THE USE OF TWO MODELS TO CALCULATE SOIL LOSS IN MBERENGWA COMMUNAL LANDS, ZIMBABWE

by

John Andrew Bryden
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We accept this thesis as conforming
to the required standard

[redacted]

Dr. E. Van der Flier-Keller, Supervisor (Centre of Earth and Ocean Research)

[redacted]

Dr. M.C.R. Edgell, Departmental Member (Department of Geography)

[redacted]

Dr. E.A. Roth, Outside Member (Department of Anthropology)

[redacted]

Dr. D.V. Ellis, External Examiner, (Department of Biology)

University of Victoria

Supervisor: Dr. Eileen Van der Flier-Keller

ABSTRACT

The potential of using the Universal Soil Loss Equation (USLE) and the Soil Loss Estimation Method for Southern Africa (SLEMSA) to calculate soil loss in the Mberengwa Communal Lands of Zimbabwe is investigated. Both models have been used to predict soil loss over large areas of subsistence agriculture in the developing world. Design of the USLE was based on data gathered on conditions common to temperated latitudes of the U.S. In spite of the word "universal", the model was intended not to use globally but to slow soil erosion by water in areas of American commercial agriculture. The SLEMSA model originated in Zimbabwe. While it stresses the importance of ground cover to protect soil from high energy convective rainfall, SLEMSA also was designed for conditions disimilar to that found in Mberengwa's communal lands. Both models require information about soil erodibility, rainfall erosivity, slope angle and length, cropping practices and conservation methods. Both the predicted quantity and the distribution of soil loss vary considerably between the two models. While no conclusions can be made about the relative accuracy of the two models, the wide variation in results indicates that much research is needed in order to accurately model soil erosion in areas of subsistence agriculture.

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Dr. E. Van der Flier-Keller, Supervisor (Centre of Earth and Ocean Research)

[redacted]

Dr. M.C.R. Edgell, Departmental Member (Department of Geography)

[redacted]

Dr. E.A. Roth, Outside Member (Department of Anthropology)

[redacted]

Dr. D.V. Ellis, External Examiner, (Department of Biology)

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CHAPTER ONE

Introduction

1.1 Food Security in Africa

Soil erosion will remove about 18% of the total tropical rainfed cropland by the year 2000 and reduce present crop productivity by about 29% (FAO, 1984). At the same time there is little quantitative data regarding the relationship between different subsistence practices and soil loss, the current rates of erosion associated with tropical ecosystems, or what acceptable levels of erosion may be (Lal, 1988).

Increasingly, food security is becoming a problem in Africa. It is at least in part linked to soil loss and the declining productivity of the small farmer. In Africa, as it was in North America before the 1930s, small farms support the majority of the population. It is in the interest of the population of Africa and the world at large that declining soil productivity be reversed.

A need exists in the developing world for an effective way to predict soil loss from erosion. The identification of soil loss distribution and its quantification are necessary to make effective decisions concerning the allocation of limited funds. Bodies such as the Food and Agricultural Organization (UNFAO) of the United Nations and tropical research centres such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and the International Institute for Tropical Agriculture (IITA) in Nigeria all recently have explored potential means to accurately predict soil loss.

The number of people in developing countries who are dependent on successful crop and livestock production is increasing, while at the same time soil erosion leads to a reduction in the amount of available agricultural land (Stocking, 1985). Africa, with the largest continental land mass found between the tropics of Cancer and Capricorn, is the only continent where per capita food production has decreased in the past twenty years (Wright, 1986). As of 1982 twenty-six subsaharan African countries with a total population of 150 million were reporting food shortages (Stocking, 1985).

1.2 The case of Zimbabwe

A recent estimate suggests that 20-30% of young children in the rural areas of Zimbabwe are undernourished (Bratton, 1987). These rural areas of subsistence agriculture, termed the communal lands or peasant farming areas, are facing severe population pressures with a growth rate of 3.6% per annum and a doubling time of under twenty years. Aerial remote sensing has determined that 1.8 million hectares of land in Zimbabwe (out of a total area of 39 million hectares) are classified as seriously degraded (Whitlow, 1988b). Most (83%) of this eroded land is located in peasant farming areas, where survival is tied to existing soil conditions.

1.3 Ethnic Background

The people of Mberengwa are mostly Karanga (Tabex, 1987). The Karanga are a linguistic and cultural subgroup of the Shona, the largest single ethnic division within Zimbabwe, making up 75% of the total population. The Shona themselves are a branch of Bantu-speaking peoples who arrived about 300 A.D. according to the Bantu migration theory .

European settlers moved into the areas in the late nineteenth century, predominantly from what is now South Africa and primarily in search of gold. The massive strikes of the Rand were never matched in Zimbabwe and disappointed entrepreneurs quickly turned to agriculture as an alternative source of income.

1.4 Land Division

In the early twentieth century land was divided along racial lines. Land allocated to European settlers was usually positioned along the railway in areas with a better natural resource base (Stocking, 1985). Initially the reserves set aside for the African population were not greatly affected by soil erosion. Around 1911 it was calculated that population densities in the tribal areas were low, at about 12 people per square mile. The colonial administration and the subsequent Rhodesian government gave little assistance or attention to the peasant farmers who were separated geographically and economically from the slowly expanding network of roads, distribution, and collection centres. Resources were directed to the European commercial farms in an effort to make them competitive, primarily in the international tobacco market.

The result of this early land distribution is that present day communal lands (the former tribal trust lands or reserves) are located around the periphery of the more centrally located commercial farms. As in other parts of Africa, this has added the problems of marginality and remoteness to any programme focused on the improvement of subsistence agriculture, including efforts at soil conservation.

1.5 Economic Constraints

Because Mberengwa and other Communal Lands are not easily accessible, small farmers must pay extra transportation costs for the delivery of any agricultural inputs such as machinery, fertilizers, or pesticides. As well, the scale of production is too small to make use of large-scale farming technologies or to have access to commercial services (Bratton, 1987). Inadequate finances to purchase oxen reduces draft power, slowing the early preparation of land before the first rains arrive.

Farming in Mberengwa is labour-intensive with the primary goal being to produce enough to feed family members throughout the year. However, declining soil fertility and shortages of land have caused family members (usually young males) to look for work outside of their community. In many places in Africa, this out-migration has resulted in a labour shortage within subsistence agriculture. Inadequate labour supply prevents timely land preparation, leads to late sowing, and delays early weeding (Doggett, 1986). These factors all play a role in reducing crop growth and ground cover during the rainy season, leading to increased soil erosion.

1.6 Physical Constraints

The communal lands in Zimbabwe generally border the highveld plateau and are characterized by low, erratic rainfall, steeper than average slopes, and infertile soils (Whitlow, 1988b). Mberengwa has no perennial rivers. The region's largest river, the Mwenezi, flows through the study area for only a few months during the rainy season and is dry for the remainder of the year.

The crystalline basement that underlies much of Mberengwa (and much of Africa) results in discontinuous pockets of ground water found in overburden or stored in isolated fractures of the granitic bedrock (Wright, 1986). As a result, subsurface water is often both difficult and expensive to find.

1.7 Land Tenure

Zimbabwe (known as Rhodesia before 1979), remains a dualistic agricultural economy with a large-scale, privately-owned commercial sector coexisting alongside peasant farms associated with communal grazing. These two sectors differ widely in structure, ownership and size. The average land area for the commercial farms is 3000 ha while the average holding for the Communal Lands is 3 ha plus grazing (Bratton, 1987). As with traditional agriculture in much of Africa, livestock are individually owned, but grazing and water resources are shared by the community (Nestal, 1986). Fields for grain are assigned to families by local chiefs and small vegetable gardens are kept near households. Livestock are kept from fields during the growing season, but after harvesting when the rains have stopped, ungulates are free to roam anywhere in search of vegetation and water. This fact has important implications for the lack of success of certain conservation techniques that are often employed.

Tropical soils typically have low fertility levels (Grant, 1981). In the past this situation was compensated for by shifting cultivation, allowing land to lie fallow for more years than it was used. In Mberengwa, as in much of Africa, this system is being abandoned as population pressures build (Aina, 1979; Madimu, 1985). Sedentary farming is the remaining option, with fields becoming increasingly fragmented as population increases. Whitlow (1988b) suggests that both economic and physical constraints, combined with population densities and communal grazing rights have led to the degradation of soil conditions in areas of subsistence agriculture.

1.8 Conservation - Past and Present

The Zimbabwe Department of Conservation and Extension

(CONEX), with a mandate similar to the Soil Conservation Service of the U.S.D.A., was formed in 1948. Stocking (1985b) suggests that in this early post-war period CONEX was technically one of the better soil conservation services in the world. In the late 1940s and through the 1950s Zimbabwe was in direct competition with the southeast region of the United States for the European market in tobacco products. Both agriculture and soil conservation were supported by an active research section (Research and Specialist Services), the infrastructure for which exists to the present day. During the early 1950s a policy of obtaining extensive national aerial photographic and topographic coverage also was put into place.

However, government research and the diffusion of information at this time was limited to areas of commercial agriculture. Traditional agricultural methods in the communal lands and subsistence crops such as millet and sorghum were all but ignored by research and extension services. Any conservation or extension work that did occur in the communal areas was slowed in the 1960s and 1970s as the civil war in Rhodesia intensified, culminating in the eventual withdrawal of all extension workers in the 1970s (Whitlow, 1988b). During this time conservation services throughout the country suffered as manpower and financial resources were being redirected to the military.

As the reins of government passed to the black majority in 1980, many of the old guard within the country were concerned that those now in charge would not have the same commitment to soil conservation as those previously in charge. In addition, implementing soil conservation policies has often been difficult in former African colonies. In the pre-1945 period, campaigns to prevent soil erosion were often teamed with the collection of hut taxes (Stocking, 1985b). The insistence that small farmers reduce their herd size to match a calculated carrying capacity often led to antagonism towards extension workers and politicians (Stocking, 1985a). Large-scale conservation projects such as bench terracing were viewed as a drain on the subsistence farmer's most important assets, time and labour, without producing any noticeable increase in soil fertility. Upon independence, the new government of Tanzania denounced the policy of soil conservation as a tool of repression for past colonial governments. In both Kenya and Zambia the governmental infrastructure dealing with conservation was removed.

Zimbabwe did not abandon soil conservation programmes, and since 1980 government policy has emphasized the importance of development in the areas of peasant agriculture (Whitlow, 1988a). The present government has repeatedly given its support to resource conservation in rural areas (Whitlow, 1988b). However the implementation of conservation policy has been slowed due to a shortage of staff and financial resources. As well, in 1982 and 1983, reduced rainfall in the growing season combined with deteriorating soil conditions necessitated the supplementary feeding of 2.1 million people, one half the estimated communal land population (Bratton, 1987). Current conservation policy is largely limited to a national reafforestation program and the settlement of people from overpopulated Communal Lands into areas purchased from the commercial sector or recently cleared of tsetse fly.

CHAPTER TWO

Research Objectives

The UNFAO has grouped soil degradation processes into six categories (FAO, 1979). These are wind erosion, excess of salts (subdivided into salinization and sodification), chemical degradation (subdivided into acidification and toxicity), physical degradation, biological degradation, and the most important, water erosion. Water erosion itself can be subdivided into sheet and rill erosion, gully erosion, and mass movement. This study will examine the two major methods of assessing soil loss from erosion due to water:

1) The United Nation's Food and Agriculture Organization (FAO) version of the Universal Soil Loss Equation (USLE) .
2) The Soil Loss Estimation Method for Southern Africa (SLEMSA).

USLE methodology, developed for American climatic conditions, is often used to determine soil loss in the developing world. If the technique is changed, it is usually to deal with data shortages, and not to adapt to the often very different nature of local physical conditions and farming practices.

African soil conservation projects often have a sense of urgency. In the case of the USLE, it is thought by some that any movement away from existing calculations of erosivity of rainfall and erodibility of soil would both increase costs and delay projects established to study subsistence agriculture (Onstad, et al. 1984).

Large areas of Zimbabwe's small-scale low input (SSLI) agriculture are experiencing extensive soil erosion and declining yields. If the distribution and extent of soil loss could be accurately modelled, the limited resources available for soil conservation could be directed to the areas with the potential of experiencing the greatest losses.

Determining the distribution and quantity of soil loss has been hampered in the past by the use of models designed for temperate regions and/or inadequate data concerning both the physical and cultural factors involved in subsistence agriculture. As a result, predictions of soil losses at the field level may be inaccurate when used outside of the United States. Also, scarce primary and secondary sources of data in the tropics have often limited the use of predictive models to highly generalized small-scale studies.

Both the USLE and SLEMSA were originally designed to calculate erosion levels for individual fields of farmers involved in commercial agriculture. Once the extent of soil loss is determined, the models are then used to decide what methods the farmer could employ to reduce soil loss within that field to tolerable levels. Within a single field, soil conditions were expected to be fairly consistent.

Zimbabwe has an excellent record of erosion research (e.g. Grant, 1981; Mashiringwani, 1983) but seldom have the fruits of that research been applied to a large-scale study in an area of SSLI agriculture. The Zimbabwean model SLEMSA is currently being used to produce national erosion potential maps. However, in the past both the USLE and SLEMSA have proved most effective as a planning tool in the fight for soil conservation at the individual commercial farm level. While it may be possible to use these two soil erosion models to produce a qualitative representation of the distribution of potential erosion over a large area, they do little to identify the appropriate agricultural and conservation measures that are needed at the field level to reduce soil losses and that can be practically applied by the SSLI farmer. The ability of both models to accurately predict both the quantity and distribution of soil loss associated with SSLI agriculture remains to be proven.

A need exists for a simple accurate soil erosion model to organize information in Zimbabwe and other areas of less developed countries, where large numbers of small farmers live in dispersed and remote locations.

The objective of this study is to:

Determine if the two soil loss models (the FAO USLE and Zimbabwe's

SLEMSA) can be used to adequately predict soil erosion quantities in a 100 square km area of small scale low-input agriculture within Zimbabwe's communal lands. (Keeping in mind that the predictive methodology of these soil loss models has proved most effective in combating soil erosion when used at the field level, comparison of results of the two models will be used to estimate their effectiveness as soil management tools in the developing world.)

This study will also:

- Describe the environmental and agricultural conditions that lead to excessive soil erosion by water in this region.

- Examine the basic premises, differences and similarities of the two soil loss prediction models most commonly used in the tropics.

- Look at the potential of the individual models answer the following questions using data gathered from Mberengwa Communal Lands:
    a) How closely related are the soil loss quantities and distribution predicted by the two models within the study area?
    b) Can the models be used to identify land use and conservation practices that will reduce erosion rates to

tolerable levels?

- What data are available that comply with the variables upon which the models are based and what research has to be undertaken for their successful application to areas of subsistence agriculture?

CHAPTER 3

Study Area

3.1 Location

This study will examine soil erosion from Mberengwa Communal Lands, one of several areas of small-scale peasant agriculture in Zimbabwe. It is located in the drought-prone southern portion of the country (Figure 1).

Mberengwa communal lands are between latitude 20 degrees 45'S and 21° 00'S and longitude 29° 00'E and 29° 45'E.

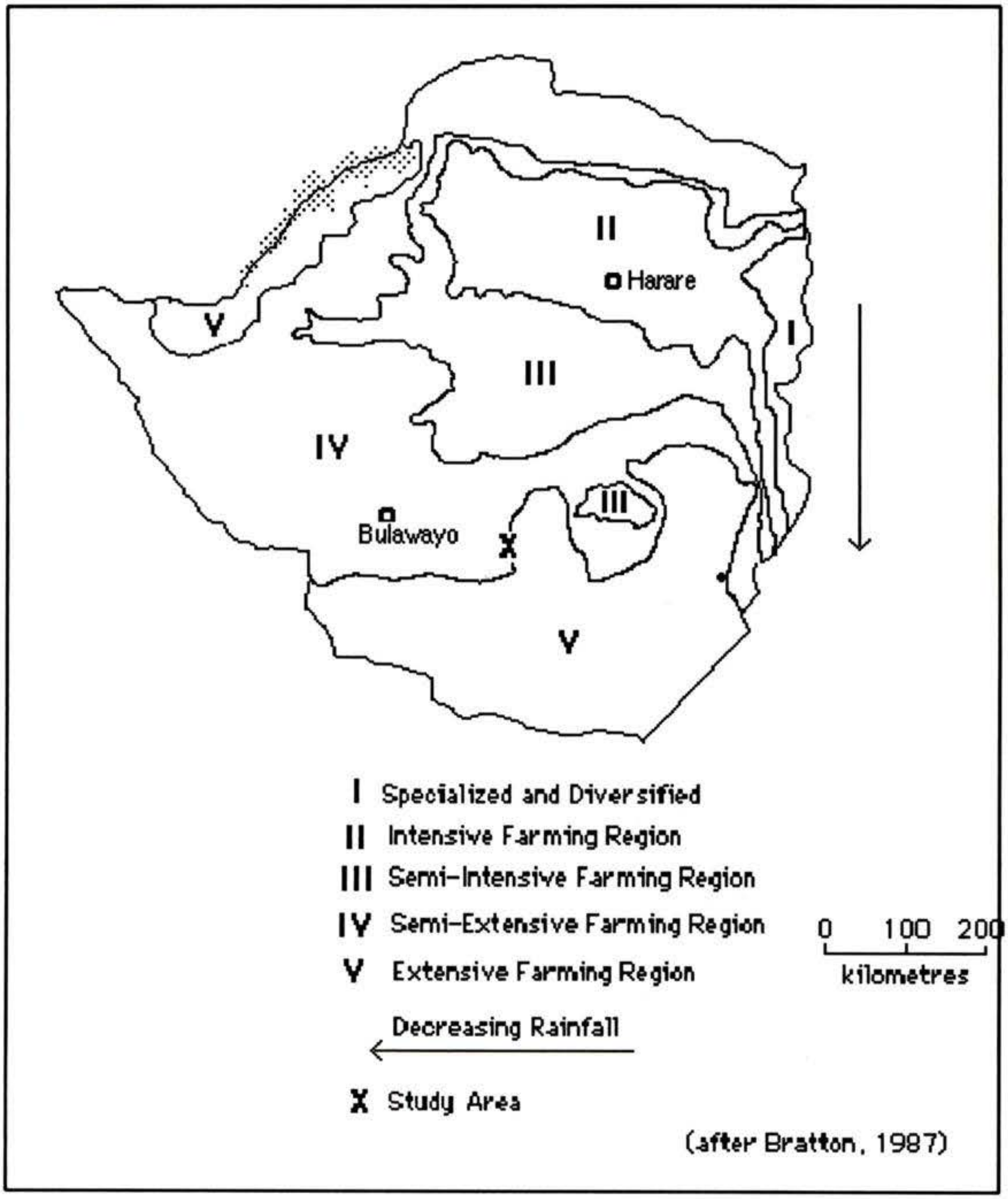
The boundaries of the roughly 100 km^2 were chosen to include:

a) Areas sampled or travelled to frequently by the author on foot or by vehicle.

b) The range of landforms and land uses most common to Mberengwa specifically and Zimbabwean communal lands in general.

For the purpose of government planning, Zimbabwe has been divided into five agro-ecological regions (Figure 1). The major criteria for these divisions are both the amount and reliability of rainfall which affects the distribution of natural vegetation and agricultural potential. Mberengwa is located in the southern portion of Region IV, an area where acceptable yields of even drought-resistant

FIGURE 1: ZIMBABWE NATURAL AGRO-ECOLOGICAL REGIONS



(after Bratton, 1987)

millet and sorghum cannot be guaranteed. Close to 75% of the Communal Lands are found in Regions IV and V - areas of low agricultural potential. The remaining 25% of the Communal Lands are found in regions I - III and this small group of farmers in 1983-1984 produced 80% of the maize surplus sales derived from peasant agriculture (Bratton, 1987).

3.2 Local Soils and Sampling Methodology

Tropical soil erodibility tends to increase further away from the equator while erosivity and total rainfall decrease. This is partially because excessive leaching in high rainfall areas close to the equator produces aluminum and iron sesquioxides (Al_2O_3, Fe_2O_3) which bind soil together producing a coarse texture from clay particles. Further away from humid areas, leaching is reduced and sesquioxide-rich Oxisols are generally replaced with coarse textured, poorly structured Alfisols (U.S. Soil Taxonomy). The forest-grassland transition zone of the savanna associated with alfisols has generally undergone more extensive clearing and sedentary agriculture than the tropical rainforest. As a result, the already fragile aggregate stability of savanna soils over a wide area has degraded over time as its protective cover has been removed (Roose,1980).

Much of Zimbabwe including Mberengwa is covered with a range of sandy soils weathered in situ from coarse-grained granite. The dominant soils of Mberengwa are classified as Fersiallitic (Stocking &

Peak, 1986), a Zimbabwean classification which corresponds broadly to Alfisols and Luvisols of the FAO/UNESCO classification.

Soils in the southern portion of the study area are predominantly Lithosols along the Sandawana ridge associated with a complex of metamorphic rock. The coarse sandy texture of Mberengwa's Fersiallitic soil is related not only to parent material but also to selective erosion with finer material being transported away by surface runoff. Because they are sandy in texture they have a low water holding capacity and very low base saturation.

Mberengwa's soils have other unfavourable physical properties: a compact, massive structure which impedes rooting, and a tendency to crust after heavy rains and to set very hard when dry. The problem is made worse amongst surviving shrubs and trees where the ground surface is rendered impervious by hoof compaction. Most soils in the local area have formed in situ from granitic parent material, are rich in quartz and do not contain the sesquioxide cements of more highly weathered Ultisols and Oxisols. Also, they do not have the quantity of organic matter of more humid regions, thus they are unable to form a lasting stable structure (Webster & Wilson, 1986). Highly weathered clays also contribute to soil aggregates that rapidly break apart upon wetting.

