profile will be of great influence for transmission as well as for *storage*. It sometimes is called the *hydrologic depth*.

**topsoiling**

Application of topsoil to exposed or eroded areas, or to subsoil exposed by erosion or excavation such as in the case of cut-and-fill.

a) The purpose is to assist stabilisation with vegetation.

**torrential**

The type of flow of a stream where water is fully turbulent and has great velocity.

**tracers**

Easily detectable material which may be added in small quantities to flowing surface water or groundwater to depict the path lines or to serve in the measurement of characteristics of flow. e.g. velocity, transit times, age, dilution, etc. (UNESCO 1992:312).

a) Caesium-137,

a1) *Deposition* of Cs-137 from atmospheric testing of thermonuclear weapons between 1950 and 1970 was global. On a national scale the amount appears to be related to the amount of precipita-tion. At field level the deposition appears to be rather uniform.

a2) Cs-137 is strongly bound to clay minerals (Staunton 1994; Forsyth 1994).

a3) An overview of applications of the methods is in Walling & Quine (1990). A case study is discussed in Loughran a.o. (1990).

a4) After 1970 Cs-137 fallout ceased, therefore freshly exposed surfaces, like gully floors, have natural quantities of radionuclides (Be-7) but no Cs-137 (Caitcheon a.o. 1992).

b) Radium-226 and Thorium-232 are natural radionuclides. They vary in relative abundance at a scale of hectares. In small catchments this allowes to characterise the source area of a certain sediment (Caitcheon a.o. 1992).

c) Beryllium-7 and Caesium-137.

c1)The first does not penetrate deeper than about 10 mm, while Cs-137 is present to depth of 200 mm. This allowes to distinguish between sediments derived from the immediate surface from those derived from deeper in the profile (Caitcheon a.o. 1992).

c2) Cs-137 in the soil is the result of fallout from nuclear testing from about 1955 - 1970. This allowes to date sediments deposited in this period and later (Caitcheon a.o. 1992).

d) The ratio of two stable oxygen isotopes O-18/O-16 can be used for distinguishing biological and mineral origin of for instance phosphates (Caitcheon a.o. 1992).

**tractive force**

The force which mobilises and entrains particles in flowing water.

**translatory flow = replacement flow**

- interflow
- seepage
- subsurface flow
- throughflow

Subsurface flow or throughflow, where antecedent water is replaced by a new supply of subsurface flow for instance from recent rain.

a) Occurs in the saturated zone of soils on slopes (Derbyshire a.o. 1979:57).

**transport capacity**

The ability of runoff to carry sediment from one point to another.

a) The load carried by concentrated *overland flow* depends on the *sediment* size, shape and density; the flow amount, velocity and turbulence; and the *channel* cross-section, steepness, and *hydraulic roughness* (Meyer 1981:34).

b) For *overland flow*, the transport capacity is increased by *splash* on the flow because it increases turbulence. When falling on a water layer deeper than the drop diameter, *splash* becomes less effective (Renard 1977).

c) *Sediment* transport by *overland flow* depends on volume, transport capacity and *sediment concentration* (Renard 1977:32). The discharge by *overland flow* depends on:
- hydraulic properties of flow
- physical properties of the soil
- surface characteristics of the *land*

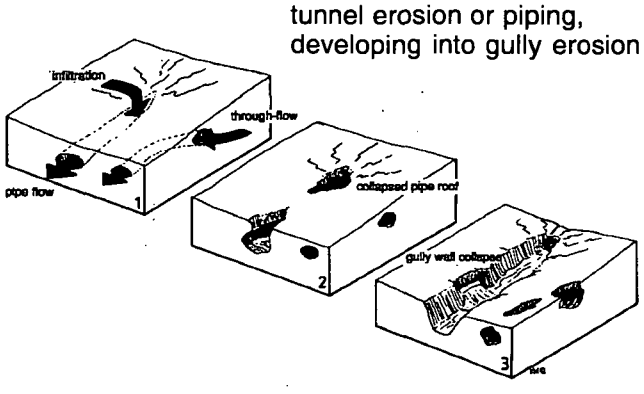
**trickle flow**
The extended low flow which occurs in many catchments following major runoff events.
a) In some *catchments* such flows may be sustained by groundwater *seepage*. This is known as *baseflow*.
b) Control of trickle flows in earthen structures is most important to prevent the killing of vegetation and the consequent *erosion* along and below their *spillways*. Control is normally achieved by the use of *trickle* pipes (Houghton & Charman 1986:138) or linings of concrete or rock material.

**trickle irrigation,** see drip irrigation

**trickle pipe**
A small diameter pipe inserted through the wall of a ponding structure to accomodate trickle flows.

**truncation,** see decapitation

**tunnel erosion = piping = tunnel scour**
The formation of natural pipes in soil or other unconsolidated deposits by eluviation or other processes of differential *subsurface erosion.*
a) The process proceeds as follows: water seeps into dry soil causing dispersion and/or *slaking* of soil particles into *suspension* . The dispersed soil is removed by *seepage* , until the *seepage* path takes the form of a tunnel. The tunnel normally collapses in due course and a *gully* is formed (Houghton & Charman 1986:50).
b) The soils involved are normally highly dispersible (Houghton & Charman 1986:50; Thornes 1980:153).



tunnel erosion or piping, developing into gully erosion

c) In Australia one tends to associate the term piping with tunnel erosion in earthworks, piping = earthwork tunnelling (Houghton & Charman 1986:46).
d) It includes the effects of *tunnel scour* , seepage weathering, and seepage induced transport (Howard & McLane III 1988).

**turbulent flow**
A type of flow in which the water particles move downstream in eddies.
a) It is common in open *conduits* , and in *rainwash* and *rill* flow (Hooghart 1986).
b) The water is agitated by cross currents and eddies (Soil Cons.Soc.Am. 1982:179).
c) Fluctuations of velocity in turbulent flow increase from the surface downwards. The flow is more irregular near the bed (Embleton & Thornes 1979:42).
d) A type of flow that is somewhat independent of the viscosity of the liquid. (Hooghart 1986).
e) The relative intensity of turbulence depends on the *roughness* of the bed and the *Reynold's number* (Embleton & Thornes 1979:42).
f) The *Reynold's number* , equal to velocity x hydraulic radius divided by kinematic viscosity, would be higher than about 2000 (Hooghart 1986).

**tunnel scour,** see tunnel erosion

**two stage approach of land evaluation**
~ land evaluation
A land evaluation methodology in which a first approximation of land suitability is made on the basis of physical criteria, and in which economic and social analysis is carried out as a second stage on the land-use alternatives which appear most promising on the basis of physical evaluation.

**undercutting**
Streamflow removing material by scour at the base of a slope.
a) It is a cause of base failure of slopes.

**undersowing**
The procedure whereby two sowings are made in one seedbed either at the same time, or more usually one after the other.
a) The technique is typically used to sow a pasture mixture under a cereal crop and ensures that, given adequate seasonal conditions, the grass is fully established by the time the cereal is harvested. This gives advantages in time saving, *grazingmanagement* and *erosion control* (Houghton & Charman 1986:139).

b) The concept is also used in the growing of two row crops which are sown and mature at different times, thus ensuring maximum plant *cover* and soil protection for the greater part of the year (Houghton & Charman 1986:139).

**urbanisation**
The expanding use of land for concentrated human habitation.
a) It introduces streets, sidewalks, driveways, parking lots, and other impervious areas. These directly increase *runoff* volumes and stream velocities (Stratton 1985:395).
b) It has an associated effect on groundwater and vegetation (Stratton 1985:395).
c) Poor control of water discharging from pipe *outlets*, and poor lot grading lead to increased *interrill*, *rill-* and *gully erosion* (Stratton 1985:395).

**Universal Soil Loss Equation,** abbreviation USLE
An erosion equation designed to compute long term average soil losses from interrill and rill erosion under specified conditions, developed mainly from data of the eastern USA.
a) The application of the equation is meant for certain conditions, and care has to be taken to fulfil these conditions (Peterson & Swan 1979)
b) It is also useful for construction sites and other non-agricultural conditions, but its does not predict *deposition* and does not compute *sediment yields* from *gully-*, *streambank* -, and streambed erosion (Wischmeier & Smith 1978, abstract).
c) When the predicted losses are compared with given *soil loss tolerances*, they provide specific guidelines for effecting *erosion control* within specified limits (Wischmeier & Smith 1978, abstract).
d) It is meant to be universal in that the *factors* used are responsible for *accelerated erosion* universally.
e) Use of the USLE may lead to large errors unless the values proposed for the United States are confirmed by measurements before they are applied in other countries (Bolline 1985:213).
f) Because of its clarity it is widely used in education and research as a starting point in developing understanding of *erosion hazard* prediction.
g) The equation groups the many influences on the *erosion* process into five categories:
   - climate
   - relief
   - soil profile
   - vegetation and *land use*
   - land management practices, including *conservation practices*, such as contouring and terracing.

   These five groups of influences, the well known erosion *factors*, are each characterised by a value in the equation. The product of these five values gives the expected soil loss in tons per acre or tonnes per hectare depending on the units used in the climate and soil factor. The other *factors* are dimensionless ratios that compare the studied situation with a standard reference situation (Wischmeier & Smith 1978; Meyer 1981:31).
g) The USLE is: A=RLSKCP, wherein
   - A is the average annual soil loss in tons per acre or tonnes per hectare per year
   - R is the *rain erosivity* factor.
   - S is the percent slope
   - L is the *length* of slope
   - K is the *soil-erodibility* factor
   - C is the *cover* and management factor
   - P is the conservation practices factor
   (Soil Cons.Soc.Am. 1982:181; Houghton & Charman 1986:118).

**USLE**, see Universal Soil Loss Equation

**vertical interval**
The vertical distance from one soil conservation structure to another.

**vulnerability of productivity to erosion**
The rate of productivity decline on a certain soil per unit of erosion.
~ yield sensitivity
(Pierce a.o.1983):
a) It is expressed as the relative loss in benefit minus cost caused by a unit of *erosion*, for instance 1 cm soil loss.
b) It is considered for a certain time horizon, for instance 25 or 100 years.
c) It gives a correction on the ranking of *erosion hazard* above soil loss *tolerance*, as a basis for a soil's priority for *conservation*. Soils with shallow unsuitable layers will have a high vulnerability, and therefore qualify for high priority of *conservation input*.
d) Data on corn yield illustrate the concept of yield sensitivity and vulnerability of productivity (Kohnke & Bertrand 1959):

| Depth of A horizon | Yield of corn (bushels/acre) | | | Yield sensitivity: yield decline per 10 cm decapitation of A hor. | | | Vulnerability: % yield decline | | |
|---|---|---|---|---|---|---|---|---|---|
| | Soil 1 | 2 | 3 | Soil 1 | 2 | 3 | Soil 1 | 2 | 3 |
| 30 cm | 120 | 90 | - | | | | | | |
| | | | | 25 | 15 | - | 21 | 17 | - |
| 20 cm | 95 | 75 | 50 | | | | | | |
| | | | | 25 | 20 | 15 | 26 | 13 | 30! |
| 10 cm | 70 | 65 | 35 | | | | | | |

- = does not occur

It appears that on soil 1 the yield sensitivity is highest, but on soil 3 the relative yield decline is greatest. If the soils would correlate with different farmers then soil conservation would be most urgent in case with soil 3.

When such data are used, a distinction is important between natural soils of various depth, sites of different annual soil loss on one soil, and scalped soils.