Coarse-textured soils containing little organic matter are not very fertile. As the percentage of sand increases, the yield of important crops such as maize, and protective vegetative cover decreases. The organic matter content of the study area's soils has probably been diminished further because of increased soil temperature and aeration due to cultivation. Accelerated surface runoff compounds the problem even more. These coarse-textured soils contain only very small amounts of exchangeable calcium, magnesium, and potassium. Soil water makes its way quickly through the profile; therefore nutrients like potassium and available nitrogen can be leached easily beyond the root zone.

The low organic content of Mberengwa's degrading soils not only increases their inherent erodibility; it also contributes to reduced yields leading to lower percentages of effective ground cover. The lack of humus is linked to shortages of nitrogen and sulphur resulting in decreasing crop yields, less plant cover, and increased erosion due to rain-splash. The most important limiting nutrients for successful crop growth in this region are nitrogen, phosphorus, and sulphur. Maize is a non-leguminous crop and the shortage of available nitrogen is a major limiting factor for its success. Because chemical fertilizers are not readily available to Mberengwa's subsistence farmers, nitrate supplies are dependent on decomposing organic matter from manure or plant material applied to the soil. Most Zimbabwean soils are inherently low in phosphates, a situation which can seriously limit root growth. Healthy roots are needed to make use of all available soil moisture, especially in the coarse-textured, droughty soils of Mberengwa.

Sulphur is associated with the presence of organic matter. In the sandy permeable soils of Mberengwa, any available sulphate associated with the low levels of organic matter is probably leached beyond reach of many plants. Peanuts, which are needed to build up nitrogen levels in local soils, require high levels of sulphur; therefore their yield is diminished. Only small quantities of potassium are needed and the granitic sands of Zimbabwe generally release sufficient amounts as they are slowly weathered (Grant, 1981).

A factor which adds to the complexity of determining the distribution of tropical soil erodibility is the development of catenas. Catenas are a differentiation in soil formed on a uniform parent material and result from differences in moisture regimes from the top to bottom of a slope, as well as the effects of the lateral movement of water. Catenas are common in tropical areas where mean annual rainfall is seasonal and ranges from about 550 mm to 950 mm (Mberengwa's annual average is at the low end of this range). On lower-slope sections soils are often mottled under the influence of a seasonally fluctuating water table, while those at the base are usually gleyed. Differences in drainage can lead to different clay mineralogy, with kaolinite the common silicate clay mineral in higher well-drained soils and smectite in lower poorly drained locations. Montmorillonite has a much higher cation exchange capacity (CEC) than kaolinite which has a lowered ability to retain nutrients and maintain stability. Within a soil catena in Zimbabwe soil factors can vary significantly, not only in organic matter and moisture content but in clay mineralogy as well.

In total 30 separate soil samples were brought back to Canada from the Mberengwa study area (Table 1). Samples were gathered during May and June, 1988. They represent a range of horizons for 10 individual site profiles. The number of sample sites was limited and they were unevenly spaced where their impact on local farmers would be minimized (Figure 7). Sample sites were also based on judging which locations were representative of both land use and soil type. Sample sites reflect the most commonly occurring soil type occupying the greatest area as interpreted from aerial photographs *Bulawayo 1735 and 1736* (1985). Because there is little horizon differentiation in tropical soil profiles, surface samples were taken from a standard 0-10 cm. depth for all sites. At present it remains an assumption that samples reflect average soil conditions throughout the study area. The Southern Rhodesia Geological Survey #43 (Worst, 1956) (combined with air photo interpretation) was used along with these profiles to produce a map showing the local distribution of soils within the study area (Figure 3).

Sites 1-5 and 8-10 were taken from Fersiallitic soils formed on granite. The samples represented the two major land uses for this soil type - grazing (sites 3,4,5,8, and 9) and cultivation (sites 1,2 and 10). Visually, it was obvious that the upper horizons of all profiles had very limited organic matter content. Samples used to calculate erodibility of sites were taken from 0 to 10 cm. Samples were also taken at depths of 20, 40, and 60 cms. at site 9 (grazed fersiallitic soil) and 20 and 80 cms at site 10 (arable fersiallitic soil). The darker, possibly more fertile fersiallitic soils found at the base of soil catenas were not sampled.

The broad band of lithosolic soils running from east to west across the study area was also sampled (sites 6 and 7). These soils carry much more forest cover than the fersiallitics and are predominantly used for grazing. The break between fersiallitic and lithosolic soils is easily determined through air-photo interpretation. The two soils coincide with a sharp break in parent materials demarcated by large differences in soil colour, geomorphology, vegetative cover, and land use.

3.3 Rainfall

Of all the physical constraints on agriculture in the Communal Lands, the lack of water and rainfall unreliability are major limiting factors. Within Zimbabwe, rainfall tends to decrease from north to south and east to west. At the same time total rainfall in the north varies by only about 20% from year to year whereas in the south annual

TABLE 1:

SOIL ORGANIC MATTER CONTENT OF MBERENGWA SAMPLES:

SITE LOCATION	% ORGANIC MATTER
1) Termite mound (Marufu field)	0.2
4) Marufu field (80 cm.)	0.1
5) Masarira field (0-10 cm.)	0.1
9) Masarira field (0-10 cm.)	0.0
10) Fenced Grassland (0-10 cm.)	0.1
11) Unfenced grazing (0-10 cm.)	0.1
12) Marufu field (20 cm.)	0.1
13) Fenced grassland (0-10 cm.)	0.1
14) Fenced grassland (0-10 cm.)	0.1
15) Sandawana Ridge (0-10 cm.)	0.3
16) Termite mound (Marufu field)	0.2
17) Sandawana ridge (0-10 cm.)	0.3
19) Unfenced grazing (20 cm.)	0.1
21) Unfenced grazing (60 cm.)	0.1
22) Unfenced grazing (0-10 cm.)	0.1
25) Marufu field (0-10 cm.)	0.1
30) Unfenced grazing (40 cm.)	0.1

FIGURE 2 : SAMPLE SITE LOCATIONS (APPROX.)

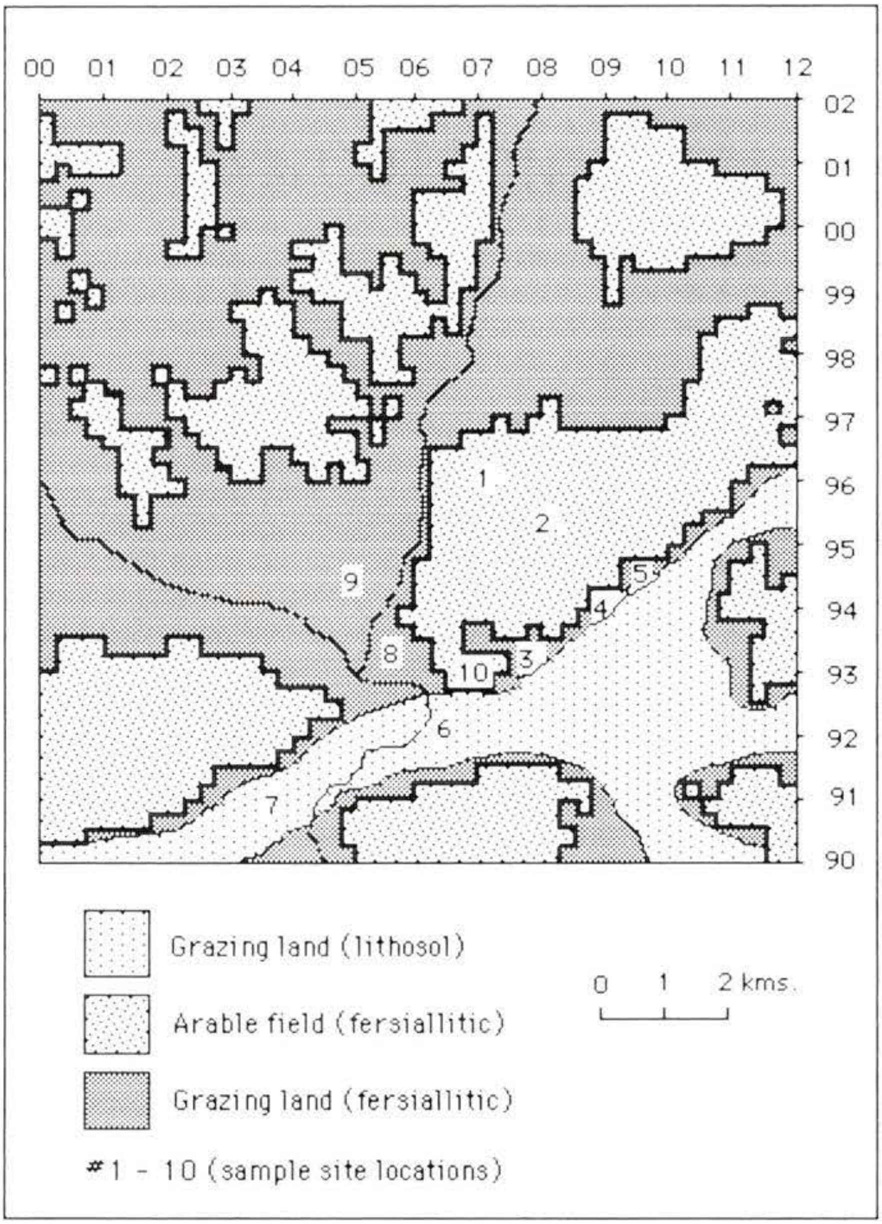
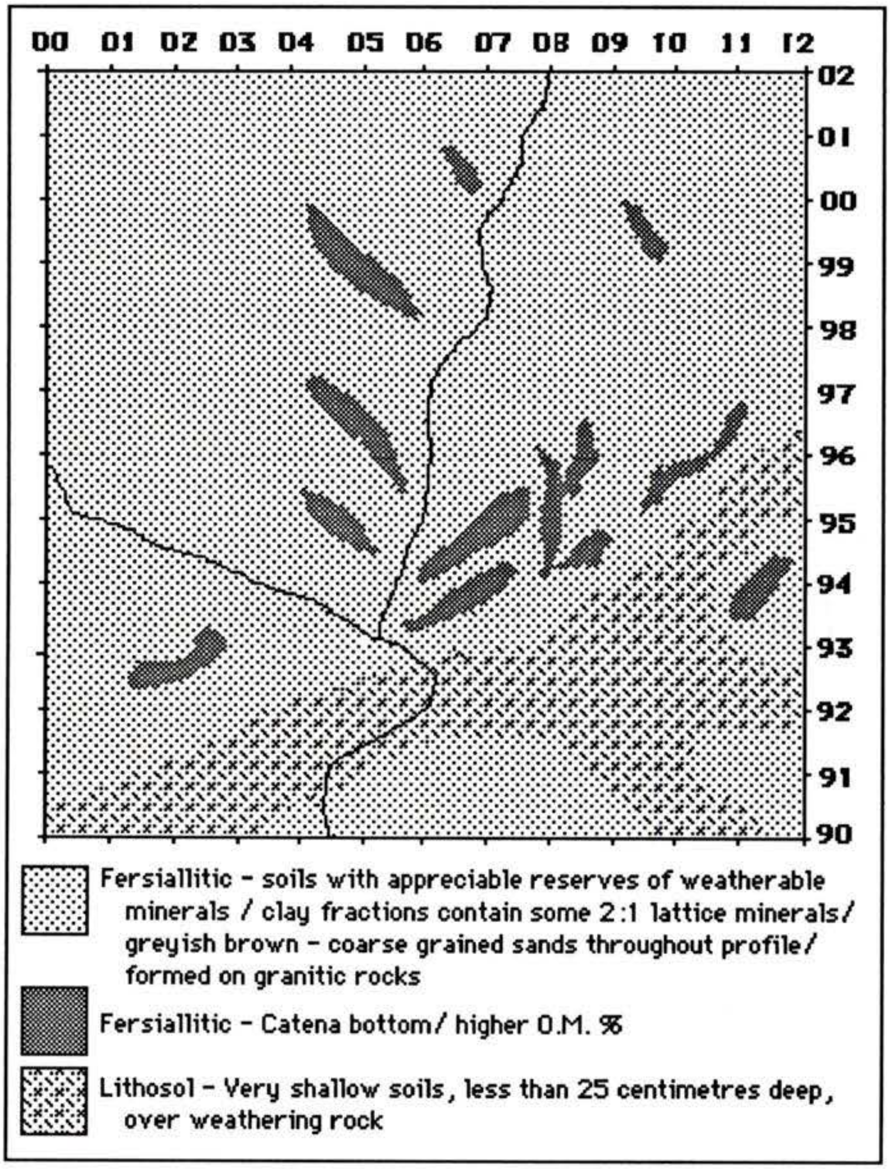


FIGURE 3: SOIL CLASSES IN MBERENGWA AREA



totals differ by as much as 45% (Bratton, 1987). Both surpluses and deficits can expose the soil to increased soil erosion. The south is also vulnerable to growing season dry spells. If a short dry spell occurs when drought-prone crops such as maize have a critical need for moisture, yields can seriously decrease.

Tropical rainfall differs from the frequent low-energy small storms of temperate regions. High-intensity, high-energy tropical rainfall results in a large percentage of water being lost as runoff. This factor coupled with steep slopes and soil exposed through cultivation has resulted in great soil loss (Sheng, 1982). Even in sub-humid to semi-arid tropical countries like Zimbabwe or Botswana, rainfall intensities of 150 mm/hr. are experienced regularly (Hudson, 1981). Tropical storms also have been found to have a large rain-drop diameter and high terminal velocity as each drop strikes the soil surface (dePloey and Gabriels, 1980).

Precipitation totals vary considerably during different times of the year in tropical areas with seasonal rainfall (Jackson, 1981). All areas of Zimbabwe generally have a single unimodal rainy season occurring during the summer months of November to March (Hudson, 1981). Much erosion is associated with a few erosive storms during the rainy season. Research undertaken in Northern Australia (which has a similar climate and soil to the study area) found that for 60% of all years tested a single event accounted for more than 50% of total annual soil loss (Edwards, 1985).

The ability to predict annual rainfall volumes and erosivity declines in tropical regions from the wet equatorial regions to areas of seasonal rainfall (Hulme, 1987). The same pattern is found from north to south within Zimbabwe. In terms of annual rainfall, Mberengwa lies on the shifting border between the climatic regions of semi-arid and dry savanna. Like many places with such climates, Mberengwa has poor rainfall reliability, not only from year to year but from decade to decade.

Mean annual rainfall in Zimbabwe varies from over 2000 mm in the eastern highlands to less than 500 mm immediately south of the Mberengwa study area (Stocking, 1973), a distance of approximately 400 kilometres. Rains can be even more localized with precipitation dependent on the changing location of isolated cumulonimbus clouds over a relatively flat plain.

Throughout Zimbabwe, the erosive energy of rainfall is generally highest between mid-January and mid-February (Stocking et al. 1973). However, in many years, erosive rains occur in October when crop cover is minimal or crops have yet to be planted. This situation was observed in Mberengwa during December 1987 when highly erosive rains fell on bare tilled fields which had been just recently planted, resulting in excessive loss of soil. During the rainy summer season Mberengwa, like the rest of Zimbabwe, experiences heavy rainfall from convective storms. However a small quantity of Mberengwa's winter precipitation falls as drizzle and light rain, due to the SE trade winds moving upslope towards the highveld (Chakela and Stocking, 1988).

3.4 Slope

Cultivation on steep slopes is common in many developing countries with soil losses often exceeding 100 metric t/ha/yr, far above any North American estimation of tolerable soil loss. Steep-slope cultivation is not as common in Africa as it is in Asia largely due to basic differences in geomorphology.

Approximately 15% of Zimbabwe is covered by large steep-angled granitic domes. These domes (or inselbergs) are surrounded by long sloping pediments (Whitlow, 1988). Surface runoff from this relief can result in excessive erosion, especially where pediment slopes no longer have a natural plant cover. Within Zimbabwe's communal areas these landforms are common. In Mberengwa, most cultivated fields are associated with long, low-angled pediments within the range of slope percentages covered by the USLE (2-18%). Percentages of the land surface associated with different slope angles in the Mberengwa study area can be seen in Table 2.

TABLE 2:
THE DISTRIBUTION OF SLOPE CLASS FOR MBERENGWA LAND USE

Slope Percentage	Percentage of Arable Land	Percentage of Grazing Land	Percentage of Total Study Area
≤3	73.5	30.3	48.0
>3- ≤6	15.8	28.8	25.8
>6- ≤9	6.3	21.2	18.2
>9- ≤12	3.2	9.0	5.7
>12- ≤15	1.1	2.8	1.6
>15- <20	0.0	1.2	0.7

3.5 Crop Choice and Ground Cover

By 1980, 80% of all grain produced in the communal lands of Zimbabwe consisted of maize. Millet and sorghum (Sorghum bicolor), traditional drought tolerant crops, made up only 11% and 3% of the total (Bratton, 1987). If the farmer feels confident enough that he or she will grow enough for family needs, cash crops like tobacco, sunflower and cotton are often grown in addition. A marketing board established to purchase grain surpluses is headquartered in Mataga approximately 25 km to the southeast of the study area.

Most farmers plant a combination of maize, millet and sorghum in case of drought. Maize, if it fails, provides minimal ground cover. Because of the relationship between cover and erosion, the decision to plant maize instead of millet, for whatever reason, may result in much more soil loss than if millet were planted (Whitlow, 1983). When (and if) ground cover finally reaches 40-50% in mid-January there is a rapid decline in soil loss.

Maize is, in many ways, a poor choice of staple crop for the drought-prone areas of Zimbabwe. Generally associated with lower yields than millet, it initially required the expansion of land under cultivation to maintain production at subsistence levels (Whitlow, 1988b). As well, millet can survive storage longer than maize. Despite its lower tolerance to soil-moisture deficiencies, farmers depend on maize even in areas where the success rate is only one year out of four (Bratton, 1987). Small farmers usually grow drought-resistant crops at the same time as the maize crop (Stocking, 1985). If the rains fail, millet and sorghum play the role of insurance against seriously reduced maize yields. Growing maize is the result of introduced urban preferences as well as an associated reduction of labour requirements. Machinery has not been developed to separate millet from the chaff and doing so requires much effort and time, whereas maize is easily separated from cobs. Unlike maize which is shielded by husks, pearl millet and sorghum require constant monitoring against bird damage (Shumba, 1984). Surplus maize also has the potential of being sold at higher prices than other grains at local marketing boards.

In drought-prone regions like Mberengwa small grains are more suitable. Both millet and sorghum have a much reduced failure rate in comparison to maize and provide a more reliable ground cover from year to year. Traditional crops like millet and sorghum are drought resistant, require fewer inputs and provide a degree of yield stability from year to year. However, despite its link to excessive soil loss, maize remains the most popular crop in Midlands province where Mberengwa is located. If, for whatever economic reason, Mberengwa farmers insist on growing maize, one function of a map of potential soil loss distribution would be to identify possible slopes to avoid. Especially for steeply sloped fields within the study area, crops that provide more potential cover like millet instead of drought-prone maize could then be grown.

Maize and the smaller grains, millet and sorghum, are intercropped with curcubits (the pumpkin family) (Bratton, 1987). This practice makes effective use of soil moisture and decreases the amount of ground exposed to raindrop impact. In Zimbabwe, inoculated groundnut seeds are expensive to buy and transport and are generally unavailable to farmers in the communal lands. In 1988 a 50 kg bag sold for $28-$30 plus transportation (Madimu, 1985). As a result the beneficial-nitrogen fixing attributes of these legumes are often passed by in favour of grain, the seeds for which are more readily available.

In Mberengwa all crop cover is highly variable both in size of individual plants and spacing between them. This is largely due to considerable variability in soil fertility over small distances. Past breaching of contour bunds has produced fields with uneven erosional surfaces. Contour bunds are earth banks 1.5 to 2 metres wide, built across the slope to act as an obstacle to surface runoff and to divide the length of a hillside into shorter sections (Morgan, 1980). The sandy soils of Mberengwa have a natural low-nutrient status which has been degraded further through overuse. Attempts at improving fertility are usually carried out by applying small quantities of available animal manure. Manure used for its nutrient status is not applied evenly over a field because of limitations in quantity and available technology. At the same time areas near termite mounds may be more fertile due to textural and organic matter differences (Grant, 1981).

Planting methods and timing also contribute to a highly variable crop cover. When it comes to determining percentage of crop cover, broadcast crops such as millet and sorghum can be unevenly scattered (Hudson, 1981). Planting is carried out in Mberengwa from early October up to the last two weeks of December to compensate for unpredictable rainfall. This extreme range in planting dates reflects the problem of availability of draught animals, as well as the replanting of crops that have failed early due to temporary cessation of rain.

The most effective method available in the communal lands for reducing the erosive energy of rainfall is to provide a protective vegetative cover or mulch. For the subsistence farmer, this practice is far less capital- and labour-intensive compared to other conservation practices such as the building of contour ridges or physical structures (Lewis, 1988). Mulching has the advantage not only of speeding the rate of infiltration, but also reducing topsoil temperature extremes, preventing surface sealing, and increasing crop yield. Compared to a standing crop, mulches intercept falling raindrops so near the ground that they do not have the distance required to regain any damaging velocity (Wischmeier et al. 1978). On the ground surface, runoff is impeded, reducing the total amount of soil material that can be transported. Mulches, if later incorporated into the soil, improve its physical structure, reduce inherent erodibility. slowly make nutrients available, and increase the potential for nutrient and moisture retention in the root zone.

In order to effectively protect soil from both rain-splash and overland flow there should be at least 5 tonnes per hectare of mulching material available. However crop yields in dry areas like Mberengwa with low-input agriculture do not produce enough plant residue for this purpose. Stalks of millet, maize, and sorghum, for example, have become important (and often, the only) fodder for cattle during the dry season as the carrying capacity of the surrounding grasslands has declined. In many cases plant material is quickly removed from the fields and fed to livestock in family kraals where the manure is concentrated to be added to fields at spring planting. Because cattle are free to roam during the dry season, this prevents other people's livestock from eating this valuable resource (I.M. Dube, personal communication, 1988). Plant stalks that do remain are eaten down to a few centimetres in height and have little effect on reducing the energy of both the rain and the wind.

Cattle are kept not only to pull a plough and for prestige; a farm's output is directly related to the amount of manure that is produced and subsequently added to the soil. The stalks or stover from harvested crops are fed to livestock. Animals are permitted to roam during the dry season as far as feasible, then returned to the household kraal each night. As a result some of the day's grazing, in the form of manure, can be collected. However, partially reflecting the declining nutrient status of Zimbabwean communal land soils, studies have shown that there are serious nutrient deficiencies in the manure itself (Mugwira, 1986).

The use of oxen-drawn ploughs has necessitated clearing more land than under shifting cultivation. Also, increased draft power has enabled more land to be cleared (Whitlow, 1988b). However, farmers with healthy oxen are better able to plow and plant early enough to take advantage of the first rains of the season. This usually results in higher yields and more effective ground cover to protect soil from the energy of tropical rain storms.

Soil erosion and lack of effective vegetative cover are also problems outside of the arable fields of Mberengwa. An approximate five % cover of scattered Acacia trees remain in the areas of fersiallitic soils formed on granitic parent material. Largely due to overgrazing, both grass and litter cover are decreasing and perennial grass species are being replaced by annuals. Annuals take longer to establish themselves at the beginning of the rainy season, thus leaving the ground exposed for a longer period of time.

3.6 Conservation Practices

In Mberengwa the two main conservation practices employed are contour cultivation (ploughing along the contour) and regularly spaced ridges of earth (contour bunds). In the communal lands of Zimbabwe contour cultivation is the normal practice when erosion is serious and the slope is greater than 2%. Past observations and experiments have indicated that contouring is most effective on slopes ranging from 2% to 7%, and less effective on near-level areas and on steeper slopes (Hudson, 1981).

Contour bunds are a common conservation practice used by small farmers in the tropics to reduce slope length. Reduction in slope length reduces the probability of rill and gully formation (Shaxson, et al, 1989). Besides reducing slope length, bunds sometimes form a small water storage area on their upslope side, allowing increased infiltration. Morgan (1981) suggests they are suitable for slopes up to 12%, beyond which they are at risk of being breached . Within areas of subsistence agriculture the construction of contour bunds does not usually follow exact specifications. However on low-angled slopes deviations in their alignment of up to 10% from the contour are acceptable without causing major runoff problems.

Elaborate conservation structures beyond basic contour tillage and contour bunds are not often maintained or even initiated. This is due to the few resources available other than labour and the small return that is derived from the effort these practices require under non-mechanized conditions. The range of conservation practices and crop choices that is employed by subsistence farmers cannot be varied or changed a great deal because of traditional land-use practices and economic constraints.

CHAPTER FOUR

Soil Erosion Models

4.1 General Information

Since the United Nations Conference on Desertification (UNCOD, 1977), an important journal dealing with soil erosion and degradation has been the *Desertification Control Bulletin*, published by the United Nations Environment Programme (UNEP) in Nairobi, Kenya. The journal deals with soil erosion problems, generally within the tropics, and occasional articles have dealt specifically with Zimbabwe (Darkoh, 1986). The issue of soil loss in Zimbabwe and its relationship to the use of marginal land is discussed by Whitlow (1979, 1982, 1985). Nyamapfene (1986), and Kanyanda (1985) deal more specifically with the distribution and description of problem soils throughout the country.

4.2 Soil Loss Models (USLE)

Since its introduction in the early 1960s the Universal Soil Loss Equation (Wischmeier & Smith, 1978) has become the most important planning tool of the Soil Conservation Service branch of the U.S. Department of Agriculture (Meyer, 1985). Wischmeier and Smith used the collected soil-loss data from 7000 test plot years and 500 watershed years of research from the U.S. to develop the equation. The equation brought systematic quantification to soil management for the first time. As well as revealing erosion totals, it allowed the numerical calculation of what types of ground cover and conservation practices were needed to meet tolerable rates of erosion for an area. Originally, a factor that limited the universal application of the USLE was that it had not undergone standardized metric conversion. To enable it to be employed in an international setting, a conversion of the universal soil loss equation to SI metric units was carried out by Foster et al. (1981).

Due to its success in the United States the equation and variations of it are now employed worldwide (FAO, 1979). Applications in Europe and tropical regions are far outside the range of collected data on which the USLE is based and led Wischmeier to publish a disclaimer (1976). Along with differences in soil types, average slope and rainfall, the economic and social conditions influencing tropical agriculture are quite different from those found in North America (Hudson, 1985).

Both erosion models SLEMSA and FAOUSLE are modifications of the American USLE equation. All three methods involve assessment by parametric methods. Separate factors are assigned values based on statistical analysis of past field tests. They are then combined in order to estimate potential soil-erosion rates. The basic USLE equation is as follows:

$$A = RxKxLSxCxP \tag{1}$$

where A = Soil loss (metric tons/hectare/year)

R = Rainfall factor

K = Soil erodibility factor

L = Length of slope factor

S = Slope gradient factor

C = Crop management or vegetative factor

P = Erosion control practices factor (FAO, 1983)

Across a landscape the values for different factors change (e.g. slope gradient), resulting in spatial differences in anticipated soil loss.

In the U.S., the value assigned to each parameter for a given agricultural area is determined from USLE test plot research by finding an equivalent rainfall regime, soil type, cropping practice etc.

For example:

Rainfall Erosivity, (R) = 300

Soil Erodibility, (K) = 0.6

Slope, (S) = 4%

Length of Slope, (L) =100 metres

Cropping Practice, (C) = 0.4

Conservation Practice, (P) = 0.8

Therefore soil loss due to water (A) = 300 x 0.6 x .65 x 0.4 x 0.8

= 37 t/ha/yr

The model also introduces the idea of tolerable levels of soil loss (T). Material removed through erosion below these rates is replaced by natural soil formation processes. If annual soil loss in metric t/ha/yr is determined to be above this tolerable rate of soil loss, the equation is generally used to look at what changes should come about in the various relevant factors in order to reduce erosion to these acceptable levels.

For example if T has been established as being 10 t/ha/year the equation can be employed to determine the necessary crop-management techniques (C). LS is calculated from slope percentage and length data as shown in Appendix A: figure 1. Tolerable soil loss (T) is substituted for soil loss due to water (A) from equation 1.

$$\boxed{\begin{aligned} C &= T/\mathrm{RxKxLSxP} && (2)\\ C &= 10/300\mathrm{x}0.6\mathrm{x}0.65\mathrm{x}0.8 && \\ &= 0.1 && \end{aligned}}$$

A management technique is then chosen having a value equal to or less than 0.1 as determined from past USLE test plot research.

Fairly recently Hudson (1981) has suggested levels of tolerable soil loss for different Zimbabwean soil types.

4.2.1 USLE Erosivity

Erosion by water is a function of both the inherent erodibility of a soil and the erosive nature of local precipitation (Hudson, 1981). Rainfall erosivity is related both to the energy contained in rainsplash and the quantity of water that runs off a soil surface. The volume of surface runoff is not only related to soil-surface conditions but also to the quantity and intensity of rainfall.

Within the Universal Soil Loss Equation the Erosivity Index is defined as the product of storm kinetic energy (KE) and the maximum 30 minute intensity (I_{30}) (defined as the greatest average intensity experienced in any 30 minute period during a storm). Early research showed that the factor most significantly related to erosion was the total kinetic energy of a single rainfall event. However, there remained variation in predicted erosion which was diminished by using the product of KE and the maximum 30-minute intensity. The resulting calculation EI_{30} showed a strong correlation with measured erosion rates in the United States (Hudson, 1981). An advantage of EI_{30} is that the only instrument needed to gather both types of information (KE and I_{30}) is a continuously recording rain gauge.

The rainfall-erosion index for a given area is determined by averaging the annual accumulation of EI_{30} during rainfall events over a 22 year period (Mutchler and Murphree, 1985). It is felt that this time period includes both cyclical effects and random variations in weather patterns (Wischmeier, 1976). Calculations of EI_{30} over long periods of time have resulted in the production of isoerodent maps for most of the United States. In order to identify erosivity for an area, where neither recording or non-recording rain gauges exist, the site must be located on an existing isoerodent map (Wischmeier and Smith, 1978) and a value obtained by linear interpolation.

Besides building an annual erosivity index for a region, a measure of the monthly or seasonal distribution of erosivity is necessary in order to understand the relationship between erosivity and the seasonal distribution of vegetative cover, tillage and other erosion factors (Foster, et al. 1982). In the USLE, annual variations in EI_{30} are used to help establish a crop management factor which is a function of both crop stage periods and relative rainfall erosivity within those periods (Moore, 1979). Within both erosivity equations (USLE, SLEMSA) the timing of erosive rains with respect to the percentage of crop cover is important in determining the amount of erosion that will occur.

In summary, calculation of the R factor for use in the USLE requires extensive rainfall data. This involves monitoring both individual storm energy totals and rain intensity (in mm per 30 minute period).

Rainfall-erosivity calculations, as part of water erosion assessments, have been carried out in many parts of the world. USLE methodology is described in detail by Wischmeier and Smith (1978). Of interest to this study are techniques employed in the developing world such as Iraq (Hussein, 1986), Western Africa (Roose, 1977) and Zambia (Pauweln et al. 1988; Lenvain et al. 1988). The distribution of rainfall erosivity throughout Zimbabwe is described and mapped by Stocking and Elwell (1976). This information played a role in the development of SLEMSA and is applicable to the model for estimating soil loss. Finally, more detailed and site-specific rainfall data are available from the Zimbabwean Department of Meteorological Services (1981).

4.2.2 USLE Erodibility

There are several factors that lead to one soil type being inherently more erodible than another. Clay particles in soil tend to combine with organic matter to form water-stable structures or peds with the bonds between soil colloids being protected from moisture and subsequent dissolution (Morgan, 1986). As a result, fine-textured clay soils have greater aggregate stability than coarser-textured, non cohesive sandy soils (Meyer, 1985). This is especially important for surface horizons where a content of more than 30-35% clay can increase splash resistance, preventing individual particles from being easily separated from the soil mass and subsequently lost.

Generally soils with 40-60% silt and less than 2% organic matter are the most erodible (Morgan, 1986). More specifically the most erodible particles, by both overland flow and surface splash, are in the range of 2 through 100 microns. This size class includes both silts and fine sands (using USDA particle size criteria). A soil type containing a large percentage of this size fraction will be susceptible to erosion by intensive rainfall and subsequent runoff.

The USLE erodibility (K) value is a reflection of the range of inherent soil characteristics that lead to different rates of soil loss from area to area. Within the USLE soil erodibility is a basic soil property that remains fixed over time. Calculation of K is determined from inherent soil properties and is kept separate from the complicating effects of soil management and tillage, in order to facilitate comparisons between similar and dissimilar soils.

Early in the development of the USLE, differences in soil erodibility were linked to five distinct soil parameters: the percentage silt and very fine sand (0.002 - 0.1 mm in dia.; the percentage sand 0.1 - 2mm in dia.); percentage organic matter; structure; and permeability.

Very fine sand ranging between 40 and 50 microns is not used to determine erodibility. Early research showed that these particle sizes behave more like silt in their susceptibility to erosion than larger sand particles (Pitty, 1978). As a result very fine sand is included with silt in calculations of K. Because infiltration rates and soil permeability can affect the quantity of surface runoff their measurement is important in determining K. While both texture and organic matter content are measured under laboratory conditions, values for structure and permeability are determined in the field using criteria described in the USDA soil survey manual (Romkens, 1985). Within the United States K values have been experimentally determined for a wide range of agricultural soils.

K is determined from the soil-loss rate over a set time period per erosivity index unit (EI_{30}) for the same time period. (Romkens, 1985). Within this ratio of soil loss to rainfall energy, "0" represents the least erodible soils and "1" the most erodible.

By using test plots that conform to USLE methodology some tropical soil classes have been given erodibility ratings in a few scattered study areas (Roose, 1980; Wiersum, 1985). The erodibility of most tropical soil has not been directly measured in the field. A limited amount of field work such as Roose's in West Africa has shown that the "K" index may be applicable to some fersiallitic and ferrallitic soils (1977).

4.2.3 USLE Slope

Both the length and the angle of a slope affect how much soil is ultimately lost. As the gradient of the slope becomes steeper the velocity of runoff escalates, and the ability of rain splash to transport soil down slope increases. As slope length increases so does the potential for accelerated soil loss due to erosion (Bergsma, 1974). Slope length is defined as the distance from a local high point to either a point where slope decreases to the extent that deposition occurs, or the point where runoff enters a well-defined channel. A slope two times as long as another intercepts twice as much rain resulting in an increase in the amount of water moving downhill. At the same time, the longer the slope, the greater the chance that runoff will accelerate, increasing its ability to transport soil. Increasing slope steepness intensifies erosion much more than does increasing slope length. Methods for determining the beginning and end of a slope as well as dealing with irregular-shaped slopes are discussed extensively by Dissmeyer (1980).

Both slope length (L) and slope angle (S) can be determined separately. However for the calculation of the USLE (and SLEMSA) the two factors are usually combined. The combined factor for slope length and steepness can be determined within the USLE using a combined slope graph (Hudson, 1981).

Early studies in the U.S. (Zingg, 1940) concluded that soil loss varies as the 0.4 power of percent slope. Building on this research the slope gradient equation established by Wischmeier and Smith for the USLE is:

$$S = 65.41 \sin^2 A + 4.56 \sin A + 0.065 \qquad (3)$$

Where S is the slope gradient factor and A is the angle of slope. The USLE is based and extensively tested, primarily in the U.S., on slopes of 2 through 18% with lengths ranging from 7 to 100 metres.

The USLE equation assumes that the standard slope is 9% (the accepted angle for most standardized test plots). In the field the actual slope will usually be different and the slope factor in the equation is a ratio to adjust for this, all conditions other than slope angle being held constant. The slope length factor (L) is defined as the ratio of soil loss from a field's slope length to that from a standardized 22.1 m (72.6 feet) length under identical conditions (Wischmeier et al. 1978). In the U.S. model the relationship between the standard conditions of a 9% slope and a length of 22.1 metres produces a topographic ratio of unity.

U.S. experimental data has indicated that soil loss is a function of the ratio between slope length of the field being studied and slope length of the standard test plot modified by an exponent based on slope angle. The slope length equation is:

$$L = (Y/22.1)^m \qquad (4)$$

Where Y equals slope length of the area being studied and 22.1 is the length of the standard plot size. Values for m are based on the relationship with slope gradient and are as follows (Singh et al. 1985) (Table 3):

TABLE 3:
Relationship between m and slope percentage

Slope Gradient	Value of m
less than 1%	0.2
1 - 3%	0.3
3.5 - 4.5%	0.4
5% and more	0.5

In the Fraser River Valley of British Columbia an attempt was made to overcome the difficulty of having little information available on slope length by assigning the standard slope length of 22.1 and L ratio of unity (1) to all slopes (Vold, Sondheim and Nagpal, 1985).

Calculating slope angle for a large area requires a far more generalized technique than the calculation of slope angle for a single field, the scale both the USLE and SLEMSA were originally designed for. In the British Columbian application of the USLE, average slope was taken to be the centre value in a range of slope angles assigned to each soil-mapping unit. However the accuracy of this method suffers from lack of knowledge about the proportion of different slope gradients within each mapping unit. Each slope class within the FAO method (Table 4) includes too much variation to be effectively used for the more detailed scale employed in the Mberengwa study area.

Soil degradation is such a widespread problem in areas of subsistence agriculture that the USLE is often applied to large tracts of land which incorporate a wide range of slopes (Stocking, 1972). Within the FAO version of the USLE it is suggested that if data are available the USLE combination of slope gradient and slope length is directly useable (FAO, 1978). For small-scale studies where only very generalized information is available the FAO method compresses factors L and S into a single topographic factor (T) (FAO, 1979). For T, soil-loss ratios have been assigned to the main slope classes of the FAO World Soil Map. Values for these classes have been altered slightly between 1978 and 1979. This writer has not been able to determine from the literature whether these changes were based on field research.

This method reveals a dependence on secondary sources other than field measurement to determine slope factors such as degree, length, and form (Bergsma, 1974). Data have been extracted in the past from aerial photographs and satellite imagery (Millington, Robinson & Browne, 1982). Existing topographic maps have been used to work out the combined LS factor in both India and Southern Africa (Stocking, 1987).

4.2.4 USLE Human Factors

Estimating soil loss also involves determining land use and assessing the extent and types of conservation practices in place. Values for these factors have been assigned within the USLE. However, they are based on usage and practices common in North America. Although this particular soil-loss equation is widely accepted as being reliable and has become a standard technique employed globally by soil conservation workers in the developing world (Morgan, 1980, FAO, 1965), it often involves a degree of extrapolation, especially when dealing with subsistence land use and conservation practices. To cover this deficiency in the USLE, values have subsequently been assigned to land use more commonly associated with tropical Africa (Roose, 1975; FAO, 1979).

Some work has been carried out in West Africa establishing P values for a limited variety of conservation practices (Roose, 1977). For example, tied ridging which creates closed basins that slow runoff and increase infiltration rates was found to have a value of 0.1 to 0.2. Anti-erosive vegetative buffer strips with widths varying from 2 to 4 meters had values ranging from 0.3 to 0.1. Neither of these conservation techniques are employed in the Mberengwa study area.

TABLE 4:
SLOPE CLASSES OF THE FAO WORLD SOIL MAP

Slope Class	a	ab	b	bc	c
Slope % range	0-8	0-30	8-30	8-30+	30+
Rating (1978)	0.01-0.2	2	5	8	10
(1979)	0.35	2	3.5	8	11.0

There are many factors involved in the plant-soil relationship that can affect erosion. Organic matter contributed by plant material and mixed in with mineral soil improves both structure and water holding capacity (Stocking, 1988). Structurally soil peds are bound together by plant roots and by chemical bonding between organic and inorganic material. Humus-rich soils in semi-arid environments are also able to maintain a more vigorous cover during times of rainfall deficit. On the soil surface plant cover reduces the impact of falling rain, slows overland flow, and increases infiltration rates along root channels. Decisions that the farmer makes concerning which crops to grow and what conservation practices to undertake therefore have a direct effect on total soil loss.

Factors R,K,L and S of the USLE represent susceptibility to erosion of land while C and P represent the factors which are used to counteract soil loss. Because the USLE was designed not only to predict but to also manage erosion rates, inclusion of the C and the P factors (the variables most easily manipulated by small farmers) is very important.

Not only the type but the timing of the agricultural practices the farmer chooses are of key importance. Total soil loss depends largely on how much erosive rain falls during the time period when crop and management practices provide the least protection. Within the soil-loss equation, the higher the numerical value assigned both to C and P the greater will be the resultant soil loss (FAO, 1979).

The C factor of the Wischmeier equation expresses the combined effect of plant cover and management techniques on soil erosion. It is defined as the ratio of soil loss from a field with a specific cropping and management procedure to that from bare fallow land (FAO, 1979). C values are most accurately measured by comparing soil loss from an experimental treatment with that from a standard fallow plot. In the U.S. this has led to extensive research concerning the temporal relationship between erosive rain and crop management practices (Hudson, 1981). Under temperate, commercial agricultural conditions, maize alone has sixty different C values because of the variety of ways it is grown (Stocking, 1988). The true measure of C requires year-round measurement of cover, and tillage operations no matter what crop or combination of crops is grown. Both percentage of crop cover and type of farming operations change throughout the year. Therefore for accurate results it is necessary to divide the growing season into periods and calculate C and R for each of these crop-stage periods (Hudson, 1981). For example crop-stage periods such as rough fallow, seedbed establishment, crop development, maturing crop, and residue or stubble must be related to the seasonal distribution of rainfall kinetic energy.

Before effective crop cover develops in the growing season, conservation practices P are extremely important in protecting soils from early erosive rains (Roose, 1977). P is the erosion-control practice factor, a ratio of soil loss with conservation practices such as contouring, strip cropping and terracing etc. to that with ploughing straight up and down the slope (the worst possible erosion situation) (FAO, 1979). However P-factor support practices such as contour ridging cannot be evaluated using the standard-sized USLE plot, therefore the effectiveness of support practices is sometimes difficult to accurately measure (Mutchler et al, 1988). For many conservation practices the established P-factor values have been derived not from years of field tests but by group agreement amongst researchers.

There is an important relationship between the timing and type of agricultural management practices and rainfall erosivity. For example, the decision of which week to plant can have a profound effect on eventual soil loss. Tillage and planting on the contour have been found to provide almost complete protection from storms of low to moderate intensity (Roose, 1977). However the technique provides little protection against occasional severe tropical storms which occur from year to year.

4.3 SLEMSA

At the same time as the USLE was being implemented in the United States, researchers in Rhodesia were attempting to apply the model to local conditions (Stocking, 1985b). The establishment of test plots and research stations in the U.S. with the goal of predicting soil losses instigated similar actions in Rhodesia and Nyasaland (Malawi). The USLE was tried in Rhodesia but tended to give inconsistent results (Abel & Stocking, 1987).

During the years 1953-63, Norman Hudson and others carried out extensive erosion experiments at Hendersen Research Station near what is now called Harare (Whitlow, 1988a, 1988b). These experiments looked at the relationship between tropical rain erosivity and soil loss from test plots. This important relationship between high energy precipitation and the type of ground cover marked the beginning of the search in Zimbabwe for a more accurate soil loss prediction method for the tropics than the USLE.