**Wamatengo pit**
~ microbasin
Shallow pits, with a radius of about 2 metres, circu-lar or semi-circular in shape, dug to trap runoff and silt for maize cropping (Mututho 1989:318-319).
a) Such pits offer a new approach to reclaiming badly denuded sites on *grazing lands*
b) They are most effective when proper *grazing management* is executed.
c) They prove to be superior to conventional terracing on *grazing land*.
d) Drawings of the structure are presented by Mututho (1989:319).

**wash**
~ rainwash slope wash
~ braidwash surface wash
~ gully wash
Rain erosion affecting the whole of a hillslope by the change in place of the processes over time.

**water conservation**
The physical control, management and use of water resources in such a way as to supply crop, grazing, and forest lands; vegetal cover; wildlife; and wildlife habitat for maximum sustained benefits to people, agriculture, industry, commerce and other segments of the national economy.

**water detention,** see surface detention

**water harvesting**
Collecting water from water retention and diversion practices for supply to cultivated plants, animals and drinking water storage tanks, applied in areas with limited and uncertain rainfall.
a) A discussion of the practice is in Rapp & Hasteen-Dahlin (1990).

**water-holding capacity,** see field capacity

**water-spreading**
Diverting runoff from natural channels or gullies by means of a system of dams, dykes or ditches and spreading it over relatively flat areas to improve natural vegetative cover and/or to allow pasture or crop production, while reducing the risk of erosion.

**water stable aggregates**
Soil aggregates which are stable to the action of water such as falling drops, or agitation as in the wet sieving analysis.

**water stable aggregation**
The degree to which different size fractions of aggregates resist breaking up by agitation in water as in the wet-sieving procedure.
a) The degree of water-stable aggregation is used as a general indicator of *soil erodibility*. However, the procedure is not widely accepted because of problems of standardisation and paucity of clear evidence relating it objectively to a soil's susceptibility to erosion (Houghton & Charman 1986:142).

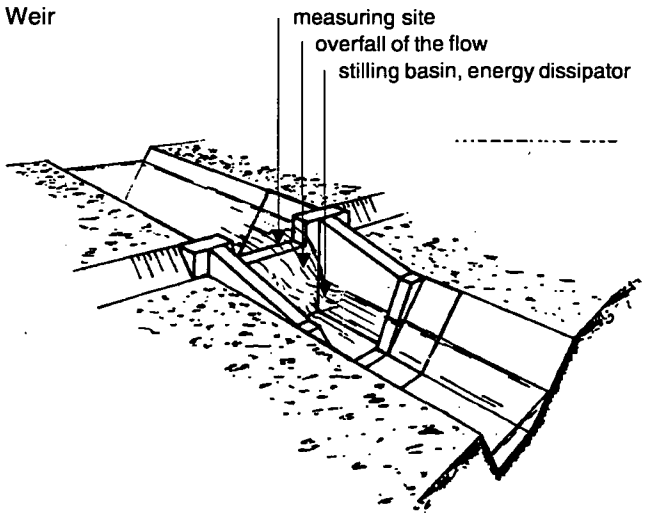
**watershed = catchment, catchment area**
~ drainage divide
The area which supplies water by surface and subsurface flow from rain to a given point in the drainage system.
a) In Australia the term used is: *catchment* divide (Houghton & Charman 1986).

**watershed management**
Use, regulation and treatment of water and land re-sources of a watershed to accomplish stated objectives.
a) Extensive experience with *conservation* results in recognition of certain principles to be observed in *conservation planning* (Moldenhauer & Hudson 1988:60-62, 275-279; Shaxson et al. 1989:20-23).
These watershed management principles include (Moldenhauer & Hudson 1988):
a1) Planning must be long term, at least 10 years.
a2) Have flexibility in planning and execution.
a3) Include the farmers in all stages.
a4) Consider *conservation* together with production, not separately.
a5) Structural measures should be used to comple-ment biological *conservation measures*, not to replace them.
a6) Short term benefits are essential to the farmer's interest.
a7) Successful projects result in minimised risks, in-creased income, more reliable yields, reduced *inputs* and/or reduced drudgery of farm life.
a8) Practices should fit easily into the prevailing *farming systems* and be within the physical and managerial abilities of the farm families.
a9) Expand gradually.
a10) Use local people and skills.
a11) Keep a record of progress versus planning, and evaluate situation regularly.
a12) Maintenance of measures and practices is essential.
a13) Follow-up and re-appraisal are very desirable. Provide for assistance by government, non government, or volunteer organisations after the project has ended or the project money runs out. (Moldenhauer & Hudson 1988; Shaxson a.o.1989).

b) A case study in Indonesia distinguishes certain desirable aspects of a watershed project (Barrau & Ketut Djati 1985:738):
- agricultural research
- model farms
- nurseries
- access roads
- extension and training
- consultants

**waterway**
A natural or constructed drainage channel of sufficient capacity to discharge surplus runoff without causing erosion.
a) It is often laid along the steepest slope (Hurni 1986:78).

**weir**
A structure or wall built across a flowline to allow diversion or measurement of discharge rate.




**WEPP = Water Erosion Prediction Programme**
A model simulating the main processes that impact soil erosion by water, runoff being one of the more important ones.
a) Model parameters can be determined by a simplification based on the emperical relationships with readily measurable soil and vegetation characteristics.
This allows for instance to simulate the impact of vegetation change to rangeland water cycles (Wilcox a.o. 1992).

**wet sieving - wet sieving analysis,** abbreviation WSA
~ dry sieving
Standardised sieving of dry or prewetted soil structural elements under water, to determine the water-stable aggregate fractions of the soil
a) Water-stable aggregation is measured by the percentage weight of aggregates retained on sieves, after 20 minutes of sieving under water at 60 cycles per minute (with a certain amplitude) (Bryan 1977:63,69).
b) The size fraction most effective in prediction of soil loss is the WSA > 0.5mm (Bryan 1977; Bryan 1969).

**Wischmeier equation,** see Universal Soil Loss Equation

**yield sensitivity to erosion**
~ vulnerability of productivity to erosion
The reduction in yield caused by erosion of a unit depth of soil, for instance 1 cm soil loss.

**zero tillage,** see no-tillage

**zone tillage**
The system of tilling the soil, whereby untouched strips or zones (including row crops) alternate with tilled zones for rain acceptance and water conservation.

ALPHABETICAL LIST OF TERMS AND THEIR EQUIVALENT IN SPANISH, FRENCH AND GERMAN

The following is an alphabetical list of the terms that are included in the list of definitions and descriptive aspects.

Terms of equipment for laboratory and field investigations and for management of soils are not included.

Terms that are also discussed as Central Concepts are printed BOLD.

| English | S = Spanish equivalent<br>F = French equivalent<br>G = German equivalent |
|---|---|

## A

| | | |
|---|---|---|
| absorption bank/terrace | S: | bancal de absorpción |
| | F: | terrasse d'absorption |
| | G: | Absorptions-Terrasse |
| accelerated erosion | S: | erosión acelerada |
| | F: | érosion accélérée |
| | G: | beschleunigte Erosion |
| actual land degradation | S: | degradación actual de la tierra |
| | F: | dégradation actuelle des terres |
| | G: | a: Landdegradation,<br>b: Verschlechterung |
| afforestation | S: | repoblación forestal |
| | F: | afforestation |
| | G: | Aufforstung |
| afterflow | S: | postflujo, flujo postpluvial |
| | F: | décrue |
| | G: | Restfluss (nach Ereignis) |
| aggregate, aggregation, see soil aggregate, aggregation | | |
| AGROFORESTRY | S: | agrosilvicultura, agroforesteria, silvoagricultura (la primera actividad es la dominante) |
| | F: | agroforesterie |
| | G: | Agroforstwirtschaft |
| airphoto interpretation terms: | | |
| - airphoto greytone/ graytone | S: | tono de gris aerofotografico |
| | F: | ton grisé d'une photo aérienne |
| | G: | Luftbild-Grauton |
| - airphoto greytone texture/ airphoto texture | S: | textura aerofotografica |
| | F: | texture du grisé de la photo aérienne |
| | G: | Luftbild-Grautontextur |
| - airphoto greytone structure | S: | estructura del tono de gris aerofotografico |
| | F: | structure du grisé de la photo aérienne |
| | G: | Luftbild-Grautonstruktur |
| - airphoto greytone mottle | S: | moteado de tono de gris aerofotografico |
| | F: | tache de grisé de la photo aérienne |
| | G: | Luftbild-Grautonfleck |
| - airphoto greytone pattern | S: | patron de tono de gris aerofotografico |
| | F: | dessin des grisés de la photo aérienne |
| | G: | Luftbild-Grautonmuster |
| - (airphoto) flow pattern | S: | patron (aerofotografico) de flujo |
| | F: | réseau de drainage naturel |
| | G: | Luftbild-Fliessmuster |

| | | |
|---|---|---|
| - airphoto stereothreshold | S: | umbral estereoscopico de photografias aereas |
| | F: | seuil de perception stéréoscopique |
| | G: | Luftbild-Stereogrenzwert |
| alley cropping | S: | cultivación en callejones arbustivos |
| | F: | culture en allée, (en bandes) |
| | G: | Anbau mit Buschreihen |
| alluvial fan | S: | abanico aluvial |
| | F: | cône d'alluvion |
| | G: | Fächer, Kegel |
| alluvium | S: | aluvión |
| | F: | alluvions |
| | G: | Alluvium |
| angle of repose | S: | angulo de reposo |
| | F: | angle de dépôt d'accumulation |
| | G: | kritischer Winkel |
| antecedent soil moisture content | S: | contenido de humedad prepluvial |
| | F: | pourcentage d'humidité prépluviale du sol |
| | G: | Ausgangsfeuchtegehalt |
| area closure | S: | cierre de terreno |
| | F: | mise en défens |
| | G: | Gebietsschliessung |
| arroyo | S: | arroyo, quebrada |
| | F: | oued |
| | G: | Arroyo, Schichtflut-Kanal |
| aspect of slope, see slope exposition | | |