Climate conditions in the late sixties and early seventies dramatized the need for quantification of the amount of soil loss associated with different types of agricultural methods. Severe drought which drastically reduced yields and led to overgrazing was followed by a few seasons of heavy rains and high levels of runoff. These developments spurred on research and led to the development of the Soil Loss Estimation Method for Southern Africa (SLEMSA) (Elwell, 1984).

Like the USLE, SLEMSA was designed to make soil conservation decision-making easier, and more effective, than by using qualitative information alone. SLEMSA was designed specifically to be able to estimate rates of soil loss by sheet erosion from arable lands, to pinpoint the practices causing imbalances and to suggest alterations to farming practices which would reduce soil losses to tolerable levels (Elwell, 1982). The methodology behind SLEMSA has subsequently been reproduced in several textbooks (Morgan, 1986).

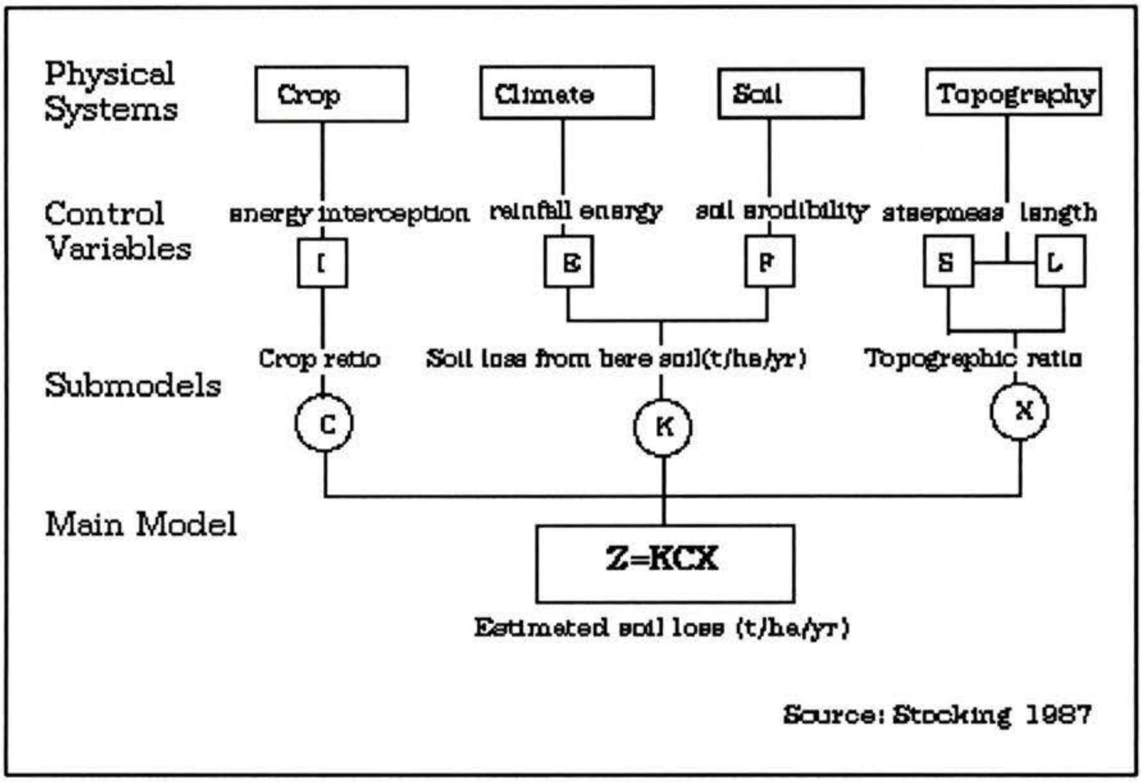
In its first published form SLEMSA was also referred to as the highveld model (Elwell, 1980). Elwell (1984) subsequently stated that work should be done to develop versions of SLEMSA for the middle and lowveld. What this means (but is not made clear in the literature) is that the method was designed for large-scale, high-input agriculture using research emulating commercial farming. Although it more accurately represented the physical conditions found in a tropical environment than did USLE, it did not incorporate the factors unique to subsistence farming. However, since 1980, widespread soil losses resulting from traditional agricultural practices have increasingly become the focus of any application of SLEMSA, both inside and outside of Zimbabwe. This reflects international concern, not only for declining soil fertility but also for the siltation of dams and decreased ground water supplies. In the mid 1980s the designers of the model (Elwell & Stocking, 1984) applied it to an area similar to Mberengwa, the focus of this writer's study. SLEMSA was used to predict soil losses of 80 t/ha/yr for subsistence crops on a shallow granite sand, varying at best into a sandy loam. No mention was made in this particular study about the problems or methodology of such an application.

During the 1980s SLEMSA has been projected as a more applicable alternative to the USLE for developing countries without the facilities or funds for expensive research programs, but in need of a decision-making tool to slow further erosion (Elwell, 1984). The model has been shown to have potential application to Botswana because of a close similarity in rainfall statistics to Zimbabwe (Elwell, 1982) where the model has already been applied. Recently in a small section of Botswana, aerial photography was used to calculate vegetative cover thereby leading to a prediction of soil loss by applying the SLEMSA model. (Abel & Stocking, 1987). In the near future, a simplified version of SLEMSA may be applied under the sponsorship of the Swedish International Development Agency (SIDA) in eight of nine nations of SADCC (Zimbabwe, Zamia, Malawi, Lesotho, Swaziland, Tanzania, Botswana, and Mozambique). Finally the FAO which uses a version of the USLE (FAO, 1979) (designed to accommodate shortages of data) has suggested that SLEMSA may be applicable over a wide range of the tropics (not just the savanna) (FAO, 1984).

The SLEMSA framework is structured differently than the USLE (Figure 4). The environment affecting the sheet erosion is divided into four physical systems, climate, soil, crop, and topography (Elwell, 1980). Within SLEMSA, both natural properties and human factors are incorporated into a single category. For example, physical properties such as soil texture and management techniques such as minimum tillage, both affect soil erodibility and are, therefore, integrated under soil (F).

For any given site within Zimbabwe a value is determined for each of five control variables: energy interception provided by crop cover (i); rainfall energy of the local climate (E); inherent soil erodibility modified by local agricultural management practices (F); slope steepness (S); and slope length (L). "i" is associated with the crop physical system; E with climate; F with soil; and S and L with topography. These variable are combined into three submodels (C,K,X). C gives an estimation of crop cover. K determines soil loss from bare soil in t/ha/per annum. X is the topographic ratio, combining the variables of slope length and slope steepness (similar to the methodology employed in the USLE). Finally the main model determines the soil loss (Z) from the cropland under study. in t/ha/yr.

FIGURE 4:
SLEMSA FRAMEWORK
(SOIL LOSS ESTIMATION MODEL FOR SOUTHERN AFRICA)



Source: Stocking 1987

4.3.1 Example

If the mean annual rainfall of a given site is 500 mm, mean seasonal rainfall energy is determined to be 8684 Joules/m^2 (E) based on local Zimbabwean research data (Appendix B: Figure 1). Two separate equations are used in B: Figure 1. In this example it is assumed that the site is located in a part of Zimbabwe where a significant amount of the total rainfall is in the form of light drizzle (guti). More complete explanations for the terms "guti" and "non-guti" are found in section 5.2 (SLEMSA Erosivity Data and Analysis). Similar procedures derive the following values. A sandy fersiallitic soil under continuous maize has an F_m value equal to 2 (Appendix B: Tables 1&2). As shown in section 5.7 low yielding maize of less than 500 kg/ha. and emerging in mid-November due to late rains has an energy interception (i) value of 15 percent. Slopes at the given site average 4 % (S), with the distance between existing contour ridges found to be 35 metres (L).

Soil loss from bare soils is determined by replacing values of E and F into the equation or graph used to determine K. (Appendix B: Figure 2) In this case K = 125 t/ha/yr. Similarly i is used to determine a crop ratio (C) of 0.43 (Appendix B: Figure 3). X is derived graphically from S and L and the topographic ratio is determined to be 0.95. Therefore mean annual soil loss = 125x0.43x0.95 = 51 t/ha/yr. As with the USLE, strategies to reduce soil loss to acceptable levels may be identified through the use of the equation.

4.3.2 SLEMSA Erosivity

An important alternative in the tropics to the USLE's EI_{30} is KE>25 developed by Hudson (1981). Hudson's work, based in Zimbabwe, showed that the kinetic energy of individual storms falling at intensities of 25 mm (1 in.)/hr or greater was more closely related to soil loss than EI_{30} for tropical and subtropical rainfall (Singh et al. 1985). As a result, Hudson established an intensity of 25 mm/hr as the threshold level separating erosive and non-erosive rain. In this way it was thought that soil loss quantities would not be over-estimated due to rainfall with a very low intensity (Onchev, 1985).

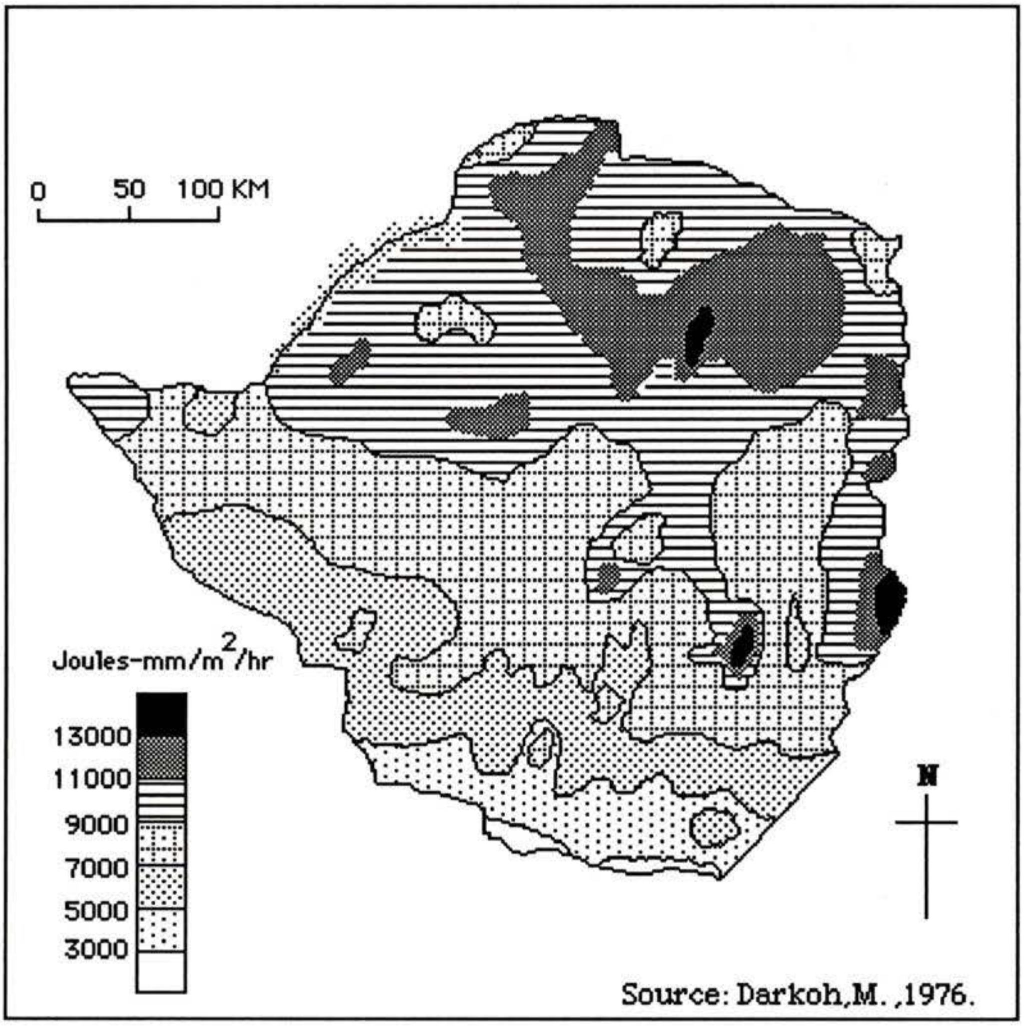
Working from the idea that there was no obvious reason why the intensity of rainfall during a thirty minute period is the best parameter, Stocking and Elwell obtained better correlations with soil loss using maximum 15 minute intensities (1973). It was found that in some cases the erosivity of a short intense tropical storm is mathematically diminished if averaged out over a thirty-minute period. In spite of this finding during the early seventies, Stocking and Elwell came to the conclusion that a combined energy-intensity parameter (such as EI_{30}) consistently gave the best prediction of individual soil losses (1973). Kinetic energy alone is principally a function of rainfall volume and in general it is not a good indicator of soil loss as it overlooks the importance of intensity in any model of soil. Therefore in the original SLEMSA methodology EI_{30} was used and not KE>25 even though the latter was developed under Zimbabwean conditions

(Stocking, Chakela, and Elwell, 1988).

As with the USLE, methodology for SLEMSA has evolved which partially addresses the lack of rainfall information from the more marginal areas of subsistence agriculture that interferes with the effective use of the USLE. Recently, Stocking and Elwell have changed their focus, indicating that a calculation of annual rainfall kinetic energy is well-correlated with soil loss from field plots (Elwell, 1978; Stocking et al. 1988). The authors claim that energy alone has an advantage over other empirical parameters in that it "provides a rational explanation of the processes involved in erosion". Like the FAO version of the USLE erosivity calculation the use of annual rainfall helps overcome the problem of serious data shortages. Therefore, in its more recent form, SLEMSA uses an estimate of kinetic energy associated with mean annual rainfall for rainfall-erosivity calculations. The calculation takes into account the presence of some low-energy rainfall within the annual precipitation totals in the southern part of Zimbabwe when compared to the more northern areas of the country.

For SLEMSA, Elwell (1980) has mapped the distribution over Zimbabwe of average rainfall energy, one of the five control variables within the model, in joules per square metre. A Zimbabwean version of the USLE isoerodent map for use with SLEMSA has also been produced in an attempt to overcome data shortages (Figure 5).

FIGURE 5:
EROSIVITY OVER ZIMBABWE (SLEMSA)



Source: Darkoh,M. ,1976.

4.3.3 SLEMSA Erodibility

In the process of degradation, the inherent erodibility of a soil may change over time. After repeated ploughing, the percentage of organic matter tends to decline and soil aggregates begin to break down. The freshly detached finer particles become easily transportable. Surface runoff usually transports fine particles while material larger than 1 mm usually remains in place. As a result, as time goes on, the remaining coarse-textured soils have greater infiltration rates which result in less erosion due to runoff than soils with more silt, clay and organic matter.

Organic matter as a soil constituent not only slows erosion rates but because the dominant tropical clay mineral kaolinite has a very low nutrient-exchange capacity, organic matter determines the fertility status of most tropical soils (Gbadegesin, 1987). Above all organic matter improves the physical properties of coarse-textured soils, especially structure, consistency and moisture content. Most mineral soils in the world contain less than 15% organic content and many sands and sandy loams have less than 2%. In Africa the organic matter content of the Ah horizon under natural vegetation is on average:

Wet savanna 2-3%
Dry savanna 1-2%
Semi-arid regions 1/2-1% (Wrigley, 1985)

The decline of this already small percentage of organic matter in marginal lands leaves a soil with little ability to retain nutrients and moisture, or to maintain its structure.

The USLE idea of erodibility differs considerably from that contained within the SLEMSA model. The latter integrates tillage and management effects into the erodibility factor (X) rather than maintaining a separate crop management factor. Within the USLE inherent soil-erodibility data are measured from uniformly bare fallow field plots, whereas SLEMSA determines erodibility of soils being managed by specific agricultural methods (Stocking, 1987). Which method is more realistic is the subject of some debate.

The SLEMSA methodology reclassifies inherent soil erodibility up or downward based on the land-use management techniques being employed e.g. ridging practices, contour ploughing, green manuring etc. The management practices which are used in this calculation are primarily those which alter physical conditions of the soil itself.

The SLEMSA calculation of erodibility requires information about local agricultural practices and the distribution of soil classes. Zimbabwean soils are classified mainly according to parent material and the degree of weathering and leaching which they have undergone in the process of their formation. Through integration of factors contributing to the development of different soil profiles a

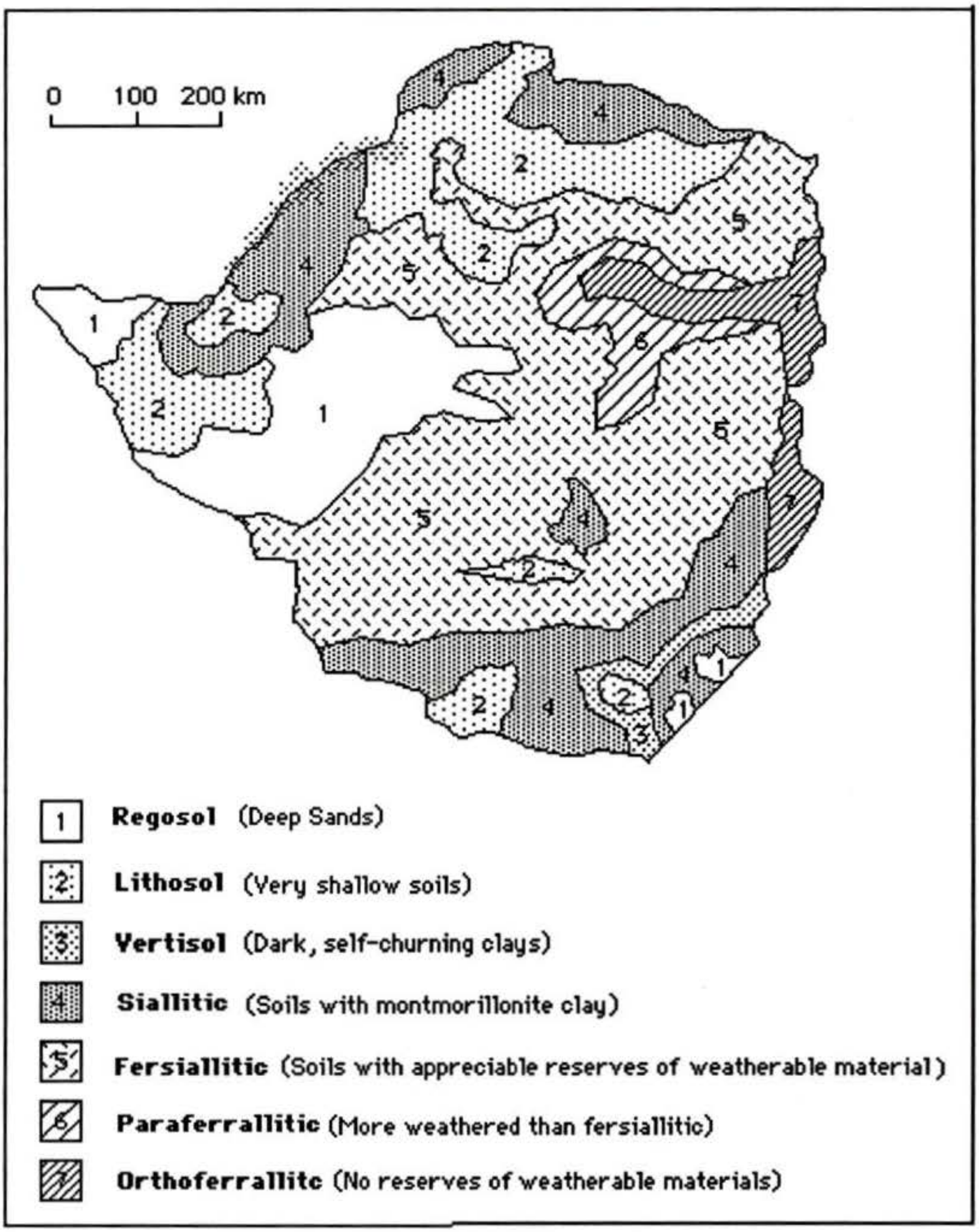
1:1,000,000 national soil map has been generated which strongly reflects the distribution of rainfall and underlying geology (Figure 6). Other than a small area of commercial agriculture close to the capital city of Harare, larger-scale maps of local agricultural regions have yet to be surveyed.

Within the communal lands themselves very little detailed soil research has been carried out. Fortunately Grant (1981) has examined the nutrient status of sandy fersiallitic soils within the subsistence agricultural environment of Zimbabwe. This soil group is of major importance within the area of focus of this study.

The basic ranking for susceptibility to erosion was first estimated for the main Zimbabwean soil orders in the early seventies (Stocking, 1973). This early classification ranked Zimbabwean soils' susceptibility to erosion in the following groups:

(1) Low - ortho-ferralitic regosols
(2) Below average - para-ferralitic
(3) Average - fersiallitic
(4) Above average - siallitic, vertisols, lithosols
(5) High - non-calcic, hydromorphic, sodic

FIGURE 6:
NATIONAL SOIL DISTRIBUTION
ZIMBABWEAN SYSTEM OF SOIL CLASSIFICATION



In SLEMSA's most recent form, this list has been modified and Zimbabwean soils have been ranked from 1 as the most erodible, to 10 for soils with the greatest resistance to erosion (Stocking, 1987). The most erodible rating is given to Sodic soils which are chemically unstable and susceptible to rill, sheet and gully erosion. Sodic soils are associated with Mopane vegetation and neither tree type or soil class are found in the Mberengwa study area. The least erodible are deep well-drained orthoferrallitic soils generally associated with highveld climatic conditions and non-granitic parent materials (classified as Rhodic Ferrasols by the FAO).