## B

| | | |
|---|---|---|
| badland | S: | tierras malas |
| | F: | bad-lands |
| | G: | Oedland |
| bad spot (of erosion) | S: | punto critico (de erosión) |
| | F: | point critique (d'érosion) |
| | G: | Kritische Erosionsstelle |
| bank/terrace, see conservation terrace/bank | | |
| bare fallow | S: | barbecho limpio |
| | F: | jachère nue |
| | G: | Schwarzbracke |
| basal (plant) cover | S: | cobertura basal, tapiz vegetal |
| | F: | couverture de base, tapis végétal, recouvrement |
| | G: | Vegetationsbedeckung |
| baseflow | S: | flujo basal |
| | F: | débit de base, écoulement de base |
| | G: | Niedrigwasser-Abfluss |
| basic infiltration rate | S: | tasa de infiltración basica |
| | F: | indice d'infiltration de base |
| | G: | Infiltrations-Grundrate |
| basin | S: | cuenca / hoya (hidrografica) |
| | F: | bassin |
| | G: | Becken |
| basin listing | S: | hacer surcos de retención |
| | F: | basin lister: chaucée spéciale pour créer des retenues d'eau dans les sillons. |
| | G: | Kammerfurchenverfahren |
| basin terrace | S: | terraza con irrigación |
| | F: | terrasse en bassin |
| | G: | Beckenterrasse |

| | | |
|---|---|---|
| batter | S: | talud |
| | F: | talus |
| | G: | Böschung |
| bedload | S: | carga de lecho |
| | F: | charge de fond |
| | G: | Geschiebefracht |
| bench terrace | S: | bancal |
| | F: | terrasse en gradins |
| | G: | Bankterrasse |
| benefit cost ratio, see cost benefit analysis | | |
| berm | S: | banqueta |
| | F: | banquette |
| | G: | Kante |
| biomass | S: | biomasa |
| | F: | biomasse |
| | G: | Biomasse |
| block glide | S: | deslizamiento en de bloques |
| | F: | glissement en masse, en planche |
| | G: | kompakter Rutsch |
| box culvert, see culvert | S: | alcantarilla de caja |
| | F: | ponceau de section rectangulair |
| | G: | kastenförmiger Durchlass |
| box inlet drop spillway, see spillway | S: | vertedero con caja de entrada |
| | F: | déversoir avec cage d'entrée |
| | G: | kastenförmiger Schacht Überfall |
| braid or braided rill | S: | trenza, surco anastomosado |
| | F: | rigole anastomosée |
| | G: | verflechtende Rillen |
| braidwash | S: | lavamiento entrelazado/trenzado/anastomosado |
| | F: | érosion pluviale en nappe par des rigoles anastomosées |
| | G: | Rinnenspülung |
| broad base bank/terrace | S: | terraza de base ancha |
| | F: | terrasse à base large |
| | G: | geneigte Terrasse mit breitem, gewölbtem Damm |
| buffer strip | S: | banda de amortiguamiento |
| | F: | bande tampon |
| | G: | Pufferstreifen |
| bulk density | S: | densidad aparente |
| | F: | densité apparente |
| | G: | Lagerungsdicke, Raumgewicht, Trockenraumdichte, Dichte des Bodens |
| bund | S: | camellon |
| | F: | diguette |
| | G: | Erdwall |

## C

| | | |
|---|---|---|
| C-factor, see USLE | | |
| Caesium-137 | S: | Caesium-137 |
| | F: | Caesium-137 |
| | G: | Caesium-137 |
| canopy | S: | dosel |
| | F: | couverture biologique |
| | G: | Baumkrone, Ueberdachung, Bodenbedeckung (durch stehende Pflanzen) |
| carrying capacity | S: | capacidad de carga |
| | F: | capacité de charge |
| | G: | Tragfähigkeit |

| | | |
|---|---|---|
| catchment | | |
| A = catchment area | S: | cuenca hidrografica /area receptora/ cuenca (de drenaje) /hoya |
| | F: | bassin versant, bassin de drainage |
| | G: | Einzugsgebiet, Wassereinzugsgebiet |
| B = conservation structure | S: | represa |
| | F: | retenue d'eau |
| | G: | Wasserrückhaltebecken |
| channel | S: | cauce, canal (artificial) |
| | F: | chenal, canal |
| | G: | Kanal, Wasserlauf, Gerinne, Flussbett |
| channel erosion | S: | erosión encauzada, erosión concentrada, erosión fluvial |
| | F: | érosion fluviale |
| | G: | Flusserosion, Kanalerosion |
| channel roughness, see also hydraulic roughness | S: | rugosidad del cauce |
| | F: | rugosité du chenal |
| | G: | Kanalrauhigkeit |
| checkdam, see gully checkdam | | |
| chute | S: | deslizadero |
| | F: | chute |
| | G: | Schussrinne, Sturzrinne |
| clay pan | S: | horizonte compacto arcilloso |
| | F: | clay pan |
| | G: | Tonpfanne (Ablagerung) |
| clean weeding = clean tillage | S: | escardillado |
| | F: | désherbage |
| | G: | jäten |
| clod | S: | terron |
| | F: | motte, grumeau |
| | G: | Erdklumpen |
| collar | S: | niple pasamuro |
| | F: | collier |
| | G: | Kragen |
| colluviation step | S: | escalon coluvial |
| | F: | colluvion en étage |
| | G: | kolluviale Stufe, Ackerterrasse |
| colluviation terrace | S: | terraza coluvial |
| | F: | terrasse colluviale, terrasse de colluvionnement, terrasse progressive |
| | G: | entwickelte Terrasse, Kolluvialterrasse |
| colluvium | S: | coluvión |
| | F: | colluvion ou colluvions |
| | G: | Kolluvium, Schnittkegel |
| compaction, see soil compaction | | |
| compound land utilisation type | S: | tipo compuesto de utilización de la tierra |
| | F: | type d'utilisation polyvalente des terres |
| | G: | gemischter Landnutzungstyp |
| conduit | S: | conducto |
| | F: | conduit |
| | G: | Leitung |
| conservation, of natural resources | S: | conservación, de recursos naturales |
| | F: | conservation, des resources naturelles |
| | G: | Konservierung natürlicher Ressourcen |
| conservation farming | S: | agricultura conservacionista |
| | F: | pratiques agricoles de conservation |
| | G: | konservierende Landwirtschaft |
| conservation planning, see soil conservation as Central Concept | | |
| conservation practice, see soil conservation practice | | |

conservation requirements
S: requerimientos de conservación
F: besoins de conservation
G: Konservierungsbedarf

conservation structure, see soil conservation practice

conservation tillage
S: labranza de conservación
F: labour en courbe de niveau
G: Konservierende Bodenbearbeitung

consistence, see soil consistence

consistency index, C5-10
S: indice de consistencia,
F: indice de consistance
G: Festigkeits-Index

consolidation
S: consolidación
F: consolidation
G: Konsolidierung

contour
S: contorno
F: courbe de niveau
G: Kontur, Höhenlinie

contour ditch
S: trincho de contorno
F: fossé, gradin en courbe de niveau
G: Konturgraben

contour farming
S: labranza en contorno
F: culture en courbe de niveau
G: Höhenlinienanbau, Quernutzung

contour furrow
S: zanjilla de contorno
F: sillon en courbe de niveau
G: Konturfurche, horizontale Furche

contour grass strip
S: bandas/franjas empastadas de contorno
F: bandes enherbées en courbe de niveau
G: Konturgrasstreifen, horizontale Grasstreifen

contour hedge
S: barrera viva en contorno
F: haie en courbe de niveau
G: horizontale Hecke

contour interval
S: intervalo de lineas de contorno
F: équidistance des courbes de niveau
G: Höhenlinien-Abstand

contour ploughing, see contour tillage

contour ridge
S: camellon en contorno
F: billon en courbe de niveau
G: horizontaler Kamm

contour ridging
S: camelleo en contorno
F: billonage en courbe de niveau
G: horizontales Kamm-Pflügen

contour stone row
S: linea de piedras en contorno
F: murette de pierres, alignement de pierres (en courbe de niveau)
G: horizontale Steinreihe

contour strip cropping
S: cultivo en bandas/franjas/fajas al contorno
F: cultures en bandes (en courbe de niveau)
G: Konturstreifenanbau, Querstreifenanbau, horizontaler Streifenanbau

contour terracing, see soil conservation terraces

contour tillage
S: arada en contorno, labranza en contorno
F: labour en courbe de niveau
G: Konturpflügen

controlled grazing
S: pastoreo controlado
F: pâturage contrôlé
G: kontrollierte Weidewirtschaft

| | | |
|---|---|---|
| Cook's method | S: | método Cook |
| | F: | méthode de Cook |
| | G: | Methode nach Cook |
| cost benefit analysis | S: | analisis de costos/beneficios |
| | F: | analyse du coût/bénéfice |
| | G: | Kosten-Nutzen-Analyse |
| cover, see SOIL COVER | | |
| cover crop | S: | cultivo de cubierta |
| | F: | plante/culture de couverture |
| | G: | Deckfrucht, Bodenbedecker |
| cover factor, see USLE | | |
| creep, or soil creep | S: | reptación |
| | F: | reptation |
| | G: | (Boden)kriechen |
| critical area | S: | area critica |
| | F: | surface critique |
| | G: | kritisches Gebiet |
| crop growth stages | S: | etapas de crecimiento de cultivos, en caso de grano:<br>- barbecho natural<br>- periodo de siembra<br>- establicemiento<br>- desarrollo<br>- maduración<br>- rastrojo |
| | F: | stades de végétation |
| | G: | Getreide-Wachstumsstufe |
| crop requirement | S: | requirimiento del cultivo |
| | F: | exigence de la culture |
| | G: | Standortanforderungen der Frucht |
| crop residue | S: | residuos de cosecha, de rastrojo, |
| | F: | résidus de culture, de récolte |
| | G: | Ernterückstand, Pflanzenrest |
| crop residue management | S: | manejo de rastrojos |
| | F: | utilisation des résidus de récolte |
| | G: | Ernterückstand-Bearbeitung |
| crop rotation | S: | rotación de cultivos |
| | F: | rotation des cultures |
| | G: | Fruchtwechsel, Fruchtfolge |
| cross grading | S: | gradación oblicua |
| | F: | gradation en travers |
| | G: | Quer-Abschrägen, -Ableiten |
| crumb | S: | miga, migajon |
| | F: | grumeau |
| | G: | Krume, Krümel |
| crusting, see soil crusting | | |
| cultivation | S: | cultivo |
| | F: | façon de cultiver |
| | G: | Anbau, Kultivierung |
| cultivation system | S: | sistema de cultivo |
| | F: | système cultural |
| | G: | Anbausystem |
| culvert | S: | alcantarilla |
| | F: | ponceau, passage couvert |
| | G: | Durchlass, Rohrdurchlass |
| cut | S: | corte |
| | F: | coupe |
| | G: | Anschnitt |

| | | |
|---|---|---|
| cut and carry | S: | corte y acarreo |
| | F: | enfourragement en vert |
| | G: | mähen und (heim) tragen |
| cut and fill | S: | corte y relleno |
| | F: | terrasser, déblayer et remblayer |
| | G: | Ab- und Auftrag, Anschnitt und Aufschüttung |
| cutoff | S: | interceptor |
| | F: | récepteur |
| | G: | Abzug |
| cutoff bank | S: | bancal de desviación |
| | F: | berge de déviation, de dérivation |
| | G: | Ableitungs-Wall |
| cutoff drain/ditch/ trench | S: | trincho de desviación |
| | F: | fossé de protection, fossé de ceinture |
| | G: | Abzugsgraben, Erosionsschutzgraben, Fangdräu |
| cutoff wall | S: | muro interceptor |
| | F: | mur récepteur |
| | G: | Abzugswall |

## D

| | | |
|---|---|---|
| dam | S: | presa |
| | F: | barrage, retenue, réservoir |
| | G: | Staudamm, Wehr |
| debris | S: | detritos, derrubio |
| | F: | débris, détritus |
| | G: | Geschiebe, Trümmergestein |
| decapitation = truncation | S: | decapitación, truncación |
| | F: | décapitation, troncature |
| | G: | Abschnitt |
| deep ploughing | S: | labranza profunda |
| | F: | labour profond |
| | G: | Tiefpflügen |
| degradation | S: | degradación |
| | F: | dégradation |
| | G: | Verschlechterung |
| delivery ratio, see sediment delivery ratio | | |
| denudation | S: | denudación |
| A: related to erosion | F: | dénudation |
| B: related to consequences of erosion | G: | Verödung, Denudation |
| deposition | S: | depositación |
| | F: | dépôt, alluvionnement |
| | G: | Ablagerung |
| depression storage = surface storage | S: | almacenaje en depresiónes |
| | F: | rétention superficielle (d'eau dans des dépressions) |
| | G: | Oberflächenspeicherung in Bodenvertiefungen |
| desaggregation | S: | desagregacion |
| | F: | désagrégation |
| | G: | Zersetzung |
| design capacity | S: | capacidad del diseño |
| | F: | capacité estimée |
| | G: | Entwurfskapazität |
| design life | S: | vida del diseño |
| | F: | durée estimée, durée de vie |
| | G: | Entwurfsspanne, Entwurflebensdauer |
| desilting area | S: | area de decantacion |
| | F: | surface de décantation |
| | G: | Sedimentations-Gebiet Sinkstoffablagerungsfläche |
| desurfacing, see soil scalping | | |

detachment, see soil detachment

detention, see detention storage

detention dam
S: presa de contencion
F: barrage de retenue
G: Rückhaltedamm

detention storage
S: almecenaje detenido
F: capacité de stockage
G: Rückhaltespeichervermögen Rückhaltekapazität

dike
S: dique
F: digue
G: Deich

discharge
S: descarga
F: débit
G: Abfluss

discharge point
S: punto de descarga
F: point de débit
G: Abfluss-(Mess)Punkt

dispersion
S: dispersion
F: dispersion
G: Dispersion

dispersion ratio
S: relacion de dispersion
F: rapport de dispersion
G: Dispersions-Koeffizient

diversion
S: desviacion
F: diversion
G: Umleitung

diversion bank, see diversion drain/ditch/channel

diversion dam
S: presa de desviacion
F: barrage de dérivation
G: Ableitungsdamm

diversion ditch/channel
S: canal de desviacion
F: fossé de dérivation
G: Ableitungskanal

diversion terrace
see also diversion ditch/channel
S: terraza de desviacion
F: terrace de diversion
G: Ableitungsterrasse

divide, see drainage divide

double cropping
S: cultivos dobles intercalados
F: cultures associées, culture double
G: Doppelanbau

double furrow
S: doble surco
F: double sillon
G: Zweifachfurche

drain
S: caño, dren
F: drain
G: Drainage

drainage basin, see catchment
= watershed
= drainage area
= catchment or catchment area

drainage divide
S: divisoria de aguas
F: crète ou ligne de partage des eaux
G: Einzugsgebietsgrenze, Wasserscheide

drainageway
S: acequia, vaguada, cañada
F: tälweg
G: Entwässerungsweg

| | | |
|---|---|---|
| drip | S: | goteo |
| | F: | égouttement |
| | G: | Abtropfen |
| drip irrigation = trickle irrigation | S: | riego por goteo |
| | F: | irrigation goutte à goutte |
| | G: | Tropfen-Bewässerung |
| drop inlet | S: | receptor de vertimiento |
| | F: | pertuis d'entrée vertical |
| | G: | Gefällseinlass, Überfall-Einlass |
| drop structure | S: | obra de caida, estructura para vertimiento |
| | F: | chute |
| | G: | Überfall-Struktur |
| dry aggregation | S: | agregacion en seco |
| | F: | agrégation à sec |
| | G: | Trocken-Aggregat |
| dry sieving | S: | tamisado en seco |
| | F: | tamisage à sec |
| | G: | Trockensieben |
| duripan, see hardpan | | |
| dust mulch | S: | cubierta polvotienta |
| | F: | couverture de poussière, mulch de poussière |
| | G: | Staubmulch |

## E

| | | |
|---|---|---|
| ecology | S: | ecologia |
| | F: | écologie |
| | G: | Oekologie |
| ecosystem | S: | ecosistema |
| | F: | écosystème |
| | G: | Oeko-System |
| effective precipitation | S: | precipitacion efectiva |
| | F: | précipitation effective |
| | G: | effektiver Niederschlag |
| embankment | S: | terraplen |
| | F: | remblai |
| | G: | Deich, Damm |
| energy dissipator | S: | disipador de energia |
| | F: | dissipateur d'énergie |
| | G: | Energie-Absorber |
| enrichment ratio | S: | relacion de concentracion |
| | F: | index d'enrichissement |
| | G: | Anreicherungs-Verhältnis |
| entrainment | S: | mobilizacion |
| | F: | entrainement |
| | G: | Mitschleppen |
| ephemeral gully | S: | carcava efímera |
| | F: | ravin ephémère |
| | G: | Trockenslucht |
| erode | S: | erodar |
| | F: | éroder |
| | G: | erodieren |
| erodibility, see soil erodibility | | |
| erodible | S: | erodable /erosionable |
| | F: | érodable |
| | G: | erodierbar, erodibel |
| erosion | S: | erosión |
| | F: | érosion |
| | G: | Erosion |

erosion classes
S: clases de erosión
F: classes d'érosion
G: Erosionseinstufung

erosion control, see soil conservation or soil conservation practices

erosion features, see rain erosion features

erosion hazard
S: riesgo de erosión
F: risque d'érosion
G: Erosionsgefährdung, Erosionsschutz

erosion mapping, see rain erosion mapping

erosion phase
S: fase por erosión
F: phase d'érosion
G: Erosions-Phase

erosion plot
S: parcela de erosión
F: parcelle d'érosion
G: Erosionsmessparzelle

erosion slope, see erosion slope length

erosion slope length
S: longitud de pendiente de erosión
F: longeur de pente de l'érosion
G: Erosionshanglänge

erosion susceptibility, see rain erosion susceptibility

erosion toposequence, see soil erosion toposequence

erosive
S: erosivo
F: érosif
G: erosiv, erodierend

erosivity, see rain erosivity

evapotranspiration
S: evapotranspiracion
F: évapotranspiration
G: Evapotranspiration

exfiltration, see seepage flow

exposition, see slope exposition

exposure
S: expuesto
F: exposition
G: Entblässung, Exposition

## F

factors of rain erosion
S: factores de la erosión pluvial
F: facteurs d'érosion pluvial
G: Regenerosionsfaktoren

fallow/ fallowing
S: barbecho
F: jachère
G: Brache

fan, see alluvial fan

Fanya juu
S: Fanya juu
F: Fanya juu
G: Wall-Graben-Struktur

farming system
S: sistema de cultivo
F: système de culture
G: Landwirtschaftssystem, Anbausystem

fast geological erosion
S: erosión geologica rapida
F: érosion géologique rapide
G: schnelle, geologische Erosion

feasibility of improvement
S: viabilidad de mejoramiento
F: faisabilité
G: Machbarkeit der Verbesserung

field boundary gully
S: zanja lindero
F: ravine de bordure de champ
G: Erosionsschlucht auf Feldgrenze

field capacity
S: capacidad de campo
F: capacité au champ
G: Feldkapazität

fill
S: relleno
F: remblai
G: Aufschüttung, Füllung

filter dam
S: presa permeable
F: retenue filtrante
G: Filtrierdamm

filter strip
S: banda de filtracion
F: bande filtrante
G: Filterstreifen, Vegetationsstreifen (als Ablagerungsfilter)

floodbraidwash
S: flujo entrelazado (afectando toda la superficie de la pendiente suave)
F: érosion pluviale par des rigoles très larges et anastomosées
G: Flutrinnenspülung, Flächenspülung,Flutflächenerosion

floodway
S: canal amortiguador
F: canal amortisseur
G: Flutablassungsgraben

flow competence
S: competencia de flujo
F: capacité d'écoulement
G: Fliesskompetenz

flume
S: aforador
F: débimètre
G: Ueberleitung, Ablaufrinne, auch: künstliches Querprofil zur Messung von Fliessgewässern, Messungsquerprofil

flute, fluting
S: estria erosiva, estriamiento
F: rainures verticales d'érosion
G: V-förmige Erosionsschlucht im Boden

fluvial erosion
S: erosión fluvial
F: érosion fluviale
G: fluviale Erosion, Wassererosion

folial cover
S: cobertura foliar
F: couverture foliaire
G: Pflanzenbedeckung

freeboard
S: capacidad de subida contenida de flujo, borde libre
F: revanche
G: Freibord

friable
S: blando
F: friable
G: bröckelig, krümelig

Froude number
S: numero de Froude
F: nombre de Froude
G: Froude-Zahl

furrow
S: surco de labranza
F: sillon
G: Furche

## G

gabion, see stone mattress

geological erosion = natural erosion
S: erosión geologica
F: érosion géologique
G: geologische Erosion, natürliche Erosion

| | | |
|---|---|---|
| gorge = canyon | S: | garganta |
| | F: | gorge |
| | G: | Schlucht |
| grade, see gradient | | |
| graded bund | S: | camellon con desnivel |
| | F: | levée de terre à trés faible pente |
| | G: | seitwärts leicht hangabwärts geneigter Erdwall |
| graded terrace/bank = diversion terrace | S: | terraza con desnivel |
| | F: | terrasse à gradin |
| | G: | geneigte Terrasse |
| gradient | S: | gradiente |
| | F: | gradin |
| | G: | Neigung |
| grassed waterway | S: | desague empastado |
| | F: | chenal enherbé, drain enherbé, piste d'eau enherbée |
| | G: | begrünter Wasserabzugskänel |
| grazing, see rangeland, grazing management | | |
| grazing capacity | S: | capacidad de pastoreo |
| | F: | charge de pâturage |
| | G: | Tragfähigkeit (von Weideland) |
| grazing management, | S: | manejo de praderas |
| grazing land management | F: | aménagement des pâturages |
| | G: | Beweidung, Verwaltung von Weideland |
| green manure | S: | abono verde |
| | F: | engrais vert |
| | G: | Gründüngung |
| greenness | S: | verdor |
| | F: | réponse de la végétation en téledetection |
| | G: | grüner Farbgehalt |
| ground cover, see soil cover | | |
| groundwater runoff | S: | escorrentia de flujo subterraneo |
| | F: | ruissellement d'une mouillère |
| | G: | Grundwasser-Abfluss |
| gully | S: | carcava |
| | F: | ravin |
| | G: | Erosionsgraben, Grabenreiszen |
| gully checkdam | S: | trincho de carcava, dique regulador, dique de contencion |
| | F: | seuil anti-érosif de ravin, banquette de retenue de ravin |
| | G: | Geschiebesperre, Querregler, Stufe, Sperre, Geschiebesperre in einer Erosionsschluch |
| gully classification | S: | clasificacion de carcavas |
| | F: | classification des ravins |
| | G: | Schluchteneinstufung |
| gully control | S: | control de carcavamiento |
| | F: | contrôle des ravins |
| | G: | Schluchtenverbau |
| gully erodibility | S: | erodabilidad para carcavamiento |
| | F: | érodabilité d'un ravin |
| | G: | Schluchtenerodierbarkeit |
| GULLY EROSION | S: | erosión en carcavas |
| | F: | érosion en ravins, ravinage |
| | G: | Grabenerosion, Schluchtenerosion |
| gully fan | S: | abanico de carcava |
| | F: | cône de déjection d'un ravin |
| | G: | Schluchtfächer |

| | | |
|---|---|---|
| gully filling | S: | colmatacion de carcava |
| | F: | colmatage de ravin |
| | G: | Schluchtauffüllung, Grabenfüllung |
| gully head | S: | cabecera de carcava |
| | F: | tête de ravin |
| | G: | Schluchtkopf |
| gully head sill | S: | camellon de cabecera de carcava |
| | F: | front de la tête de ravin |
| | G: | Schutzwall über der Erosions-schlucht |
| gully plug | S: | tapon de carcava |
| | F: | fermeture d'un ravin |
| | G: | Abschluss der Erosionschlucht |
| gully re-entry | S: | re-entrada protegida |
| | F: | écoulement de rentrée dans le ravin |
| | G: | Wiedereintritt der Erosionsschlucht |
| gully shaping | S: | aplanamiento, nivelacion de carcava |
| | F: | façonnage d'un ravin, rectification d'un ravin |
| | G: | Schlucht-Einebnung |
| gully trimming | S: | atenuamiento de carcava |
| | F: | aménagement d'un ravin |
| | G: | Schluchtenbearbeitung |
| gully wash | S: | lavamiento por carcavas |
| | F: | érosion par ravin |
| | G: | Schluchtenspülung |