4.3.4 SLEMSA Slope

In the late seventies, Elwell carried out some local work aimed at finding the relationship between soil loss and slope characteristics under Zimbabwean conditions (Elwell, 1978). Earlier test plot experiments had been carried out on slopes ranging from 3% to 8% (Stocking and Elwell, 1973). The combined results suggested it was not necessary to break away from the relationships discovered in the U.S. and the LS factor of the USLE was adapted for use within SLEMSA.

As with the Universal Soil Loss Equation, SLEMSA combines topographic controls with crop, climate, and soils to predict mean annual soil loss (Figure 4). The topographic submodel "X" adjusts the value of soil loss to account for differences in slope gradient and length between the standard plot and the land under examination (Elwell, 1978). The soil loss ratio is determined by the relationship between slope length and steepness which is expressed by the equation:

$$\text{"X"} = L^{0.5}\ (0.76 + 0.53S + 0765S^{2})/25.65 \qquad (5)$$

The standard field plots of Zimbabwe and the United States are not the same. The length of slope of 22.1 m used for test plots within the USLE is shorter than the average horizontal interval between contour bunds in Zimbabwe and Mberengwa. The average field plot in Zimbabwe has a grade of 4.5% and is 30 metres long (Hudson, 1981). This required altering the USLE base of a 9%, 22.1 metre slope to conform to local standards used within SLEMSA. However the basic relationship between length and gradient and its effect on soil loss was left unchanged.

In the early 1970s Stocking established a relationship between eight relief parameters and soil erosion apparent on aerial photographs in three of Zimbabwe's communal lands (1982). Average slope appeared to be more important than other relief parameters in its relationship to the amount of erosion visible from aerial photographs in all three areas. In his subsequent work, Stocking has employed the concept of average slope in place of simple angle of slope when predicting soil loss over a large geographic area. This was done by adapting Wentworth's (1930) method which is based on the principle that the greater the number of contours there are on a map of a given area, the greater the slope will be.

Stocking recently proposed using this method to calculate erosion hazard for several Southern African Development Coordination Conference (SADCC) nations using a 5 by 5 km. grid to calculate average slope for small countries such as Lesotho and for larger countries (e.g. Botswana) using one quarter of a 1:50 000 map sheet or a 10 by 10 km. grid (1987).

4.3.5 SLEMSA Human Factors

In early Zimbabwean experiments it was found that the USLE in its North American form underestimated erosion under cropped conditions by as much as 100%. This led to the idea that the tropical C-factor needed to be revised to take into account the importance of screening canopies. Therefore the modern SLEMSA model is based on the principal that a major control of erosion in the tropics is a protective cover of vegetation and the percentage of seasonal rainfall energy that it intercepts (Abel and Stocking, 1988).

Because of the ability of vegetative cover to reduce kinetic energy due to rain, researchers in Zimbabwe think vegetative cover may be the most important factor in soil-erosion control (Stocking, 1988). Experiments in Zimbabwe have shown that bare plots have more than a hundred times the soil loss of an effectively covered plot (Hudson, 1981).

Once vegetative cover exceeds 60% there is little increase in soil loss. But the eroding soil of a subsistence farmer may only produce a 20% maize cover, especially during times of drought. Sorghum or millet which are not as limited by lack of moisture may provide a far greater rate of cover and interception (Stocking, 1988).

Besides crop choice and soil fertility, the percentage of vegetative cover is also linked to planting date. Any crop planted late in the season results in bare soil being exposed for longer periods and decreased yields (plant cover) for each field planted (Hudson, 1981).

Different crops not only have different yields under the same conditions, but plant structure varies as well. The pattern of leaves seen from vertically above the plant can affect rainfall interception from crop to crop (Stocking, 1988). To improve rainfall interception crops need to be planted which provide good cover in spite of low soil fertility. Even when annual precipitation totals decline, the chosen crop must survive in order to protect the soil surface from the occasional erosive rains that still occur.

Grazing pressure on the vegetative cover is also important. It was found that under light grazing pressure in the 600 mm rainfall zone of Zimbabwe 70% of erosive rainfall was intercepted. At the same time under heavy grazing pressure in the same area only 20% was intercepted.

Over time Zimbabwean scientists have built a data bank of cover measurements and of erosion hazard ratings (Stocking, 1988). In the past Elwell has constructed tables of interception for a variety of crops based on various yield levels and dates of crop emergence (Stocking, 1988). As well, some measurement has taken place of the mean seasonal interception of erosive rains on natural grassland in Zimbabwe based on the degree of grazing pressure (Stocking, 1987).

CHAPTER FIVE

Methodology

5.1 USLE erosivity and local data

Rainfall totals were collected in the Mberengwa study area throughout 1987,1988, and the first six months of 1989. For this study only the data from 1987 and 1988 have been used A single non-recording rain gauge was used to represent rainfall for the entire study area (see Figure 5).

Calculation of the R factor for use in the USLE requires extensive rainfall data. This involves monitoring both individual storm totals and rain intensity (in millimetres per 30 minute period). This information and the equipment to record it is usually not widely available in most parts of the developing world. However, daily, monthly and annual total precipitation data are gathered with non-recording rain gauges in many locations in Africa (ASA Special Publication, #43, 1982). Therefore it is an advantage to make use of indices simpler than EI_{30} in order to incorporate the network of available information (Lo et al. 1985).

The FAO methodology for assessing soil degradation from water erosion recommends the use of the USLE R-factor (EI_{30}) for the erosivity parameter but in Africa and Hawaii work has been done to find alternatives in the face of data shortages.

FIGURE 7:
DAILY RAINFALL -MBERENGWA / JAN. 1987 - JUNE 1988

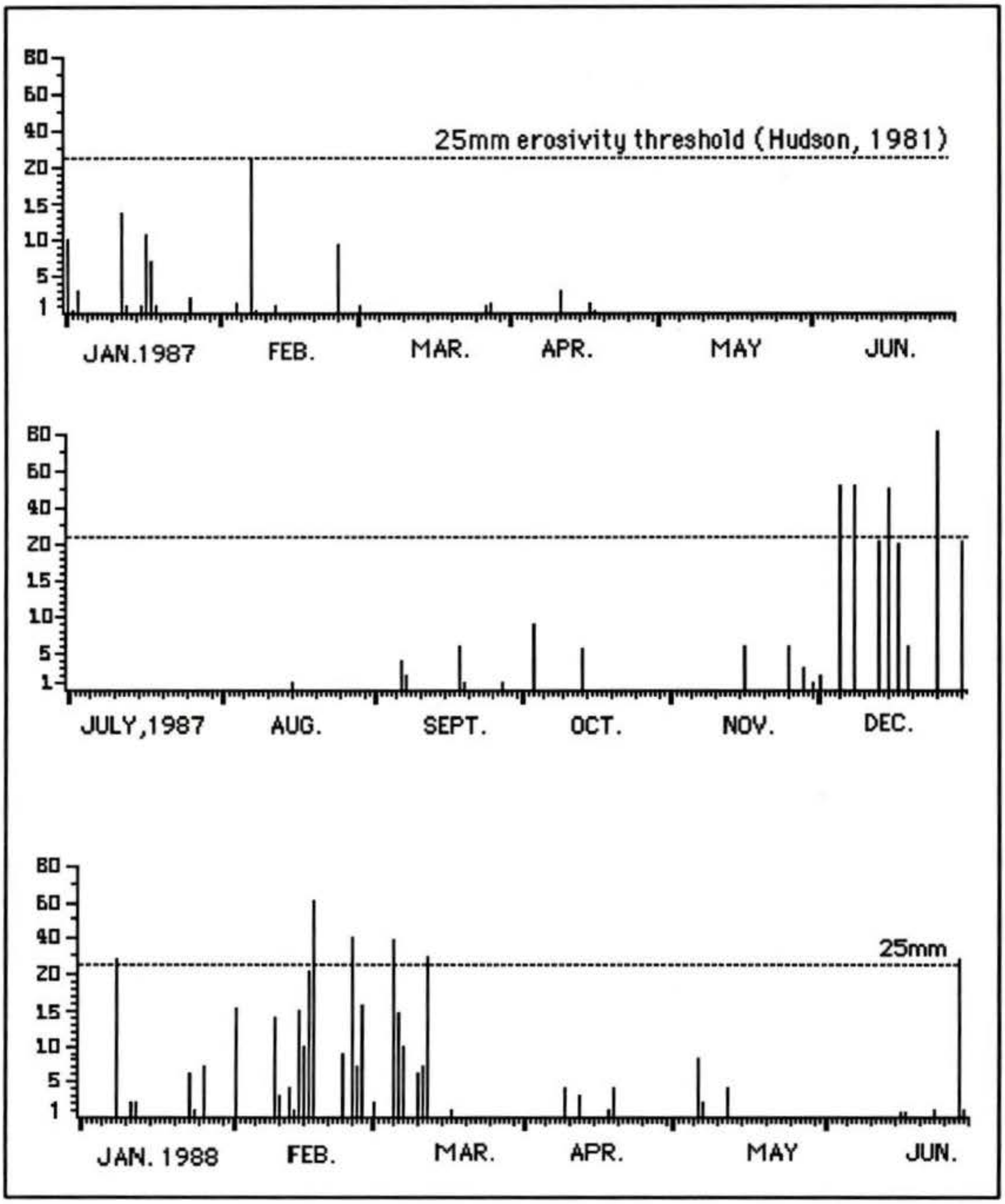
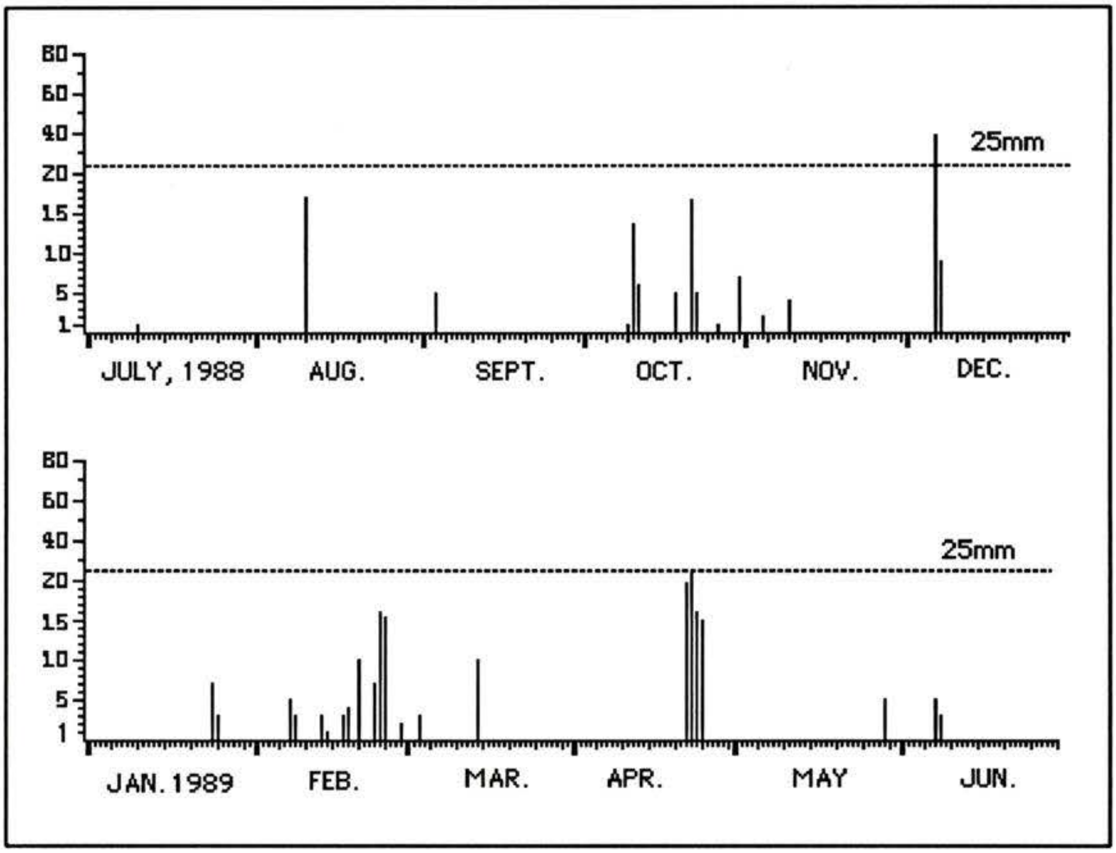


FIGURE 7: (CONTINUED):

DAILY RAINFALL / MBERENGWA / JULY 1988 - JUNE 1989



The FAO (1979) makes use of the following equation to calculate the R factor using monthly rainfall totals. The revised USLE erosivity equation is as follows:

$$R = p2/P \qquad (6)$$

where p = monthly precipitation and P = annual precipitation.

Arnoldus (1980) suggests that the FAO equation accurately reflects the potential of possible soil loss in areas of seasonal rainfall due to the presence of highly erosive periods and their relationship to limited ground cover. According to Arnoldus (1977) this calculation has an established correlation with the R factor of the USLE. In Hawaii (Lo, 1985), average monthly and annual rainfall measurements have been adapted in the same way to deal with the shortage of data needed to calculate EI_{30} in areas of variable erosivity.

In order to determine the erosivity of precipitation in the Mberengwa areas original USLE methodology had to be compromised. For this research project a recording rain gauge which could be used to isolate individual storm volumes or storm intensities was not available. A national R value isoerodent map has yet to be produced for Zimbabwe, as it has in the U.S, so interpolations of USLE erosivity for Zimbabwe can not be made using this method. "R" has been determined using FAO methodology which allows a calculation of erosivity based on monthly rainfall totals (Equation #6, p. 66). The calculation of annual erosivity for 1987 and 1988 is shown in Table 5. In this two-year period rainfall totals were 26% greater in 1988 compared to 1987. However in 1988 rainfall is more evenly distributed throughout the year resulting in a lower erosivity value.

TABLE 5:

FAO EROSIVITY CALCULATION FOR MBERENGWA

Month	Monthly totals (in m.m)		Monthly p^2/P	
	1987	**1988**	**1987**	**1988**
Jan.	47.75	44.00	4.82	3.25
Feb.	36.70	228.00	2.85	87.42
Mar.	2.80	107.00	0.02	19.25
Apr.	4.60	11.25	0.04	0.21
May	0.00	13.50	0.00	0.31
Jun.	0.00	33.85	0.00	1.93
Jul.	0.00	1.00	0.00	1.00
Sep.	12.00	5.00	0.30	0.04
Oct.	15.00	55.00	0.48	5.09
Nov.	15.25	32.50	0.49	1.78
Dec.	338.25	46.50	241.96	3.64
Annual totals	472.85[a]	594.60[a]	250.96[b]	123.41[b]

"a" is the total annual precipitation in millimetres.
"b" is the sum of each month's total precipitation divided by the annual total,
or $R = f([p^2/P)$

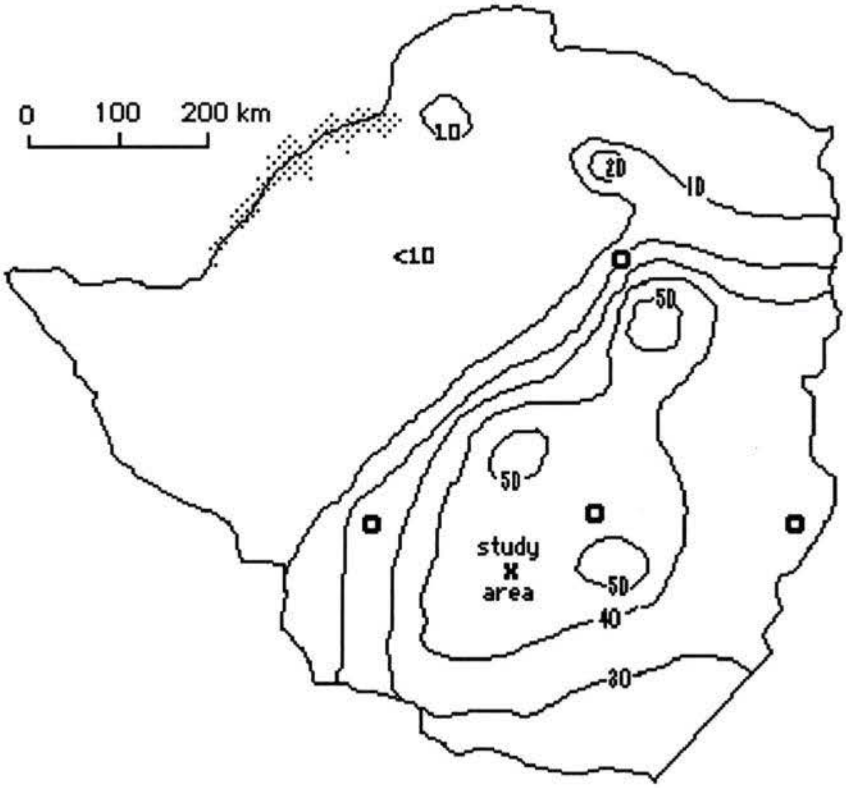
5.2 SLEMSA Erosivity Data and Analysis

While it is necessary to compromise the USLE methodology to generate R values, the same is not required for the SLEMSA calculation of erosivity (E). According to Stocking and Elwell (1976) the annual kinetic energy of rainfall in Zimbabwe is related to mean annual rainfall and is expressed in Joules / m^2 /mm of rain. This relationship is expressed in two separate equations (Appendix B: Figure 1). Equation (A) is for regions without drizzle and with normally aggressive climates. (B) is used to determine the kinetic energy for regions with occasional drizzle or "guti" as it is termed in Zimbabwe (Elwell, 1984).

Mberengwa has a ten-year mean of 45 days of early morning drizzle per annum (Zimbabwe Department of Meteorological Services [ZDMS], 1981) (Figure 8). This low-energy rain reduces the overall erosivity total. Therefore due to the presence of some non-erosive rain, erosivity is slightly less in the study area than in other regions of the country with the same rainfall volumes.

P represents total annual precipitation for both equations. Using equation (B) a measure of annual kinetic energy has been determined separately for the years 1987 and 1988.

**FIGURE 8:
ANNUAL FREQUENCY OF EARLY MORNING DRIZZLE
(10-YEAR MEANS)**



Source: Climate handbook of Zimbabwe, 1981

Using the relationship between energy and total annual rainfall described in Appendix B: Figure 1, the following calculations are made:

$$E(1987) = 17.368(P) = \tag{7}$$

$$17.368(472.85) = 8212.46$$

$$E(1988) = 17.368(P) = \tag{8}$$

$$17.368(594.60) = 10327.01$$

The "E" values calculated for the Mberengwa study area may then be compared with those given on the SLEMSA version of a national isoerodent map (Figure 5).

The small-scale map places Mberengwa near the border of two generalized erosivity regimes; 5000-7000 and 7000 - 9000 Joules /mm /m2/hr. The specific calculation of E for 1987 is found within this range. The calculation for 1988 exceeds it.

5.3 Local USLE K Factor

Techniques for determining the erodibility (USLE "K"-value) of the soil itself are outlined by Wischmeier, Johnson, and Cross (1971). The FAO adaption of the USLE employs Wischmeier's technique to calculate soil erodibility if the necessary data are available. If this is not the case, erodibility ratings are assigned to the various soil classes designated on the African edition of the FAO/UNESCO World Soil Map (FAO, 1979).

The FAO/UNESCO world soil map and accompanying legend (FAO/UNESCO, 1974) is designed to show the global distribution of soils at a small scale (1:5 000 000). The FAO has subsequently attributed an erodibility rating to each soil unit on the map (according to its texture) in its amended version of the USLE(FAO,1979). The FAO erodibility classes are as follows:

I - slight	II - moderate	III - high
0.5	1.0	2.0

Each of the 1:5 million FAO soil-mapping units is assigned one of the three erodibility classes. The FAO technique assigns a single erodibility value to soil great groups, regardless of the variation of soil factors within each group.

If data are available five soil factors are incorporated into the USLE nomograph, or used in the algebraic equation to determine erodibility (Moldenhauer & Foster, 1981). The equation for K is:

$$100K = 2.1\text{x}10^{4}(12\text{-}0.M.)M^{1.14} + 3.25(S-2) + 2.5(P-3) \quad (9)$$

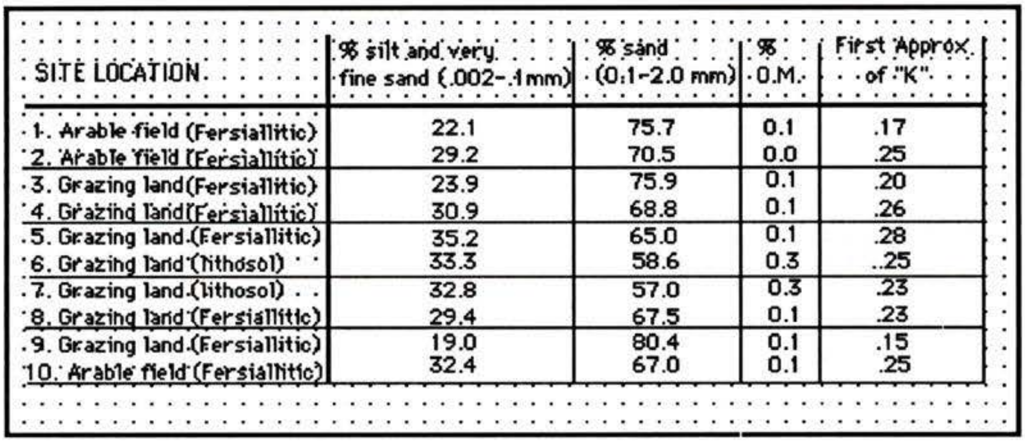
where 0.M. is percentage organic matter; S is soil structure code (granular, platy, massive etc.); P is permeability class; M is % silt and very fine sand. This study makes use of the USLE nomograph.