## H

| | | |
|---|---|---|
| hardpan = duripan | S: | duripan |
| | F: | duripan, horizon induré, carapace |
| | G: | (Boden-) Verhärtungsschicht |
| hardsetting | S: | consolidacion |
| | F: | prise en masse |
| | G: | Verhärtung |
| headward erosion | S: | erosión remontante /retrocedente /regresiva |
| | F: | érosion remontante |
| | G: | rückschreitende Erosion |
| hillside ditch | S: | trincho interceptor, acequia de desvio, acequia de ladera |
| | F: | fossé de pente, gradin |
| hillside terrace | S: | terraza de ladera |
| | F: | terrasse (de flanc de colline) avec plantation d'arbres |
| | G: | Hangterrasse |
| horizontal interval | S: | intervalo horizontal |
| | F: | interval horizontal |
| | G: | Horizontalabstand |
| hydraulic conductivity | S: | conductividad hidraulica |
| | F: | conductivité hydraulique |
| | G: | hydraulische Leitfähigkeit |
| hydraulic roughness | S: | rugosidad hidraulica, |
| | F: | rugosité hydraulique |
| | G: | hydraulische Rauhigkeit |
| hydraulic roughness coefficient | S: | coeficiente de rugosidad hidraulica |
| | F: | coefficient de rugosité hydraulique |
| | G: | hydraulischer Rauhigkeitsbeiwert |
| hydrograph | S: | hidrografo |
| | F: | hydrographe, hydrogramme |
| | G: | Abflussganglinie, Abflussmengenkurve, Abflusskurve |

hydrologic depth,
hydrologic soil depth
S: profundidad hidrologica
F: profondeur d'infiltration
G: hydrologische Tiefe, Infiltrationstiefe

hydromulching
S: hidro-aspersion de mulch
F: mulching hydraulique
G: Nassmulchen

hydroseeding
S: hidro-aspersion de semilla
F: semis hydraulique
G: Anspritzverfahren zur Aussaat, Anspritzaussaat

## I

impact block
S: bloque de impacto
F: seuil anti-érosif, dissipateur d'énergie
G: Regulierblock in Fliessgewässern

incision rill
S: surco de incision
F: rigole d'incision
G: Eintiefungsrinne

infiltration
S: infiltracion
F: infiltration
G: Einsickerung, Infiltration

infiltration basin
S: zanja de infiltracion
F: bassin d'infiltration
G: Infiltrationsbecken

infiltration capacity
S: capacidad de infiltracion
F: capacité d'infiltration
G: Infiltrationskapazität

infiltration rate
S: tasa de infiltracion
F: taux d'infiltration
G: Infiltrationsrate, Versickerungsintensität

infiltration velocity
S: velocidad de infiltracion
F: vitesse d'infiltration
G: Versickerungsgeschwindigkeit

inlet
S: boca de entrada
F: pertuis d'entrée
G: Wassereinlass

inputs (of land use)
S: aportes
F: intrants
G: Eingabe, eingesetzte Produktionsmittel

interception, see rainfall interception

intercropping
S: cultivo intercalado
F: culture intercalaire
G: Zwischenanbau

interflow
S: flujo hipodermico
F: écoulement interne, ruissellement hypodermique
G: Zwischenabfluss

interrill erosion
S: erosión entresurcos erosión difusa
F: érosion en nappe
G: Flächenerosion, Schichterosion

## K

kinetic energy of rainfall, see rainfall energy

## L

laminar erosion
S: erosión laminar
F: érosion pelliculaire, érosion en nappe
G: laminare Erosion

| | | |
|---|---|---|
| laminar flow | S: | flujo laminar |
| | F: | écoulement laminaire |
| | G: | Laminarfluss |
| land | S: | tierra |
| | F: | terres |
| | G: | Land |
| land appraisal = land resource evaluation | S: | evaluacion de la tierra |
| | F: | évaluation, estimation des terres |
| | G: | Landeinschätzung, Bonitierung |
| land attribute | S: | atributo de la tierra |
| | F: | attribut de la terre |
| | G: | Land-Merkmal |
| land characteristic | S: | caracteristica de la tierra |
| | F: | caractéristique des terres |
| | G: | Landeigenschaft |
| land classification | S: | classificación de tierras |
| | F: | classification des terres |
| | G: | Landeinstufung |
| LAND DEGRADATION | S: | degradación de tierras |
| | F: | dégradation des terres |
| | G: | Landverschlechterung, Landdegradation |
| land evaluation | S: | evaluación de tierras |
| | F: | évaluation des terres |
| | G: | Landevaluation, Landbeurteilung |
| land evaluation unit | S: | unidad de evaluación de tierras |
| | F: | unite d'évaluation des terres |
| | G: | Landevaluationseinheit |
| land facet | S: | faceta de tierra |
| | F: | facette des terres |
| | G: | Landeinheit |
| land husbandry | S: | manejo controlado |
| | F: | bon aménagement des terres |
| | G: | Landbewirtschaftung |
| land improvement | S: | mejoramiento de tierras |
| | F: | amélioration des terres |
| | G: | Landverbesserung |
| land information system | S: | sistema de informacion de tierras |
| | F: | système informatique pour les terres |
| | G: | Land-Informationssystem |
| LAND PRODUCTIVITY | S: | productividad de tierras |
| | F: | productivité des terres |
| | G: | Landproduktivität |
| land quality | S: | cualidad de tierras |
| | F: | qualité des terres |
| | G: | Landqualität |
| land resource evaluation, see land appraisal | | |
| land suitability | S: | aptitud de la tierra |
| | F: | aptitude des terres |
| | G: | Landeignung |
| land suitability classification | S: | clasificion de la aptitud de tierras |
| | F: | classification d'aptitude des terres |
| | G: | Landeignungs-Klassifizierung |
| land system | S: | sistema de tierra |
| | F: | système des terres |
| | G: | Landsystem |
| land unit | S: | unidad de tierra |
| | F: | unité des terres |
| | G: | Landeinheit |

| | | |
|---|---|---|
| land use | S: | uso de tierras |
| | F: | exploitation des terres |
| | G: | Landnutzung |
| land use limitation | S: | limitacion del uso de tierras |
| | F: | limitation d'exploitation des terres |
| | G: | Landgebrauchseinschränkung |
| land use requirement | S: | requerimiento de uso de tierras |
| | F: | exigence d'utilisation des terres |
| | G: | Landnutzungsanforderung |
| land use system | S: | sistema de uso de tierras |
| | F: | système d'exploitation des terres |
| | G: | Landnutzungssystem |
| land utilisation type | S: | tipo de utilizacion de tierras |
| | F: | type d'utilisation des terres |
| | G: | Landnützungstyp |
| landslide | S: | deslizamiento |
| | F: | glissement de terrain, foirage |
| | G: | Erdrutsch, Bergsturz |
| landslip | S: | deslizamiento superficial |
| | F: | glissement de terrain |
| | G: | Erdschlipf |
| lateral erosion | S: | erosión lateral |
| | F: | érosion latéral |
| | G: | Lateralerosion |
| lavaka | S: | barranco, lavaka |
| | F: | lavaka |
| | G: | Lavak, Erosionsschlucht |
| leaf area index | S: | indice de area foliar |
| | F: | indice foliaire |
| | G: | Blattflächen-Index |
| level bund | S: | camellon a nivel |
| | F: | levée de terre interbourrelet |
| | G: | horizontaler Erdwall |
| level terrace/bank | S: | terraza a nivel |
| | F: | terrace de niveau |
| | G: | ebene Terrasse |
| limitation, see land use limitation | S: | limitacion |
| | F: | limitation |
| | G: | Einschränkung, Begrenzung, Limitation |
| linear erosion = gully erosion | S: | erosión lineal |
| | F: | érosion linéaire |
| | G: | lineare Erosion |
| liquefaction | S: | licuefaccion |
| | F: | liquéfaction |
| | G: | Verflüssigung |
| listing | S: | zanjamiento |
| | F: | "rigolage", créer des retenues d'eau dans les sillons |
| | G: | Auflistung |
| litter | S: | litera |
| | F: | litière |
| | G: | Streu |
| live barrier | S: | barrera viva |
| | F: | barrière vive |
| | G: | vegetative Abschrankung |
| lock and spill drain | S: | caño de retencion y vertimiento |
| | F: | fossé de retention et d'écoulement |
| | G: | Ablaufgraben mit Rückhaltesperren |

## M

| | | |
|---|---|---|
| macropores = non-capillary pores | S: | macroporos, poros no capilares |
| | F: | macropores, pores non capillaires |
| | G: | Makroporen, nicht-kapillare Poren |
| major land improvement | S: | mejoramiento principal de la tierra |
| | F: | amélioration majeure des terres |
| | G: | bedeutende Landverbesserung, |
| management, see crop residue management or soil management | | |
| Manning's formula | S: | formula de Manning |
| | F: | formule de Manning |
| | G: | Manning's Formel |
| Manning's roughness factor, | S: | factor de rugosidad de Manning |
| see hydraulic roughness coefficient | F: | facteur de rugosité de Manning |
| | G: | Manning's Rauhigkeits-Faktor |
| mapping of rain erosion, see rain erosion mapping | | |
| master rill | S: | surco maestro, surco principal |
| | F: | rigole principale |
| | G: | Haupt-Erosionsrille |
| microbasin | S: | mini bancal |
| | F: | microbassin |
| | G: | Halbmond-Terrasse, Minibecken |
| micropiracy | S: | micro-captura |
| | F: | microcapture |
| | G: | Mikrokappung |
| microrilling | S: | microsurcamiento |
| | F: | microravinement, début d'érosion en rigoles |
| | G: | Microrillenerosion |
| minimum tillage | S: | labranza minima |
| | F: | travail minimum du sol |
| | G: | Minimalbodenbearbeitung |
| minor land improvement | S: | mejoramiento secundario de la tierra |
| | F: | amélioration mineure des terres |
| | G: | kleinere Landverbesserung |
| MODELS OF RAIN EROSION AND CONSERVATION | S: | modelos de erosión pluvial y conservacion |
| | F: | modèles d'érosion pluviale et de conservation |
| | G: | Regenerosions- und Konservierungs modelle |
| mole drain | S: | labranza de topo |
| | F: | drainage taupe |
| | G: | Drainageröhrung, Maulwurfsdrain |
| monoculture | S: | monocultivo |
| | F: | monoculture |
| | G: | Monokultur |
| mulch | S: | cubierta |
| | F: | mulch, paillis, couverture du sol |
| | G: | Mulch |
| multiple land utiliation type | S: | tipo multiple de utilizacion de la tierra |
| | F: | type d'utilisation multiple des terres |
| | G: | Mehrfach-Landnutzungstyp, Multipler Landnutzungstyp |
| Musle, modified soil loss equation | S: | MUSLE |
| | F: | MUSLE |
| | G: | MUSLE (Abk.) |