In order to determine a first approximation of K, the percentage silt and very fine sand, and the percentage sand (USDA particle size criteria) were calculated for the top 20 cm of soil for each site. (see Section 3.2 *Local Soils and Sampling Methodology)* Ignition of organic matter was used to determine O.M. percentage (see Table 1).

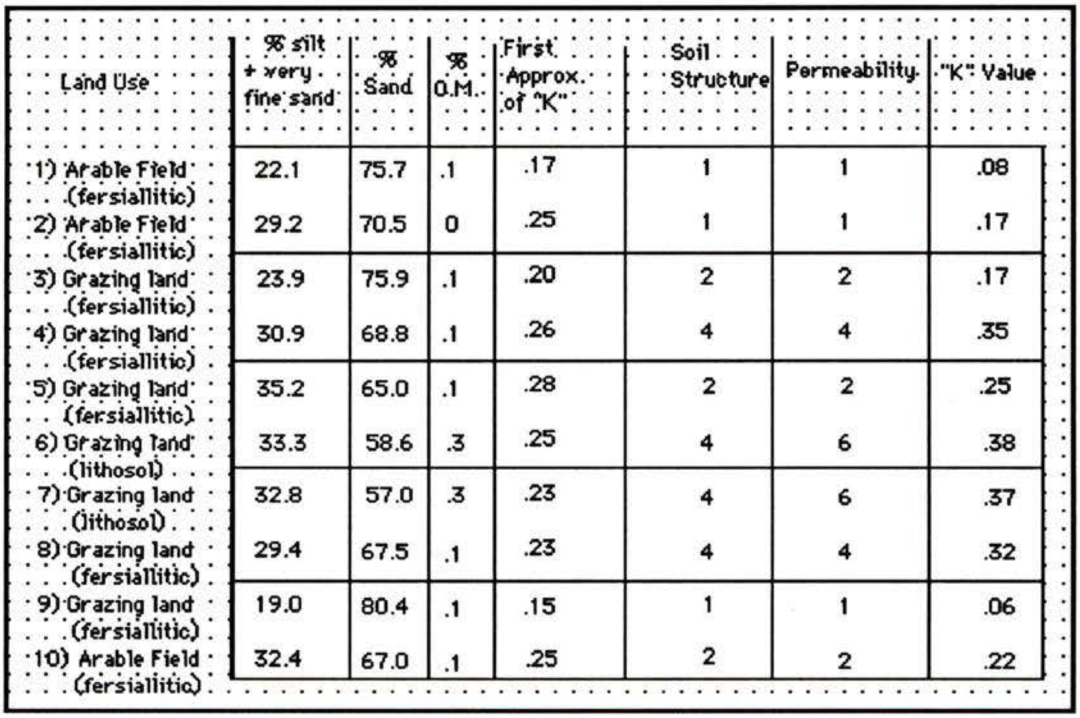
The final calculation of K requires identification of soil structure and permeability, both of which measurements are taken in the field. Structure tends to be granular for fersiallitic soils, and platy to massive for the lithosols. Measurement of permeability requires a standardized infiltrometer to properly time infiltration rates. Open-ended tins, approximately 15 cm. in diameter, were used along with a stop watch to measure infiltration rates of known volumes of water. The diameter of this improvised equipment was much smaller than that of standardized equipment, allowing only an approximation of permeability.

With these five parameters the USLE nomograph (Appendix A: Figure 2) was used to calculate K (Table 6). The K values were then averaged for the two separate land uses associated with fersiallitic soils and the single use associated with lithosolic soils. The resulting average values were .16 for arable fields and .23 for grazing land (fersiallitic soil). For communal forests (lithosols) the average K value was .37.

TABLE 6: MBERENGWA 'K'-VALUE CALCULATION



SITE LOCATION	% silt and very fine sand (.002-.1mm)	% sand (0.1-2.0 mm)	% O.M.	First Approx. of "K"
1. Arable field (Fersiallitic)	22.1	75.7	0.1	.17
2. Arable field (Fersiallitic)	29.2	70.5	0.0	.25
3. Grazing land (Fersiallitic)	23.9	75.9	0.1	.20
4. Grazing land (Fersiallitic)	30.9	68.8	0.1	.26
5. Grazing land (Fersiallitic)	35.2	65.0	0.1	.28
6. Grazing land (lithosol)	33.3	58.6	0.3	.25
7. Grazing land (lithosol)	32.8	57.0	0.3	.23
8. Grazing land (Fersiallitic)	29.4	67.5	0.1	.23
9. Grazing land (Fersiallitic)	19.0	80.4	0.1	.15
10. Arable field (Fersiallitic)	32.4	67.0	0.1	.25



Land Use	% silt + very fine sand	% Sand	% O.M.	First Approx. of "K"	Soil Structure	Permeability	"K" Value
1) Arable Field (fersiallitic)	22.1	75.7	.1	.17	1	1	.08
2) Arable Field (fersiallitic)	29.2	70.5	0	.25	1	1	.17
3) Grazing land (fersiallitic)	23.9	75.9	.1	.20	2	2	.17
4) Grazing land (fersiallitic)	30.9	68.8	.1	.26	4	4	.35
5) Grazing land (fersiallitic)	35.2	65.0	.1	.28	2	2	.25
6) Grazing land (lithosol)	33.3	58.6	.3	.25	4	6	.38
7) Grazing land (lithosol)	32.8	57.0	.3	.23	4	6	.37
8) Grazing land (fersiallitic)	29.4	67.5	.1	.23	4	4	.32
9) Grazing land (fersiallitic)	19.0	80.4	.1	.15	1	1	.06
10) Arable Field (fersiallitic)	32.4	67.0	.1	.25	2	2	.22

5.4 Local SLEMSA Erodibility

Soil group classification was determined from the Provisional Soil Map (Figure 6); parent material from the Southern Rhodesia Geological Survey # 43 (Worst, 1956) and field observations; and soil texture from soil texture analysis of samples.

The SLEMSA method requires that soil be classified at the family level, where it is assigned a basic erodibility ranking (F_b) (Appendix B: Table 1). Using this method values are assigned to the two main soil types of the Mberengwa study area (fersiallitic soils and lithosols) (Table 7). Fersiallitic soils formed on granite parent material with a texture ranging from loamy sand to sand are assigned an erodibility ranking of 4 within SLEMSA. Lithosols with the same textural classes are assigned an erodibility value of 2.

TABLE 7:
SLEMSA SOIL ERODIBILITY

MBERENGWA SITES	SOIL FAMILY	ERODIBILITY CLASS **(Fb)**	ERODIBILITY CLASS **(Fm)**
1) Arable Field	Fersiallitic (granite)	4	2.5
2) Arable Field	Fersiallitic (granite)	4	2.5
3) Grazing land	Fersiallitic (granite)	4	3.5
4) Grazing land	Fersiallitic (granite)	4	3.5
5) Grazing land	Fersiallitic (granite)	4	3.5
6) Grazing land	Lithosol	2	1.5
7) Grazing land	Lithosol	2	1.5
8) Grazing land	Fersiallitic (granite)	4	3.5
9) Grazing land	Fersiallitic (granite)	4	3.5
10) Arable Field	Fersiallitic (granite)	4	2.5

Values are further modified by SLEMSA by the particular agricultural practices used for that soil (F_m) (Appendix B, Table 2] for the full range of (F_m) values. Cropping types and tillage practices were identified through air photo interpretation and field experience. Both lithosols and fersiallitic soil F_m values are reduced by 1 based on the assumption that soil losses from the previous year were greater than 20 t/ha. Nearly all arable fields are found on fersiallitic soils. These soils are downgraded another 0.5 for having annual crops (millet, maize, sorghum) planted at angles to the contour ridges. The distribution of modified F values is shown in Figure 9.

5.5 USLE Slope

Moldenhauer and Foster (1981) suggest that the affect of slope length and steepness, as predicted by the USLE, is probably the most applicable of all factors to tropical conditions.

In Zimbabwe, subsistence agriculture is carried out on slopes averaging 4.5% with a field length of about 30 metres between contour bunds (Elwell, 1984). In the study area, aerial photographs *Bulawayo 1735 and 1736* (1985) were used to determine land use and its relationship to slope length. Measurements from aerial photographs of Mberengwa indicate that slope lengths between contour bunds closely approximate the national average of 30 metres (Hudson, 1981). Therefore 30 metres were used as a standard length for cultivated fields in the calculation of both SLEMSA and USLE. Because of the size of the area covered in this study, a set distance of 100 metres is used as the slope length of grazing land as it was in Stocking's application of SLEMSA to rangelands in Botswana (Stocking, 1987b). In Zimbabwe, Qalabane and Elwell (1988) also used the standard length of 100 metres for grazing land with no contour bunds. Based on these assumptions, slope lengths attributed to arable and grazing land are shown in Figure 10.

FIGURE 9:
SLEMSA MODIFIED SOIL ERODIBILITY DISTRIBUTION

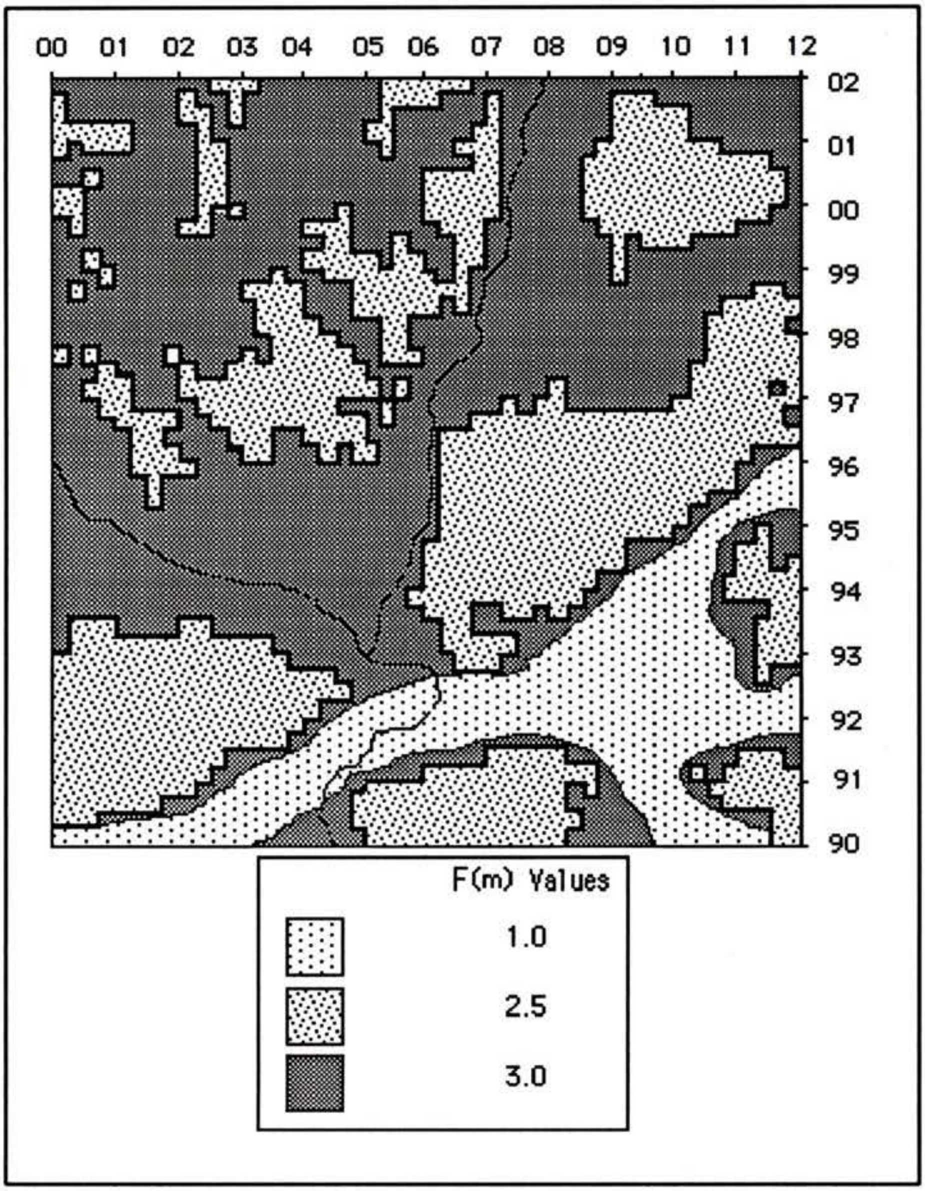
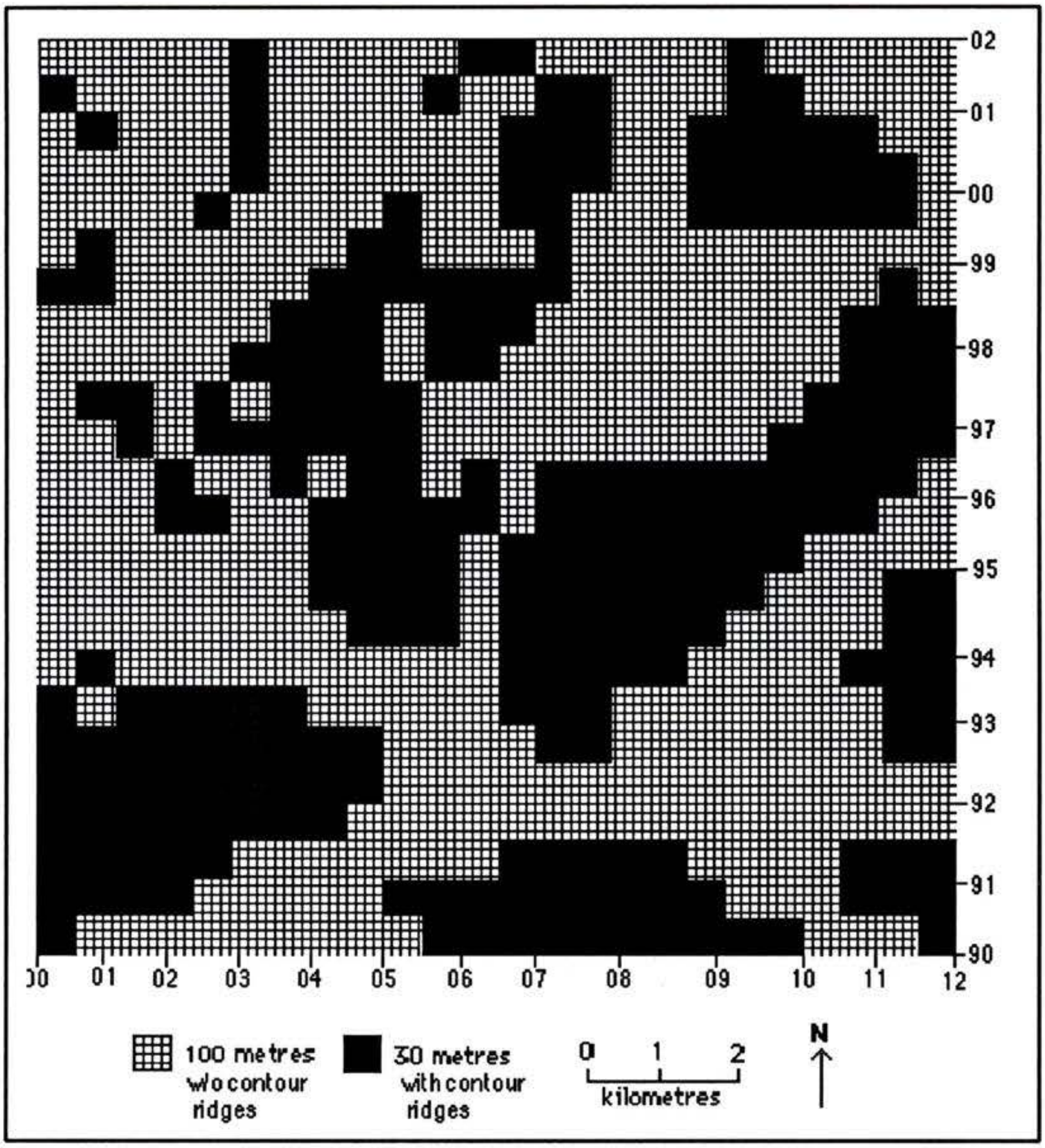


FIGURE 10: MBERENGWA SLOPE LENGTH DISTRIBUTION



Stocking's technique (1987b) was used for determining average slope percentage within a grid superimposed over the study area. The technique involves counting all contour crossings along a transect and is shown below:

$$\text{Av.Slope \%} = \frac{\text{no. contour crossings/km} \times \text{contour interval (m)}}{636.6} \times 100 \qquad (10)$$

Because of the uncertainty of the relationship between extremely steep slopes and soil loss, Stocking uses 20% as the maximum slope angle for his southern African research. Any slopes greater than this are grouped together as having the highest category of hazard.

Grid squares of 0.25 km^2 were used to calculate slope angle within the Mberengwa study area for both the combined USLE LS and SLEMSA X. This resolution is much finer than Stocking's recent work in Southern Africa (Botswana, Lesotho, Zimbabwe). The 1:50 000 topographic map sheet "Zeus Mine 2029 D4" (Government Printer, 1982) was used to calculate slope angle for Mberengwa. Each grid square was bisected twice; first in a north-south direction and then at right angles to this transect. After determining the number of intersections, the average number of contour crossings per kilometre was calculated. The slope in terms of the tangent, was then converted into percentage of slope. Within this distribution no slope steeper than 20 % is included. The distribution of slope percentage used for both the USLE and SLEMSA can be seen in Figure 11.

For both the USLE and SLEMSA the letter S is used to stand for slope percentage and L represents slope length. The relationship between slope percent and length for both equations is shown in (Appendix A: Figure 1) for the USLE and (Appendix B: Figure 4) for SLEMSA. Variations in the topographic ratio (LS for the USLE and X for SLEMSA) are seen in Figure 12.

5.6 USLE Local Crop (C) and Conservation Practices (P)

As has been shown above, detailed crop management/soil conservation data are not available in most third-world countries. A common technique for circumventing this problem has been to ignore seasonal crop stages and apply a single annual value to C and P (Hudson, 1981, Lewis, 1988). Other modifications of the original methodology include using values for the USLE cover-management factor (C) that apply to the conditions at the time of each erosive storm (Foster, 1988). Perhaps with questionable C and P values the most reasonable approach would be to calculate maximum potential soil loss based on erosivity (R), erodibility (K), and topography (LS), alone. The FAO (1979) suggests that for some applications, where CP information is limited, both factors can be taken as unity and the rest of the equation is then used to arrive at an estimate of soil loss without modification by cropping and conservation practices.

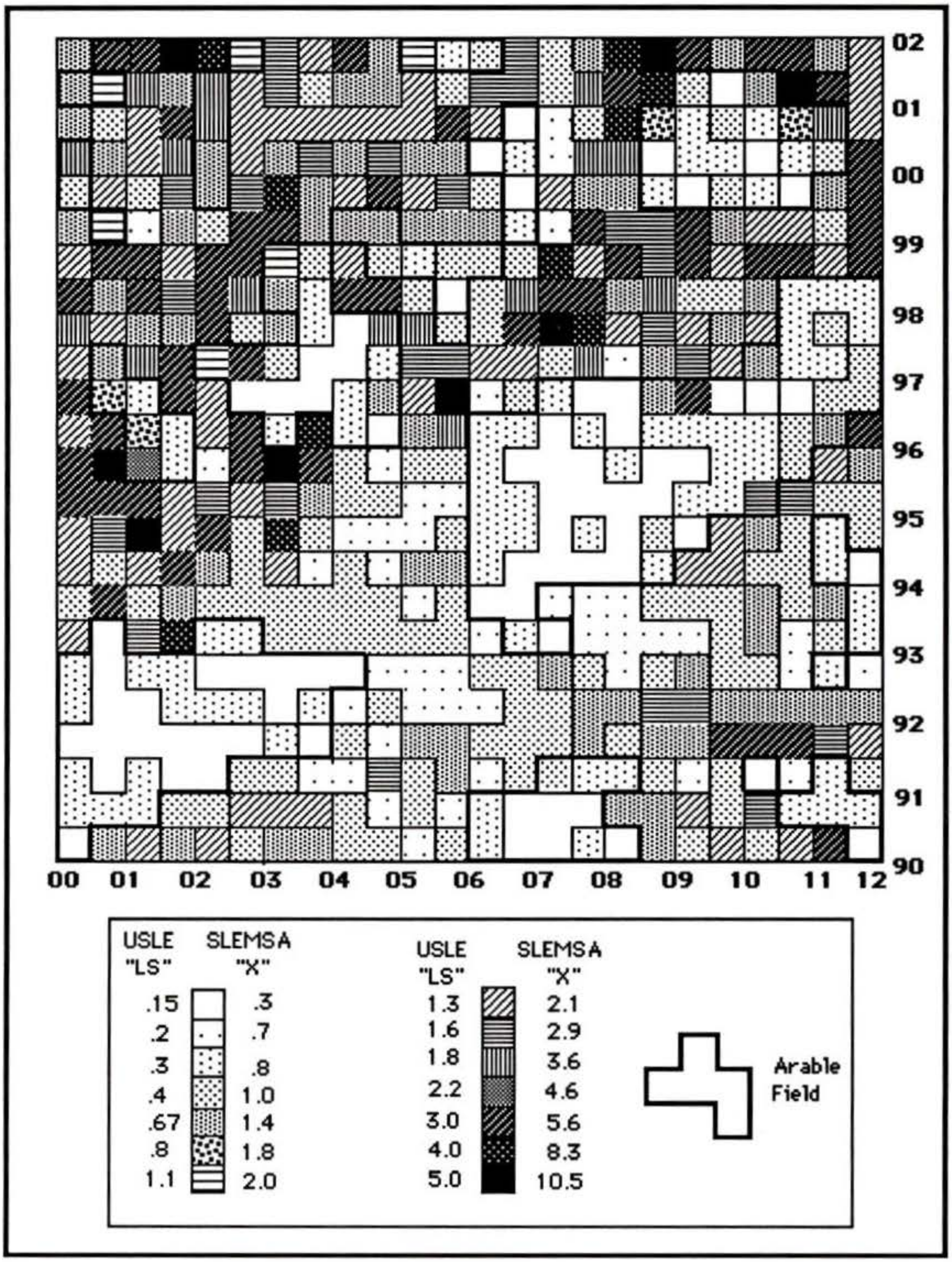
FIGURE 11:
DISTRIBUTION OF AVERAGE SLOPE PERCENTAGE

4	11	9	19	13	8	7	6	11	4	8	3	4	7	3	4	14	19	12	4	9	9	4	6
6	9	8	9	12	6	7	3	4	4	6	3	7	7	3	8	12	14	4	1	6	16	11	6
9	3	6	12	11	6	6	6	6	6	6	11	6	1	1	3	14	7	3	4	3	7	11	6
11	4	6	8	6	6	4	7	9	7	4	9	1	3	1	8	8	1	3	3	1	3	4	9
4	6	3	7	6	7	14	9	6	9	6	7	3	1	6	9	9	3	1	4	3	1	4	11
4	9	1	4	3	9	11	4	6	6	9	9	4	3	1	11	7	7	11	4	6	6	3	11
6	11	9	6	9	11	9	4	6	4	3	4	4	3	13	6	11	7	11	6	9	9	6	9
9	4	11	7	9	8	6	3	9	11	3	1	3	8	9	9	4	8	3	3	4	3	3	3
8	6	9	4	11	3	4	3	1	11	8	4	3	12	15	14	6	7	6	4	6	3	4	3
6	6	8	11	9	12	4	1	1	3	7	7	6	6	3	8	1	4	7	6	6	3	3	4
9	7	3	11	6	1	1	1	3	6	6	15	1	3	3	1	1	6	9	1	1	1	4	4
6	9	7	3	6	9	3	14	3	1	9	8	3	3	1	3	1	3	3	3	3	4	6	11
9	19	13	3	1	11	16	11	3	1	3	3	3	1	1	1	3	1	1	3	3	4	6	4
9	11	9	6	7	6	7	4	3	3	1	1	3	3	1	1	1	1	3	3	7	7	3	3
6	7	17	6	9	3	13	3	1	1	1	3	3	3	1	3	1	4	1	6	4	3	3	3
6	8	6	12	4	3	6	1	3	1	4	4	3	1	1	1	1	3	6	6	3	3	3	1
8	12	8	9	3	3	3	3	3	3	1	3	1	1	1	1	1	3	3	3	4	3	4	3
6	1	7	14	3	3	3	3	3	3	3	3	1	3	1	1	1	1	1	3	4	1	3	3
3	1	3	3	1	1	1	1	1	1	1	1	3	3	4	3	1	3	4	3	3	1	3	1
3	1	1	3	3	3	1	3	1	3	1	1	1	3	3	4	4	7	7	4	4	4	4	4
1	1	1	1	1	1	3	1	3	1	4	4	3	3	3	4	3	4	4	11	9	9	7	6
3	1	3	1	1	3	3	1	1	7	3	4	1	3	4	3	3	3	1	3	1	1	3	3
3	3	3	3	3	6	6	6	3	1	3	1	3	1	1	1	4	4	6	3	7	3	3	3
1	4	6	4	6	3	4	4	3	3	1	3	3	1	1	3	1	4	3	6	3	6	11	1

02 01 00 99 98 97 96 95 94 93 92 91 90

00 01 02 03 04 05 06 07 08 09 10 11 12

**FIGURE 12:
USLE AND SLEMSA L/S RATIOS**



For this study an attempt has been made to separately calculate both C and P. For the USLE model, both C and P values have to be determined and their distribution over Mberengwa has to be mapped.

In some regions of the tropics attempts have been made to quantify the effect of different crop management and conservation practices. Some of the most comprehensive research of vegetal cover and cultural techniques was carried out by Roose in West Africa (1977). Roose gives C values based on yield for the subsistence crops of maize, millet and sorghum ranging from 0.4 to 0.9 (Table 8).

TABLE 8:
WEST AFRICAN SUBSISTENCE C VALUES (Roose, 1977)

	Av. Annual C-factor
Bare continuously fallowed	1
Overgrazed savanna	0.1
Maize, sorghum, millet (as a function of yield)	0.4-0.9
Groundnuts (as a function of yield and data of planting)	0.4-0.8

In other regions results have been obtained that roughly correspond to those obtained in West Africa. In Rwanda, for example, a subsistence maize crop was found to have a C value of 0.35. Sorghum was found to produce only 40% of the soil loss of a bare fallow field giving it a C value of 0.4 (Lewis, 1988). Roose does not describe the relationship between percentage of crop cover and soil loss. This represents another assumption that has to be made. Because of Mberengwa's declining yields of maize, sorghum, and millet (the main local crops), a low yield value of 0.8, indicative of reduced vegetative cover, is used for the average annual C factor.

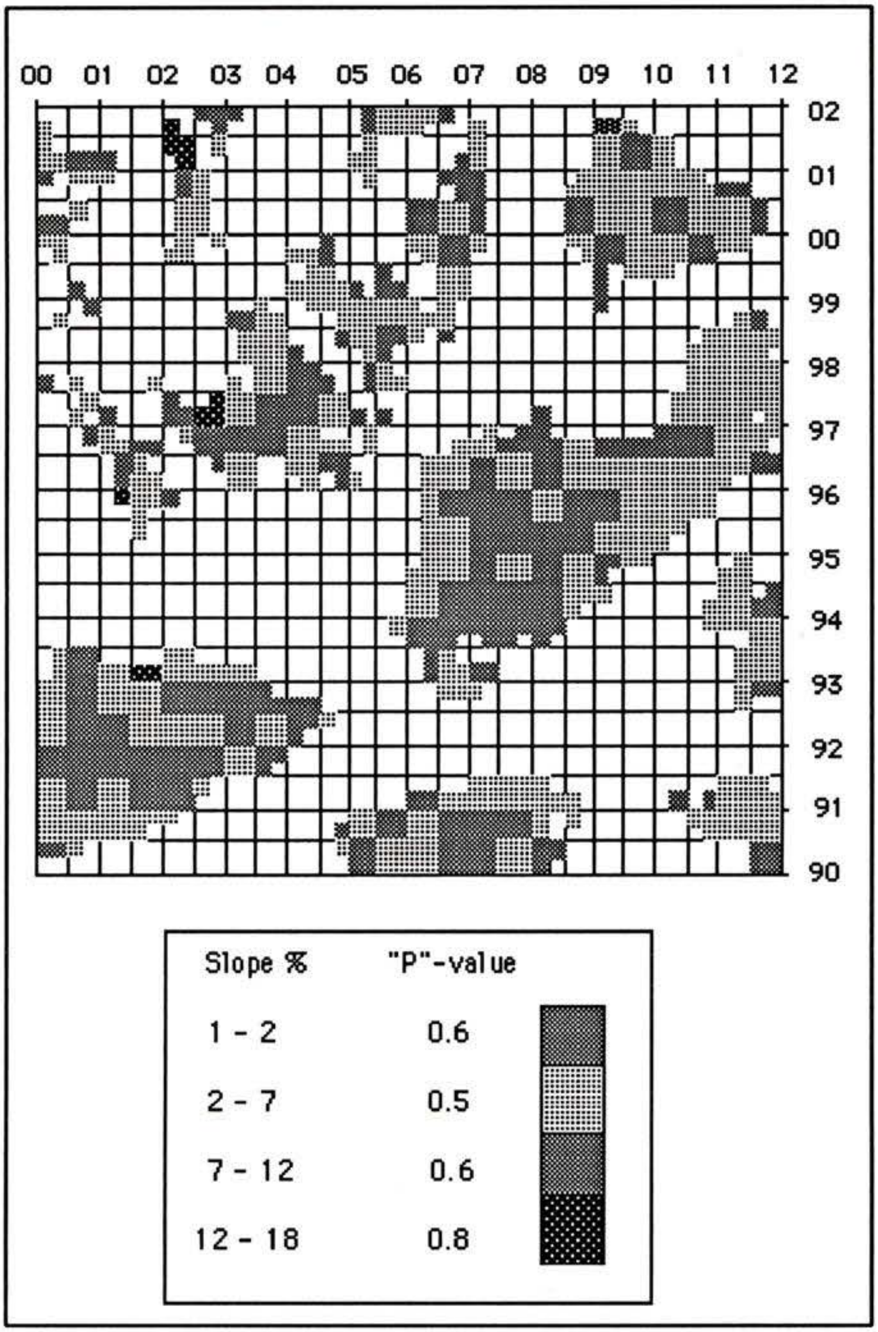
As Hudson (1981) points out, the procedure used to calculate P in Zimbabwe involves establishing values for contour ploughing. The following P values have been determined for contour cultivation based on slope steepness. Hudson however, does not make it clear how these values were derived (i.e. what the relationship between slope Y and P value is).

TABLE 9:
ZIMBABWEAN P VALUES BASED ON SLOPE %

Slope %	P-value
1 - 2	0.6
2 - 7	0.5
7 - 12	0.6
12 - 18	0.8
18 - 24	0.9

Using this method the distribution of P values in cultivated fields is related to the previously calculated average slope (Figure 11) and can be seen in Figure 13. Hudson suggests that compared to other factors P is not likely to be too different from that in the U.S.

FIGURE 13:
MBERENGWA FIELDS P VALUE DISTRIBUTION



Outside of agricultural fields the Zimbabwean method for determining the P value does not apply. The FAO version of the USLE does not distinguish between different crops or conservation practices. This leaves us dependent on the FAO "human factor" to determine combined CP values from grazing land outside of arable fields (Table 10). The FAO "human factor" is a single element which supposedly consolidates the effects of both C and P (1979). For cropland in Sahel and Savanna regions with seasonal rainfall a fixed value of 0.8 is used for this C and P combination. Humid areas such as tropical rainforests are designated a factor of 0.4. These values for agricultural fields are fixed no matter what the percentage of ground cover is over space and time. The FAO model does, however, recognize that soil loss from grazing land must also be quantified in any regional study of erosion. By including differences in forest outside of arable land, the FAO uses numbers that try to reflect variability in land use and ground cover.

Based on field observation, ground cover in the study area was estimated to be between 1 and 20% although this figure varies considerably with season and the year's rainfall patterns. Using Table 10 all land outside of arable fields is assigned a CP value of 0.32. Results of the final step involving combining established C and P values and mapping their distribution can be seen in Figure 14.

TABLE 10:

FAO USLE COMBINED CP VALUES FOR GRAZING AND WOODLAND

	Percentage Ground Cover					
	0-1	1-20	20-40	40-60	60-80	80-100
Pasture grassland and rangelands	.45	.32	.20	.12	.07	.02
Woodland with appreciable undergrowth	.45	.32	.16	.18	.01	.006
Woodland without appreciable undergrowth	.45	.32	.20	.10	.06	.01

5.7 SLEMSA Crop cover (i)

For SLEMSA the percentage of energy intercepted (i) has to be determined for different ground cover and converted to a soil-loss ratio (C). Within the SLEMSA model the value of i takes into account the influence of crop type, planting date, planting density and management (Elwell, 1978). Derived from i the canopy submodel "C" corrects the soil loss from bare soil to that from a cropped field. For wooded and grazing areas Stocking assigns mean seasonal i values of 70% for wooded areas (1987) and 20% for heavily grazed grasslands in areas with 600 mm of rainfall (see Table 11). According to the SLEMSA index these separate conditions will lead to 70% and 20% of the annual erosive rain being intercepted by ground cover. Stocking does not explain how these values have been derived.

FIGURE 14: COMBINED CP VALUES

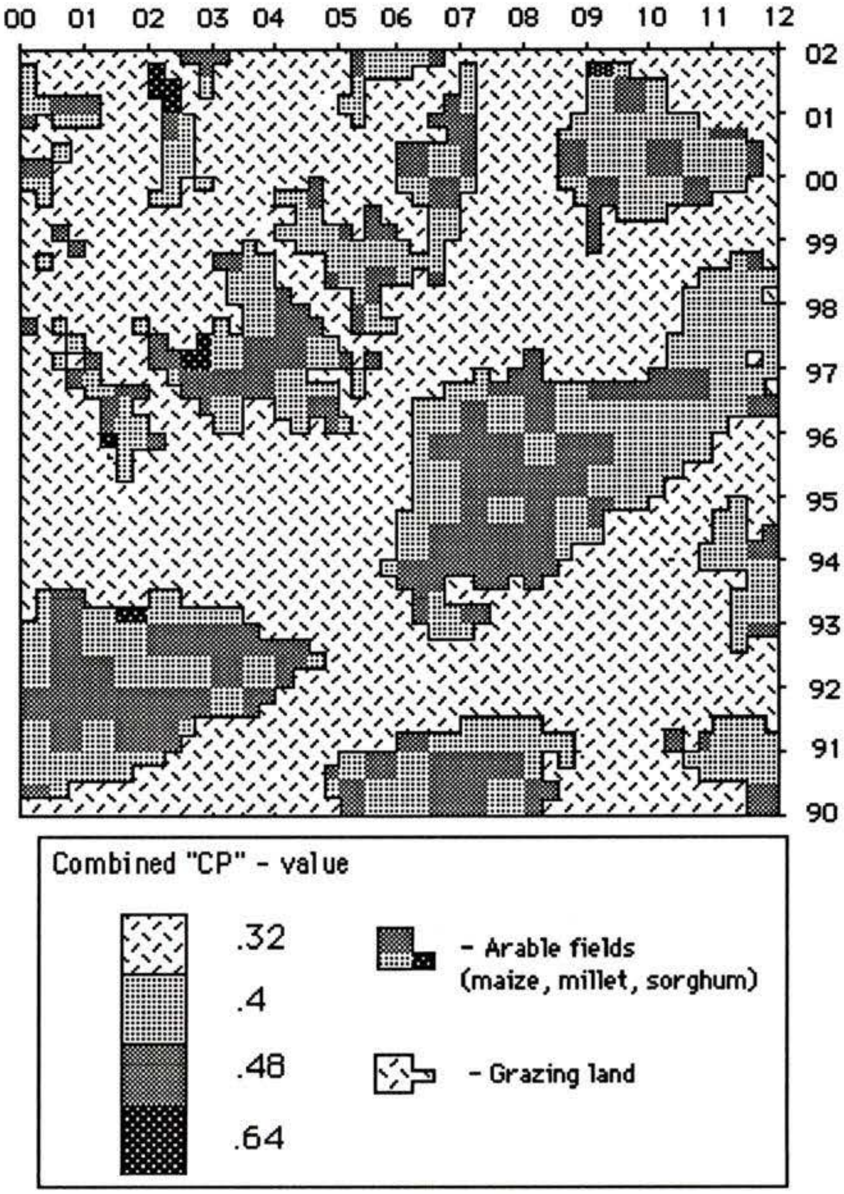


TABLE 11:
COVER VALUES (OR MEAN SEASONAL INTERCEPTION OF EROSIVE RAIN) ON NATURAL GRASSLAND IN ZIMBABWE

		Cover % or mean seasonal interception, i, %	
		Rainfall zone	
Grazing pressure	cattle-day per hectare	600 mm	800mm
light	0-100	70	90
moderate	100-300	40	60
heavy	more than 300	20	30

TABLE 12:
'i' VALUES FOR MAIZE

Yield	i% For emergence dates										
kg/ha	1/S	15/S	1/0	15/0	1/N	15/N	1/D	15/D	1/J	15/J	1/F
500	14	16	18	18	17	15	12	10	7	4	2
1000	18	21	23	23	22	20	16	13	9	6	3
2000	24	27	29	29	28	25	21	16	12	7	4
4000	34	38	42	42	40	36	29	23	17	10	5
6000	43	48	52	53	51	45	37	29	21	13	6
8000	50	56	61	62	59	53	43	34	24	15	8
10000	55	63	68	69	66	59	48	38	27	17	8

A crop of maize, which of all local crops provides the least adequate cover, was assumed for all fields in order to derive a worst-case scenario. SLEMSA i values for maize can be seen in Table 12. Low yields of 500 kilograms per hectare for maize and a crop emergence date around the fifteenth of December are assumed for this study. Both assumptions have to be based on field observation only. Using these criteria mean seasonal interception of erosive rain by maize is calculated to be 10%.

Finally the SLEMSA crop cover model (Appendix B, Figure 3) is used to convert interception value to a soil loss ratio (C). The distribution of both i values and the resulting C values are shown in Figure 15.

5.8 Soil-Loss Distribution

In order to calculate soil-loss distribution using the USLE method, values for erosivity, erodibility, slope, crop and conservation practices are combined using the USLE equation. The resulting distributions of estimated soil loss for 1987 and 1988 are shown in Figures 16 and 17.

For SLEMSA, estimated values for crop ratios, erodibility and topographic ratios are combined with distribution of soil loss in tonnes/ha to produce soil loss maps for 1987 and 1988 as shown in Figures 18 and 19.

FIGURE 15: SLEMSA COVER % AND SOIL LOSS RATIO (C)