## N

| | | |
|---|---|---|
| nappe | S: | napa |
| | F: | nappe |
| | G: | Uberfallstrabel |
| narrow base terrace | S: | bancal |
| | F: | basse terrasse étroite |
| | G: | schmale Terrasse mit steiler Böschung |
| natural erosion, see geological erosion | | |
| natural resources | S: | recursos naturales |
| | F: | ressources naturelles |
| | G: | natürliche Ressourcen |
| netting | S: | estabilizacion por redes/obra de malla |
| | F: | réticulation |
| | G: | Anbringen von Netzen |
| no-tillage, zero tillage | S: | labranza ausente, labranza cero |
| | F: | zéro travail du sol, non-travail du sol, labour zéro |
| | G: | pflugloser Ackerbau, Nichtbearbeitung, keine Bodenbearbeitung |
| normal erosion | S: | erosión normal |
| | F: | érosion normale |
| | G: | normale Erosion |

## O

| | | |
|---|---|---|
| open drain, see retention furrow | | |
| outputs (of land use) | S: | egresos |
| | F: | sorties, récolte, exportation |
| | G: | Leistung, Ertrag, Erträge |
| overfall | S: | salto |
| | F: | déversoir, déversement |
| | G: | (offener) Ueberfall |
| overfall outlet | S: | salida de desague |
| | F: | exutoire |
| | G: | Ablauf |
| overflow channel | S: | rompedero |
| | F: | chenal de débordement |
| | G: | Ueberlauf-Kanal |
| overgrazing | S: | sobrepastoreo |
| | F: | surpâturage |
| | G: | Ueberweidung |
| OVERLAND FLOW | S: | flujo superficial |
| | F: | ruissellement diffus |
| | G: | Oberflächenabfluss, Ueberland-abfluss, Rieseln, Abrieseln |
| overstocking | S: | sobrecarga |
| | F: | surcharge de bétail |
| | G: | Ueberbesatz (von Weidetieren) |

## P

| | | |
|---|---|---|
| partial area | S: | area parcial |
| | F: | surface partielle |
| | G: | Teilfläche |
| pasture renovation | S: | renovacion de pastizales |
| | F: | rénovation des pâturages |
| | G: | Weideerneuerung |
| ped | S: | ped, agregado |
| | F: | agrégat |
| | G: | (Boden) Aggregat |

pedestal
S: pedestal, estoraque
F: colonne coiffée, cheminée de fée
G: Erosionssäule, Erosionspyramide

perennial
S: peremne, permanente, multianual
F: perenne
G: ganzjährig

permeability, see soil permeability

permissible soil loss, see soil loss tolerance

pipe flow, tunnel flow
S: flujo hipodermico entubado
F: écoulement en tunnel
G: Röhrendurchfluss

pipe shaft erosion, see fluting

piping, see tunnel erosion

pitting
S: ahoyar
F: creusement de mare
G: Graben von Vertiefungen in Boden, Graben von Pflanzlöchern

plant cover, see soil cover

planting basin
S: hoya de siembra
F: petit trou composté planté en paquet
G: Pflanzbecken

ploughfurrow
S: surco de arar
F: sillon de labour
G: Pflugfurche

ploughlayer
S: capa de arada
F: couche labourée
G: Pflughorizont

ploughpan, ploughsole
S: pan de labranza, pan de arada
F: semelle de labour
G: Pflugsohle

ploughridge
S: camellon de arada, caballon
F: raie de labour
G: Pflugwall

ploughrill erosion
S: erosión en surcos de arar
F: érosion de sillons
G: Pflugrinerosion

ponding, see surface ponding

potential erosion, see rain erosion susceptibility

potential land degradation
S: degradacion potencial de la tierra
F: dégradation potentielle des terres
G: potentielle Landverschlechterung

potential rain erosion, see rain erosion susceptibility

potential rain erosion hazard, see rain erosion susceptibility

prerill
S: presurco /surquillo
F: rigole initiale
G: Vorrille

productivity, see soil productivity or land productivity

## R

rain energy, see rainfall energy

rain erosion
S: erosión pluvial
F: érosion pluviale
G: Regenerosion

rain erosion classes
S: clases de erosión pluvial
F: classes d'érosion pluviale
G: Regenerosionsklassen

rain erosion control practice, see soil conservation practice

soil erosion hazard classes
S: clases de riesgo de erosión
F: classes de risque d'érosion
G: Erosionsgefährdungsstufen

RAIN EROSION FEATURES
S: rasgos de la erosión pluvial (incluye formas de remocion y formas de depositacion)
F: traits caractéristiques de l'érosion pluviale
G: Regenerosionscharakteristiken

Terms in alphabetical list:
- arroyo
- badland
- braidwash
- colluvium
- floodbraidwash
- flute
- gully
- gully fan
- lavaka
- microrilling
- pedestal
- prerill
- rainsplash
- rainwash
- ravine
- rill
- rill erosion
- rill fan or rill spread
- rillwash
- sheet erosion
- sheetflooding
- sheetflood deposit
- sheet wash

RAIN EROSION HAZARD
S: riesgo de erosión pluvial
F: risques d'érosion pluviale
G: Regenerosionsgefährdung

rain erosion hazard factors, see factors of rain erosion

RAIN EROSION MAPPING
S: mapeo /cartografia de erosión pluvial
F: cartographie de l'érosion pluviale
G: Regenerosionskartierung

rain erosion models, see models of rain erosion

rain erosion risk, see rain erosion susceptibility

rain erosion susceptibility
S: susceptibilidad a la erosión pluvial
F: susceptibilité à l'érosion pluviale
G: Empfindlichkeit für Regenerosion, Regenerosionsanfälligkeit

RAIN EROSIVITY
S: erosividad de la lluvia
F: érosivité de la pluie
G: Regenerosivität

rain erosivity distribution
S: distribucion de la erosividad de la lluvia
F: distribution de l'érosivité pluviale
G: Regenerosivitätsverteilung

rain storage capacity
S: capacidad de almacenaje de lluvia,
F: capacité de rétention de la pluie
G: Regenrückhaltekapazität

raindrop erosion, see rainsplash erosion

raindrop impact, see rainsplash

| | | |
|---|---|---|
| rainfall acceptance | S: | aceptabilidad de lluvia por la superficie del suelo |
| | F: | capacité d'absorption de la pluie |
| | G: | Regenaufnahmefähigkeit |
| rainfall energy | S: | energia cinetica de lluvia |
| | F: | énergie de la pluie |
| | G: | Kinetische Regenergie |
| rainfall interception | S: | interception de la lluvia |
| | F: | interception de la pluie |
| | G: | Regeninterzeption |
| rainfall simulation | S: | simulacion de lluvia |
| | F: | simulation de la pluie |
| | G: | Regensimulation |
| rainfall simulator, see rainfall simulation | | |
| rainsplash | S: | chapoteo /salpicadura /salpicamiento |
| | F: | rejaillissement de la pluie, battance |
| | G: | Regentropfeneinschlag, Spritzer |
| rainsplash erosion | S: | erosión por chapoteo /salpicadura /salpicamiento |
| | F: | érosion par rejaillissement de la pluie |
| | G: | Spritzerosion, Tropfenerosion |
| rainulator, see rainfall simulator | | |
| rainwash (splash and overland flow) | S: | lavamiento pluvial |
| | F: | érosion par rejaillissement et ruissellement |
| | G: | Regenauswaschung, Verspülung |
| rangeland | S: | tierra de pastoreo |
| | F: | terre de parcours |
| | G: | Weideland |
| rating curve (hydrology) | S: | curva de tasacion |
| | F: | courbe de calibrage, d'étalonnage, gaugeage |
| | G: | Verhältniskurve |
| rating table, see rating curve | | |
| rational formula | S: | formula racional de escurrimiento |
| | F: | "formule rational" |
| | G: | Pegel-Abfluss-Formel |
| rational method | S: | método racional de escurrimiento |
| | F: | méthode rationelle |
| | G: | rationale Methode |
| ravine | S: | barranco |
| | F: | ravin |
| | G: | Schlucht, Sluchtreiszen |
| recurrence interval, see return period | | |
| reforestation | S: | reforestacion |
| | F: | reforestation |
| | G: | Wiederbewaldung |
| RELIEF FACTOR of rain erosion | S: | factor topografico de erosión pluvial |
| | F: | effet du relief comme facteur d'érosion |
| | G: | Reliefeffekt als Erosionsfaktor |
| REMOTE SENSING = teledetection | S: | percepcion remota /teledeteccion |
| | F: | télédetection |
| | G: | Fernerkundung |
| Reno mattress | S: | espolon |
| | F: | gabion, mur de protection d'un ravin |
| | G: | Reno-Sinklage |
| residual effect (of plant cover), | S: | efecto residual (de cobertura de plantas) |
| | F: | effet residuel (d'un couvert végétal) |
| | G: | Rückhalteeffekt (der Vegetationsdecke) |
| residual suitability | S: | aptitud residual |
| | F: | aptitude résiduelle |
| | G: | Rest-Eignung |

| | | |
|---|---|---|
| residue, see crop residue | | |
| residue management, see crop residue management | | |
| resistance to erosion (as a land quality) | S: | resistancia a la erosión |
| | F: | résistance a l'érosion |
| | G: | Widerstandsfähigkeit gegen Erosion, Erosionswiderstandsfähigkeit |
| retaining wall | S: | muro de soporte |
| | F: | mur de retenue |
| | G: | Rückhaltewall |
| retarding measure | S: | desacelerador |
| | F: | mesure de retardement |
| | G: | Verzögerungsmassnahme |
| retention | S: | retencion |
| | F: | rétention |
| | G: | Retension |
| retention furrow/open drain | S: | surco de retencion |
| | F: | drain ouvert |
| | G: | Rückhaltefurche |
| retention storage | S: | almacenaje de retencion |
| | F: | stockage superficiel (d'eau) |
| | G: | Rückhaltebecken |
| retention terrace | S: | terraza de retencion |
| | F: | terrace de rétention |
| | G: | Rückhalteterrasse, (für Wasser und Sediment) |
| return flow | S: | flujo de retorno |
| | F: | résurgence de l'écoulement |
| | G: | Rückfluss |
| return period | S: | periodo de retorno |
| | F: | période de retour |
| | G: | Wiederkehrzeitraum |
| revegetation | S: | revegetacion, renovacion de la vegetacion |
| | F: | réimplantation de végétation |
| | G: | Wiederbegrünung |
| revetment | S: | revestimiento |
| | F: | revêtement |
| | G: | Verkleidung, Uferdeckwerk |
| Reynolds number | S: | numero de Reynolds |
| | F: | nombre de Reynolds |
| | G: | Reynolds-Zahl |
| ridging | S: | camelleo |
| | F: | billonnage |
| | G: | Hüfeln |
| rill | S: | surco |
| | F: | rigole, ravineau |
| | G: | Rinne, Rille |
| rill erodibility / rillibility | S: | surcabilidad |
| | F: | érodabilité par rigoles |
| | G: | Rinnenerodibilität |
| RILL EROSION | S: | erosión por surcos |
| | F: | érosion en rigoles |
| | G: | Rinnenerosion, Rillenerosion |
| rill fan, rill spread | S: | abanico de surco |
| | F: | cône de déjection d'une rigole |
| | G: | Rinnenfächer |
| rillwash | S: | lavamiento por surcos |
| | F: | érosion pluviale par des rigoles |
| | G: | Rinnenauswasschung, Rillensplung |

| | | |
|---|---|---|
| rip-rap | S: | cascajo, escombros |
| | F: | enrochement anti-batillage |
| | G: | Steinwurf, Steinberollung, Steinschut von Böschungen gegen fliessendes Wasser oder Wellen |
| riser | S: | contrahuella |
| | F: | talus de terrasse |
| | G: | Böschung |
| risk of soil erosion, see rain erosion susceptibility | | |
| riverbank erosion | S: | erosión ribereña, erosión lateral de cauce |
| | F: | érosion de berge |
| | G: | Stromufererosion |
| rotational slip | S: | deslizamiento rotacional laminar |
| | F: | glissement avec rotation |
| | G: | Rotationsrutsch |
| roughness, see hydraulic roughness or soil surface roughness | | |
| roughness coefficient, | S: | coeficiente de rugosidad |
| see hydraulic roughness coefficient | F: | coefficient de rugosité |
| | G: | Rauhigkeitsbeiwert |
| routing of surface runoff | S: | sistema de vias de drenaje |
| | F: | cheminement du ruissellement |
| | G: | Wegfindung der Abfluss |
| runoff | S: | escorrentia |
| | F: | ruissellement, écoulement superficiel |
| | G: | Abfluss |
| runoff coefficient = runoff percentage | S: | coeficiente de escorrentia |
| | F: | coefficient de ruissellement |
| | G: | Abflusskoeffizient |
| runoff curve method | S: | método de la curva de escorrentia |
| | F: | méthode de prédiction du ruissellement |
| | G: | Methode der Abflusscurve |
| runoff hydrograph, see hydrograph | | |
| runoff plot | S: | predio de escorrentia |
| | F: | parcelle de ruissellement |
| | G: | Abfluss(test)fläche |
| runon / topwater | S: | sobreflujo |
| | F: | confluent |
| | G: | Zufluss |

## S

| | | |
|---|---|---|
| saltation | S: | saltacion |
| | F: | saltation |
| | G: | Saltation, Springen |
| saturation overland flow | S: | flujo superficial por saturacion |
| | F: | ruissellement de surface à saturation |
| | G: | Sättigungs-Oberflächenabfluss |
| saturation wedge | S: | cuña de saturacion |
| | F: | coin de saturation |
| | G: | Sättigungskeil |
| scour | S: | desgaste |
| | F: | curage |
| | G: | Eintiefung |
| sealing, see soil sealing | | |
| sediment | S: | sedimento |
| | F: | sédiment |
| | G: | Sediment, Sinkstoffe |
| sediment basin | S: | cubeta de decantacion |
| | F: | bassin sédimentaire, bassin de décantation |
| | G: | Setzbecken |

| | | |
|---|---|---|
| sediment concentration curve | S: | curva de concentracion de sedimentos |
| | F: | courbe de concentration en sédiment |
| | G: | Schienenkonzentrationskurve |
| sediment delivery ratio | S: | relacion de distribucion de sedimentos |
| | F: | taux de sédimentation |
| | G: | Sedimentrate |
| sediment load | S: | carga de sedimentos |
| | F: | charge solide |
| | G: | Sedimentfracht |
| sediment routing | S: | recorrido de sedimentos |
| | F: | transport de sédiment |
| | G: | Sedimenttransportwege |
| sediment storage | S: | almacenaje de sedimentos |
| | F: | stockage des sédiments |
| | G: | Sedimentrückhaltelagerung |
| sediment trap | S: | presa de sedimento |
| | F: | fossé à piégeage (et accumulation) de sédiments |
| | G: | Sedimentfalle |
| sediment yield = sediment discharge | S: | produccion de sedimentos = descarga de sedimentos |
| | F: | apport de sédiment |
| | G: | Bodenaustrag (eines Wassereinzugsgebiets) |
| sedimentation | S: | sedimentacion |
| | F: | sédimentation |
| | G: | Sedimentierung |
| seedbed | S: | cama de siembra |
| | F: | lit de semence |
| | G: | Saatbeet |
| seepage "into" | S: | filtracion (flujo que baja) |
| | F: | perte par infiltration |
| | G: | Wasserdurchtritt, Durchrinnen |
| seepage "from" | S: | flujo brotante, flojo manante(flujo que sube) |
| (surfacing subsurface flow) | F: | écoulement par suintement |
| | G: | Bodendurchfluss (an Oberfläche kommend) |
| settling | S: | asentamiento |
| | F: | sédimentation, décantation |
| | G: | Setzen, Absinken |
| shear | S: | cizalla |
| | F: | cisaillement |
| | G: | Scher- |
| shear strength | S: | resistencia al cizallamiento |
| | F: | force de cisaillement |
| | G: | Scherfestigkeit |
| sheet deposit | S: | derrame, deposito laminar |
| | F: | dépôt en nappe |
| | G: | Flächenablagerung |
| sheet erosion, see interrill erosion | | |
| sheetflooding | S: | inundacion mantiforme |
| | F: | inondation en nappe |
| | G: | Schichtflut, Flächenspülung |
| sheetwash | S: | lavamiento laminar, |
| | F: | érosion par ruissellement en nappe |
| | G: | Flächenerosion |
| sill | S: | umbral de desague |
| | F: | seuil |
| | G: | Schwelle |
| silt trap, see sediment trap | | |

| | | |
|---|---|---|
| silting (up) | S: | colmatacion, atarquinamiento |
| | F: | alluvionnement |
| | G: | Aufschlämmen, Zusedimentieren |
| slaking | S: | estancamiento |
| | F: | battance, désagrégation par l'eau |
| | G: | Strukturverlust bei Befeuchtung |
| slide | S: | deslizamiento |
| | F: | glissement |
| | G: | Gleitrutsch |
| slope aspect, see slope exposition | | |
| slope effect, see relief effect on rain erosion | | |
| slope length, see erosion slope length | | |
| slope exposition, slope aspect, direction of slope | S: | exposicion, orientacion de la pendiente |
| | F: | direction de la pente, exposition (de la pente) |
| | G: | Hangexposition |
| slope wash | S: | lavamiento de pendiente |
| | F: | érosion en nappe |
| | G: | Hangflächenerosion |
| slump | S: | deslizamiento rotacional |
| | F: | loupe de glissement |
| | G: | Erdschlipf, Rasenschälen |
| sod planting | S: | empastado con cespedones |
| | F: | repiquage de gazon |
| | G: | Einpflanzen von Pflanzenteilen, Rasenziegelpflanzen |
| sod seeding | S: | semilla en el cesped existente |
| | F: | semis dans du gazon |
| | G: | direktes Einsäen in Wiese oder Weide |
| solum | S: | solum |
| | F: | solum |
| | G: | Solum |
| soil | S: | suelo |
| | F: | sol |
| | G: | Boden |
| soil aggregate = a ped | S: | agregado del suelo |
| | F: | agrégat de sol |
| | G: | Bodenaggregat |
| soil aggregate stability | S: | estabilidad de los agregados del suelo |
| | F: | stabilité de l'agrégat du sol |
| | G: | Bodenaggregatstabilität |
| soil aggregation | S: | agregacion, estructuracion del suelo |
| | F: | agrégation du sol |
| | G: | Bodenauflandung |
| soil aggregation index | S: | indice de agregacion del suelo |
| | F: | indice d'agrégation du sol |
| | G: | Bodenauflandungsindex |
| soil brightness | S: | brillo de suelo |
| | F: | brillance du sol |
| | G: | Bodenglanz |
| soil compaction | S: | compactacion del suelo |
| | F: | compactage du sol |
| | G: | Bodenverdichtung |
| soil conditioner | S: | estabilizador artificial de suelo |
| | F: | conditionneur de sol |
| | G: | Bodenstrukturverbesserer, |
| soil conservation | S: | conservacion de suelos |
| | F: | conservation du sol |
| | G: | Bodenkonservierung |

soil conservation measure, see soil conservation practice

soil conservation practice
S: practica de conservacion de suelos
F: pratique de conservation du sol
G: Bodenkonservierungsmassnahme, Erosionsschutzmassnahmen

soil conservation structure, see soil conservation practice

soil conservation terrace/bank
S: terraza de conservacion
F: terrace de conservation
G: Bodenkonservierungsterrasse

soil consistence
S: consistencia de suelo
F: consistance du sol
G: Bodenkonsistenz

SOIL COVER
ground cover, soil cover
S: cobertura del terreno, del suelo
F: couverture du sol,
G: Bodenbedeckung

surface cover
S: cobertura superficial
F: couverture superficielle
G: Bodenoberflächenbedeckung

land use cover
S: cobertura del uso de la tierra
F: couvert des terres occupées
G: Landnutzungsbedeckung

vegetation cover/plant cover
S: cobertura vegetal.
F: couvert végétal
G: Pflanzenbedeckung, Vegetationsbedeckung, Pflanzendecke

soil crust
S: costra del suelo
F: croûte du sol
G: Bodenkruste

SOIL CRUSTING
S: encostramiento del suelo
F: encroûtement du sol
G: Bodenverkrustung

soil degradation
S: degradacion del suelo
F: dégradation du sol
G: Bodenverschlechterung, Bodendegradation

soil detachibility
S: removilidad del suelo
F: détachabilité du sol
G: Bodenloehsbarkeit

soil detachment
S: desprendimiento del suelo
F: détachement du sol
G: Bodenlösung

soil dispersion
S: dispersion de suelo
F: dispersion du sol
G: Bodendispersion

SOIL ERODIBILITY
S: erodabilidad del suelo
F: érodibilité du sol
G: Bodenerodierbarkeit

soil erodibility classes
S: clases de erodabilidad del suelo
F: classes d'érodibilité du sol
G: Bodenerodierbarkeitsklassen

soil erodibility index
S: indice de erodabilidad del suelo
F: index d'érodibilité du sol
G: Bodenerodierbarkeitsindex

soil erodibility K-factor
S: factor K de erodabilidad del suelo
F: facteur K d'érodibilité du sol
G: K-Wert der Bodenerodierbarkeit

soil erodibility nomograph
S: nomograma de erodabilidad del suelo
F: nomogramme d'érodibilité du sol
G: Nomograph der Bodenerodierbarkeit

soil erosion = accelerated erosion
S: erosión del suelo
F: érosion du sol
G: Bodenerosion

soil erosion hazard, see rain erosion hazard

soil erosion susceptibility, see rain erosion susceptibility

soil erosion toposequence
S: toposecuencia de la erosión del suelo
F: toposéquence d'érosion du sol
G: Toposequenz der Bodenerosion

soil horizon
S: horizonte de perfil edafico, horizonte pedogenetico
F: horizon du sol
G: Bodenhorizont

soil layer
S: capa de suelo
F: couche du sol
G: Bodenschicht

soil life
S: periodo util del suelo, periodo de aptitud continua del suelo
F: période utile du sol
G: Bodenleben

soil line
S: orientacion lineal de los suelos
F: droite des sols
G: Bodenlinie

soil loss
S: perdida de suelo
F: perte en terre
G: Bodenverlust

soil loss equation, see Universal Soil Loss Equation

soil loss plot, see erosion plot

SOIL LOSS TOLERANCE = permissible soil loss
S: tolerancia de perdida de suelo, perdida de suelo permisible
F: tolérance de perte en terre
G: tolerierbarer Bodenabtrag

soil management
S: manejo del suelo
F: gestion du sol
G: Bodenbearbeitung

soil pan
S: pan edafico
F: pan
G: undurchlässige Bodenschicht

soil permeability
S: permeabilidad del suelo
F: permeabilité du sol
G: Bodendurchlässigkeit

soil productivity
S: productividad del suelo
F: productivité du sol
G: Bodenproduktivität

soil profile
S: perfil de suelo
F: profil de sol
G: Bodenprofil

soil scalping = desurfacing
S: descapote de suelo
F: décapage du sol
G: Entfernung der Oberbodenschicht

SOIL SEALING = surface sealing
S: obturacion del suelo
F: cimentation, colmatage
G: Bodenversiegelung Oberflächenversiegelung

soil slip
S: deslizamiento laminar
F: glissement du sol
G: Erdrutsch, Bodenrutschung

soil stabiliser
S: estabilisador del suelo
F: stabiliseur du sol

soil strength,shear strength of a soil, see soil structural stability

| | | |
|---|---|---|
| soil structure | S: | estructura de suelo |
| | F: | structure du sol |
| | G: | Bodenstruktur |
| soil structural stability | S: | estabilidad estructural |
| | F: | stabilité structurale du sol |
| | G: | Bodenstrukturstabilität |
| soil structure grade, soil structure strength of expression | S: | grado de la estructura del suelo |
| | F: | grade de la structure du sol |
| | G: | Grad der Bodenstruktur, Bodenstrukturstärke |
| soil surface roughness | S: | rugosidad de la superficie del suelo |
| | F: | rugosité de la surface du sol |
| | G: | Bodenoberflächenrauhigkeit |
| soil texture | S: | textura del suelo |
| | F: | texture du sol |
| | G: | Bodentextur |
| soil wash | S: | lavamiento del suelo |
| | F: | érosion du sol |
| | G: | Bodenabspülung |
| solifluction | S: | solifluxion |
| | F: | solifluxion |
| | G: | Solifluktion |
| sorptivity | S: | admisibilidad |
| | F: | sorptivité |
| | G: | Aufnahmefähigkeit |
| spillway | S: | vertedor |
| | F: | évacuateur de crue, déversoir |
| | G: | Ueberlauf |
| splash, see rainsplash | | |
| splash erosion, see rainsplash erosion | | |
| sprigging | S: | plantamiento, estampar de ramas |
| | F: | repiofuage d'herbes |
| | G: | Anpflanzen von Grasteilen als Erosionsschutz |
| sprinkler irrigation | S: | riego por aspersion |
| | F: | irrigation par aspersion |
| | G: | Sprinklerbewässerung |
| stemflow | S: | flujo de tallo, flujo a lo largo de talles |
| | F: | écoulement le long des tiges |
| | G: | Stammabfluss |
| stocking rate | S: | proporcion de carga |
| | F: | taux de charge (d'un pâturage) |
| | G: | Besatzstärke, Bestockungsrate |
| stone mattress | S: | gabion, piedra con malla (mesh) |
| | F: | gabion |
| | G: | Gabion, Drahtschotterkasten |
| stoneline | S: | linea pedregosa |
| | F: | nappe de gravats |
| | G: | Steinreihe |
| stream bank erosion, see riverbank erosion | | |
| strength of soil structure, see soil structure grade | | |
| strip cropping, see contour strip cropping | | |
| stubble | S: | rastrojo |
| | F: | chaumes |
| | G: | Stoppel- |
| stubble mulching | S: | cubierta de rastrojo |
| | F: | mulching de chaumes |
| | G: | Strohmulch, Stoppelmulch |

| | | |
|---|---|---|
| subsoil | S: | subsuelo |
| | F: | sol à profondeur |
| | G: | Unterboden |
| subsoiling | S: | subsolar |
| | F: | soussolage |
| | G: | Lockern des Unterbodens |
| subsurface erosion, see tunnel erosion | | |
| subsurface flow | S: | flujo hipodermico |
| | F: | écoulement hypodermique |
| | G: | Bodendurchfluss |
| suffosion = subsurface eluviation | S: | sufusion/sufosion |
| | F: | épanchement, suffusion |
| | G: | Unterbodenauswaschung |
| surface aggregation ratio | S: | relacion de agregacion superficial |
| | F: | taux d'agrégation en surface |
| | G: | Oberflächenaggregationsrate |
| surface cover, see soil cover | | |
| surface detention | S: | detencion superficial |
| | F: | rétention de surface |
| | G: | Oberflächenrückhalt |
| surface erosion | S: | erosión superficial |
| | F: | érosion superficielle |
| | G: | Oberflächenerosion |
| surface gravel | S: | gravilla superficial |
| | F: | gravier de surface |
| | G: | Oberflächenkies |
| surface ponding | S: | empozamiento (de larga duracion)<br>encharcamiento (de breve duracion) |
| | F: | formation de flaques d'eau en surface |
| | G: | Pfötzenbildung |
| surface roughness, see hydraulic roughness and soil surface roughness | | |
| surface runoff | S: | escurrimiento superficial |
| | F: | ruissellement superficiel |
| | G: | Oberflächenabfluss |
| surface sealing, see soil sealing | | |
| surface storage | S: | almacenamiento superficial |
| | F: | capacité de rétention en eau de surface |
| | G: | Oberflächenspeicherung (in Bodenvertiefungen) |
| surface wash | S: | lavamiento superficial |
| | F: | érosion par ruissellement de surface |
| | G: | Oberflächenabspülung |
| suspension | S: | suspension |
| | F: | suspension |
| | G: | Suspension |
| sustained use | S: | uso sostenido |
| | F: | utilisation soutenue, continue |
| | G: | nachhaltige Landnutzung |

## T

| | | |
|---|---|---|
| talud | S: | talud |
| | F: | talud |
| | G: | Sturzbett, Deckwerk |
| terrace/bank, see soil conservation terraces | | |
| terrace/bank interval | S: | intervalo de terrazas |
| | F: | interval entre terrasses |
| | G: | Terrassenabstand |

terrace/bank spacing
S: espaciamiento de terrazas
F: interval entre terrasses
G: Terrassenabstand

throughfall
S: lluvia no interceptada
F: pluie au sol
G: direkter Niederschlag

throughflow
S: flujo hipodermico
F: ruissellement, écoulement hypodermique
G: Durchfluss

tied ridging
S: camelleo conectado
F: diguettes en damier
G: Furchenkammerung

tile drain
S: tubo de desagüe
F: drain par tuyau
G: Dräurohr

time of concentration
S: tiempo de concentracion
F: temps de concentration
G: Sammelzeit, Konzentrationszeit

time to ponding
S: tiempo hasta encharcamiento
F: temps de formation des flaques en surface
G: Pfötzenbildungszeit

time to runoff
S: tiempo hasta escurrimiento
F: temps de ruissellement
G: Abflussverzögerung

tolerable soil loss, see soil loss tolerance

topographic factor (of erosion), see relief factor

topsoil
S: suelo superficial
F: terre arable
G: Oberboden

topsoil saturation overland flow
S: flujo superficial por saturacion del tope del suelo
F: ruissellement diffus de saturation de la partie supérieure du sol
G: Oberflächensättigungsabfluss

topsoiling
S: recubremiento superficial con suelo
F: remis de sol superficial
G: Aufbringen von Oberboden

torrential
S: torrencial
F: torrentiel
G: turbulenter Fluss

tracer
S: elemento trazador
F: élément trace
G: Tracer

tractive force
S: fuerza de cizalla, traccion
F: force de traction
G: Zugkraft

translatory flow
S: flujo trasladado
F: écoulement transversal
G: Transversalfluss

transport capacity
S: capacidad de transporte
F: capacité de transport
G: Transportkapazität

transport competence, see flow competence

trickle flow
S: hilillo de agua
F: goutte à goutte
G: Wasserdurchfluss

trickle irrigation, see drip irrigation

| | | |
|---|---|---|
| trickle pipe | S: | tubo de conduccion de hilillos de agua |
| | F: | gouteur |
| | G: | Tropfenröhre (für Bewässerung) |
| truncation, see decapitation | | |
| tunnel erosion, piping | S: | erosión en tunel |
| | F: | érosion en tunnel, renard |
| | G: | Tunnelerosion, Sickerröhrenbildung |
| turbulent flow | S: | flujo turbulente |
| | F: | écoulement turbulent |
| | G: | turbulente Fluss |
| two stage approach of land evaluation | S: | enfoque de la evaluacion de la tierra en dos etapas |
| | F: | méthode en deux phases d'évaluation des terres |
| | G: | Zwei-Stufen-Landbeurteilungs-Methode |
| tunnel scour, see tunnel erosion | | |

## U

| | | |
|---|---|---|
| undercutting | S: | socavacion /socavamiento /zapamiento |
| | F: | havage, sous-cavage |
| | G: | Untergraben der Böschung durch Erosion |
| undersowing | S: | siembra bajo cubierta |
| | F: | semis sous couverture |
| | G: | zwischensäen |
| urbanisation | S: | urbanizacion |
| | F: | urbanisation |
| | G: | Verstädterung |
| Universal Soil Loss Equation, | S: | Ecuacion Universal de la Erosión del Suelo |
| | F: | Equation Universelle de Perte en Terre |
| | G: | Universale Bodenverlustgleichung |
| USLE | S: | EUPS |
| (Universal Soil Loss Equation) | F: | EUPT |
| | G: | UBVG |

## V

| | | |
|---|---|---|
| vertical interval | S: | intervalo vertical |
| | F: | intervale vertical |
| | G: | Vertikalintervall |
| vulnerability of the productivity | S: | vulnerabilidad a la erosión, |
| to erosion | F: | vulnérabilité à l'érosion |
| | G: | Erosionsverletzlichkeit |

## W

| | | |
|---|---|---|
| Wamatengo pit | S: | depresión Wamatengo |
| | F: | microbasin Wamatengo |
| | G: | Halbmond-Einsicherungsgraben |
| wash | S: | lavamiento |
| | F: | érosion pluviale par ruissellement |
| | G: | Oberflächenabtrag |
| water conservation | S: | conservacion de agua |
| | F: | conservation de l'eau |
| | G: | Wasserkonservierung |
| water detention, see surface detention | | |
| water harvesting | S: | captacion de aguas |
| | F: | captage de l'eau |
| | G: | Sammeln von Oberflächenwasser |
| water holding capacity | S: | capacidad de retencion de agua |
| | F: | capacité de rétention en eau |
| | G: | Wasserrückhaltekapazität |

| | | |
|---|---|---|
| water spreading | S: | diseminacion de agua |
| | G: | Wasserverteilung (von Abfluss auf landw. Flächen) |
| water stable aggregates | S: | agregados estables en agua |
| | F: | agrégats stables à l'eau |
| | G: | wasserstabiele Aggregate |
| water stable aggregation | S: | estabilidad hidrica estructural |
| | F: | agrégation |
| | G: | wasserstabile Bodenaggregate |
| watershed | S: | cuenca /hoya |
| | F: | bassin versant |
| | G: | Einzugsgebiet |
| watershed management | S: | manejo de cuenca |
| | F: | aménagement de bassin versant |
| | G: | kontrollierte Bewirtschaftung eines Einzugsgebiets |
| waterway | S: | desague |
| | F: | chenal de drainage |
| | G: | Wasserlauf, Wasserabzugskänel |
| weir | S: | vertedor, azud |
| | F: | déversoir, barrage |
| | G: | Wehr |
| wet sieving/ wet sieving analysis = WSA | S: | tamizado en agua, analisis de tamisado en agua |
| | F: | tamisage sous l'eau |
| | G: | Tauchsiebung (Gerold 1985), Nass-Siebanalyse |

Wischmeier Equation, see Universal Soil Loss Equation

## Y

| | | |
|---|---|---|
| yield sensitivity to erosion | S: | sensibilidad de la cosecha a la erosión |
| | F: | sensibilité du rendement à l'érosion |
| | G: | Ertragsanfälligkeit (für Erosion) |

## Z

zero tillage, see no-tillage

| | | |
|---|---|---|
| zone tillage | S: | labranza en fajas |
| | F: | travail du sol en bandes |
| | G: | Zonenweise Bodenbearbeitung |

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