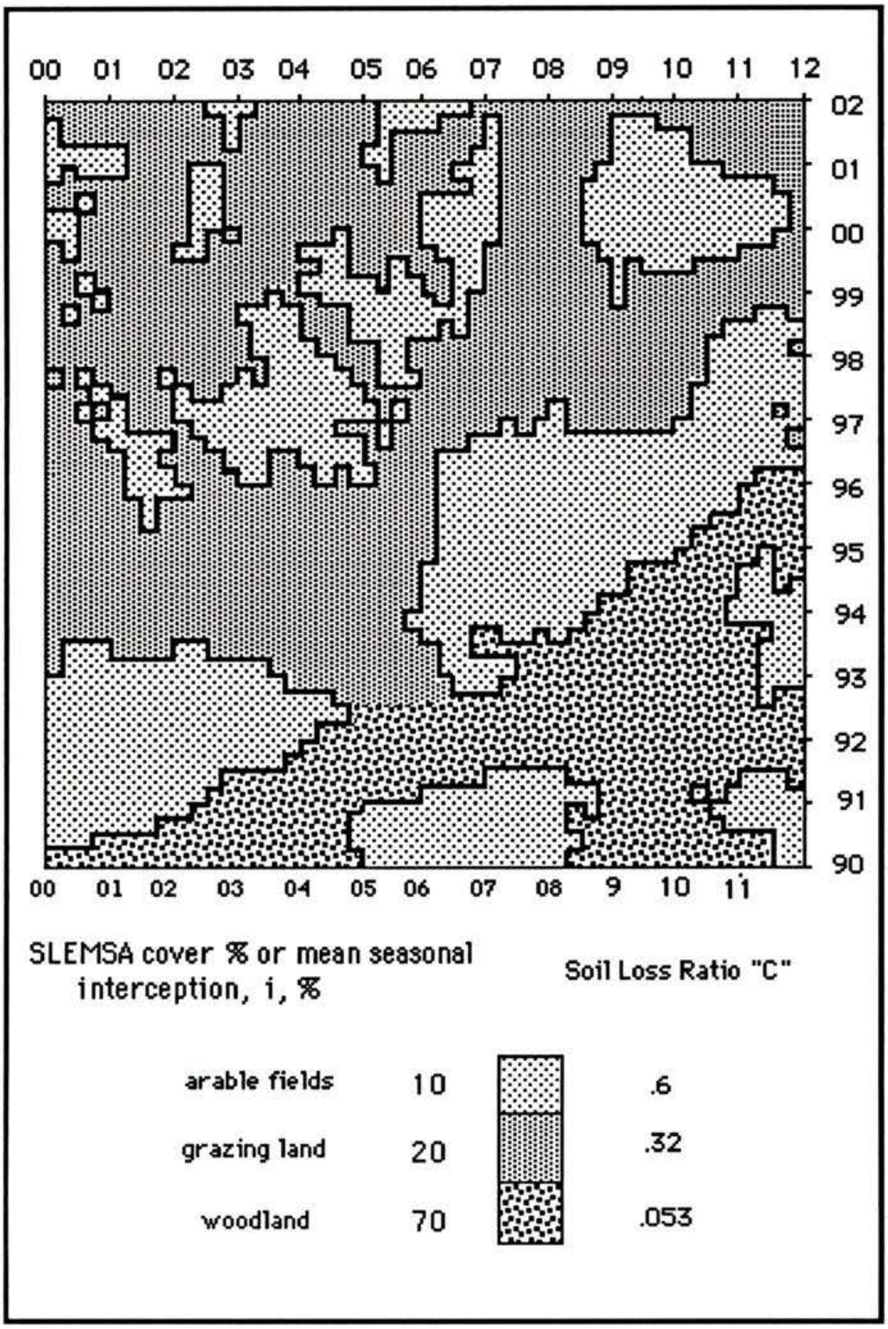


FIGURE 16:
DISTRIBUTION OF SOIL LOSS (1987) USING USLE

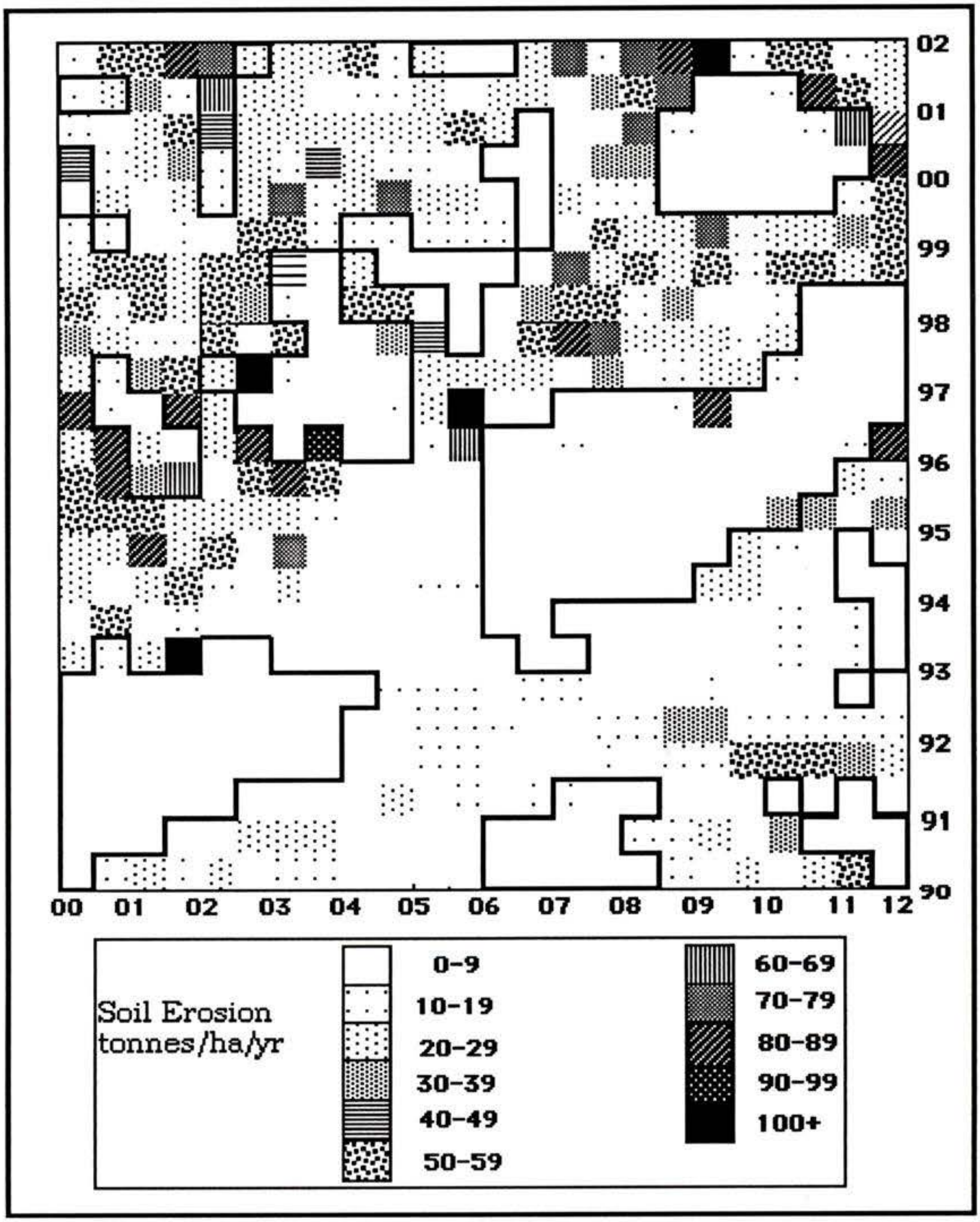


FIGURE 17:
DISTRIBUTION OF SOIL LOSS (1988) USING USLE

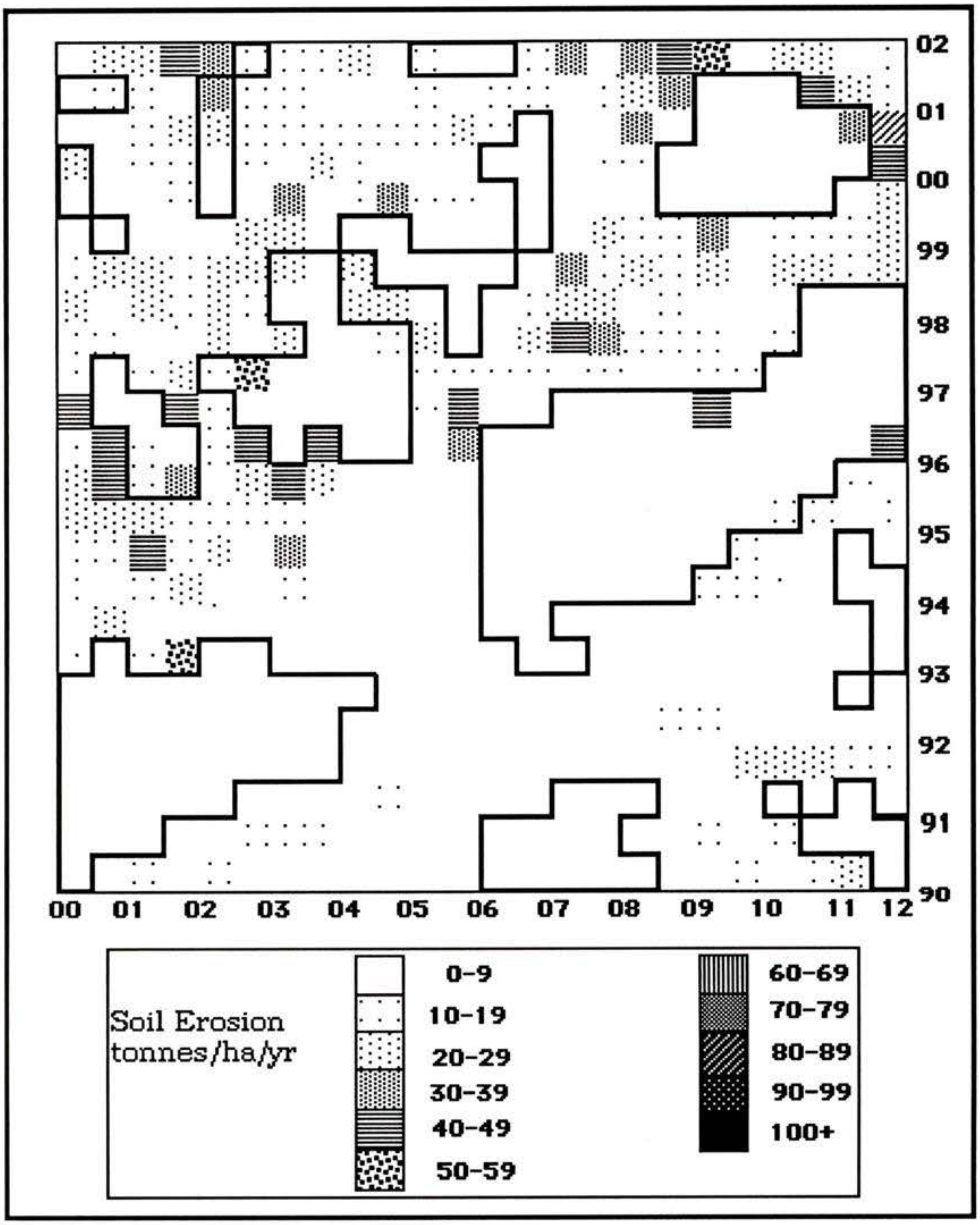


FIGURE 18:
DISTRIBUTION OF SOIL LOSS (1987) USING SLEMSA

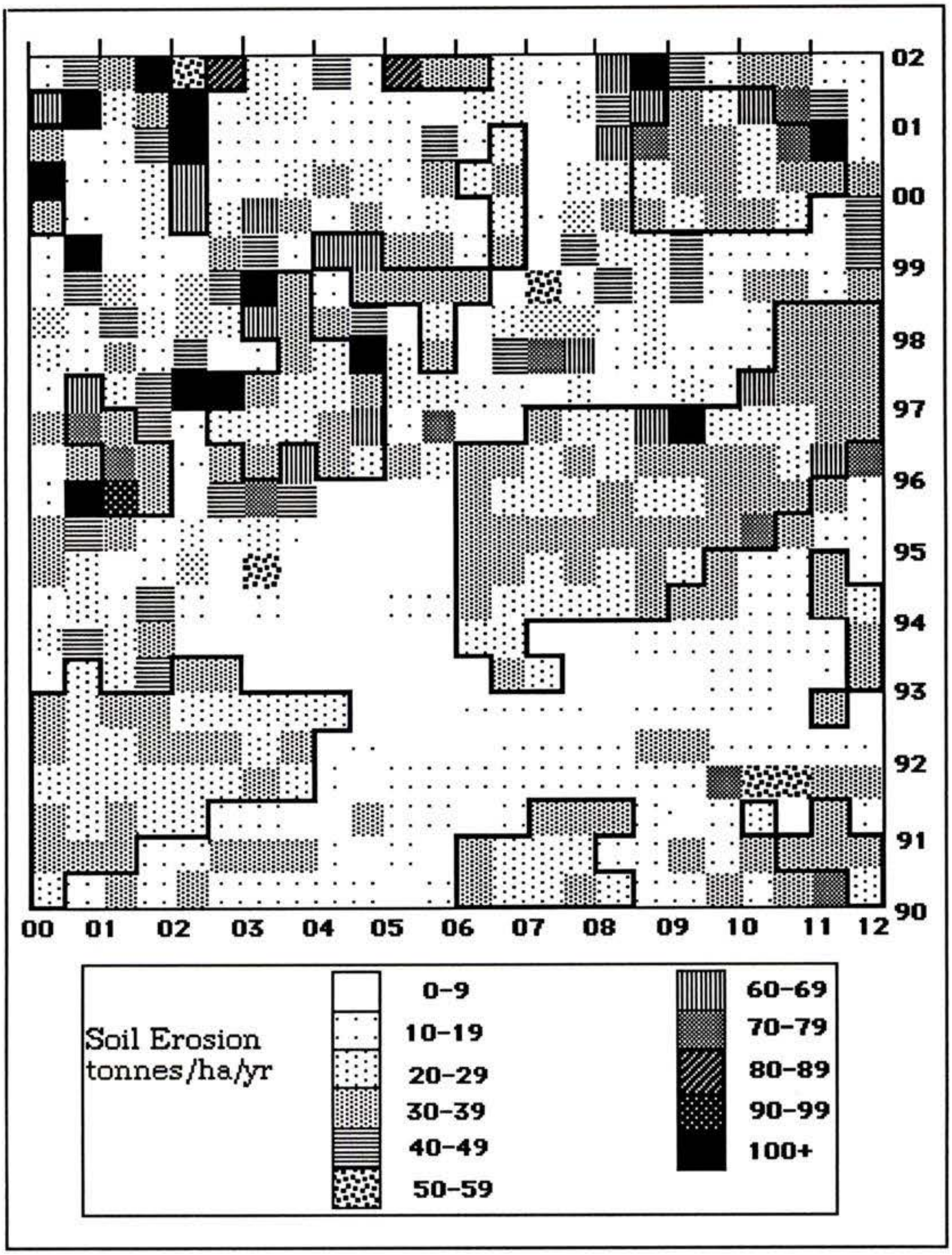
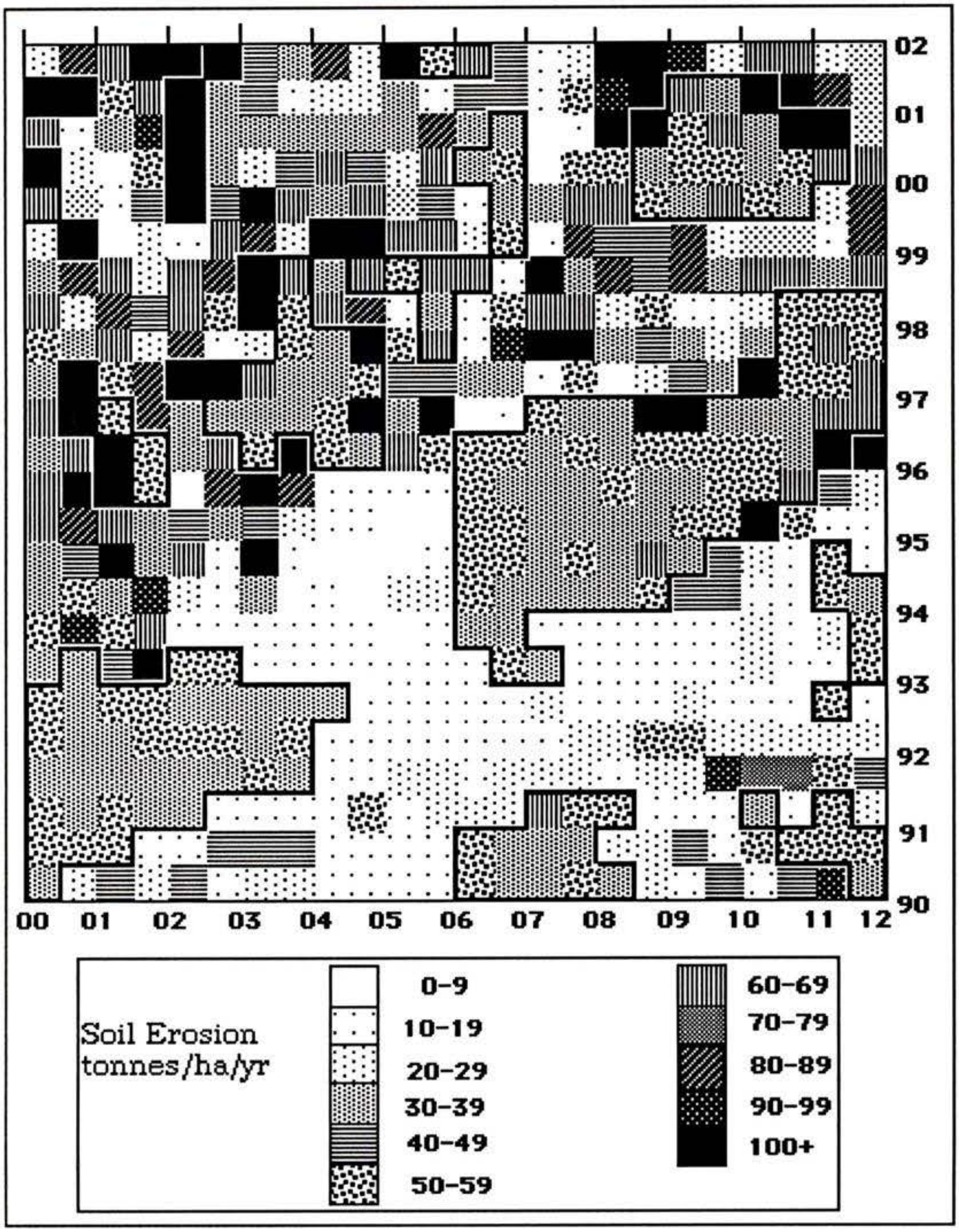


FIGURE 19:
DISTRIBUTION OF SOIL LOSS (1988) USING SLEMSA



CHAPTER SIX

Results and Discussion

6.1 Results

- Using USLE methodology, predicted soil loss for all three types of land use decreased in 1988 compared to 1987 (see Table 13).
In 1988 there was: a 24% decrease in predicted soil loss compared to 1987 for arable fields; a 47% decrease for communal grazing land; and a 43% decrease for communal forest land.

- Using SLEMSA methodology, predicted soil loss for all three types of land use increased in 1988 compared to 1987. In 1988 there was: a 45% increase in predicted soil loss compared to 1987 for arable fields; an 88% increase for communal grazing land; and a 42% increase for communal forest land.

- Using USLE methodology most soil loss was predicted to occur from 1) communal grazing land, followed by 2) communal forest land and, 3) arable fields in both 1987 and 1988.

- Using SLEMSA methodology most soil loss was predicted to occur from 1) arable fields, followed by, 2) communal grazing land, and 3) communal forest land in both 1987 and 1988.

- In all cases except for communal grazing land in 1987 SLEMSA predicted the loss of more soil than the USLE method.

TABLE 13:
AVERAGE SOIL LOSS, STANDARD DEVIATION, AND VARIANCE OF SAMPLE RELATED TO LAND USE IN MBERENGWA RESEARCH AREA

	1987		1988	
	USLE	**SLEMSA**	**USLE**	**SLEMSA**
Mean (soil loss-mt/ha/yr)				
-arable fields	8.96	38.86	6.78	56.19
-grazing land	30.7	23.89	16.27	44.96
-communal forest	14.02	17.95	8.01	25.49
Standard deviation of sample				
-arable fields	11.89	20.76	6.78	23.01
-grazing land	25.1	19.61	16.27	29.29
-communal forest	13.2	13.89	8.01	18.04
Variance of Sample				
-arable fields	141.45	430.79	48.55	529.57
-grazing land	630.0	384.48	165.71	858.0
-communal forest	174.23	192.87	47.43	325.0

In 1987 SLEMSA predicted;

- 334% more soil loss than USLE for arable fields;
- 22% less soil loss than USLE for communal grazing land;
- 28% more soil loss than USLE for communal forest land.

In 1988 SLEMSA predicted;

- 729% more soil loss than USLE for arable fields;
- 176% more soil loss than USLE for communal grazing land;
- 218% more soil loss than USLE for communal forest land.

- Using USLE methodology, the greatest variance in soil loss occurred in communal grazing land for both 1987 and 1988.

- Using SLEMSA methodology, the greatest variance in soil loss occurred in both communal grazing land and arable fields for both 1987 and 1988.

6.2 Discussion

Key components in the methodology inherent in the USLE and SLEMSA need to be looked at in order to understand why results differ.

Mberengwa received more rainfall in 1988 than in 1987. The erosivity factor in SLEMSA uses a direct correlation between total rainfall and its erosive energy. As a result SLEMSA "E" increases in 1988 compared to 1987.

However, the tropical adaption of the USLE "R"-factor also takes into consideration the monthly concentration of rainfall. In 1987 a smaller precipitation total was concentrated in only a couple of months, effectively raising the USLE erosivity rating of 1987 over 1988.

When trying to assess the <u>accuracy</u> and <u>validity</u> of one method over the other, ideas that need to be considered include:

The measure of SLEMSA erosivity was developed for use in Zimbabwe based only on limited test-plot analysis. Most of this work was carried out in high plateau areas north of the Mberengwa study area where:

a) rainfall patterns are more predictable and reliable and;
b) soil classes are different than those of the Mberengwa area.

USLE methodology at least partially incorporates the importance of concentrated, high-intensive rainfall. However it blurs the importance of the relationship between heavy rainfall and crop stage or ground cover percentages which are never static through a 12 month period. A concentration of rainfall in November, when fields are bare and grazed of all protective stubble at the end of the dry season, would result in more soil loss than the same area in January when crop and grass cover has reestablished itself. USLE methodology does not reflect this temporal variation.

A point worth repeating is that neither method has fully established the exact relationship between tropical rainfall energy and vegetative cover.

Except for grazing land in 1987 SLEMSA consistently predicted more soil loss than USLE both over time and with different types of land use. Both methods have a measure of erodibility based on inherent properties of the soil itself. However soil erodibility is taken a step further within SLEMSA by the incorporation of cultural practices that can increase susceptibility to erosion and predicted estimates.

An estimate within SLEMSA of average plant cover and its importance in intercepting rainfall energy also leads to higher predicted soil loss.

In trying to determine the validity of one method over the other, ideas to consider include:

Subsistence cultural practices, including ploughing that is not parallel to the contour, can increase soil loss. By what amount has yet to be quantified through test plots.

An estimate of average plant cover does not incorporate the seasonal relationship between crop stage and the kinetic energy of rainfall. This relationship and its effect on soil loss can only be accurately determined if long term test plots are used that accurately reflect conditions that exist in areas of subsistence agriculture.

Predicted soil loss is much more variable in the northern third of the Mberengwa study area than it is in the south. This is partially the result of averaging slope percentage within a grid square in an area of rapidly changing slope angles. The common land form of the northern portion is the steep-sided inselberg surrounded by a sharp break in slope and gently sloping pediments. A grid square that averages the two will not accurately reflect the effect of slope on soil loss.

6.3 Model Validation

Before either (or any) model can be used, methods should be determined for validating their accuracy in areas extraneous to where they were developed. The most accurate method of validating the results of either model would be to measure soil erosion in the field. While remote sensing can be used to interpret the distribution of erosion, its use to quantify soil loss would still needs to be "ground truthed" through field work.

Attempts to distinquish the main classes of topsoil texture through remote sensing have shown low levels of prediction (Dent & Young, 1981). Gullying, shows up clearly on the air photographs used in this study, but neither model was developed to determine soil loss outside of sheet and rill erosion. Sheet erosion usually shows as paler tones on arable land. However, in Mberengwa, soil erosion is so extensive differences in tone within the same soil type can no longer be distinguished. Cattle trampling and related soil compaction also shows up as white patches in air photos. Again this condition is almost universal throughout the study area.

This study indicates the importance that SLEMSA places on vegetative cover for calculating soil loss. If field work could be used to establish the nature of this relationship, then remote interpretation of vegetative cover, in combination with knowledge of other factors about soil, rainfall, slope, and conservation practices, may come closer to accurately quantifying soil loss.

Field measurements may be carried out either volumetrically or dynamically (Hsieh, 1992). Volumetric methods, such as the use of simple erosion pins, provide less information than dynamic methods and do not provide information about the constituents of eroded material However, sophisticated volumetric methods, such as portable contour plotting frames and laser scanners, may provide enough information to test the relative accuracy of the two models.

In the future if either soil erosion model is to be adjusted to more accurately reflect factors found in tropical low input agriculture, dynamic methods which capture water and sediment will be required. In its simplest form sediment yield in river basins may be measured and linked to upstream erosion. However, a correlation needs to be established between down stream sediment yields and upstream soil loss. This method also does little to calculate the distribution of soil erosion.

Dynamic methods usually require the construction of a run-off plot which can be laborious and expensive, but provide information about the properties of eroded materials that are important to soil management. Two types of erosion plots may be useful -small and standard USLE/SLEMSA plots. (Mutchler et al. 1988). Small plots are typically a square metre in size, can be constructed in a lab and allow the researcher to isolate some small part of the erosion process. Small plots could be used to isolate certain factors such as soil erodibility within each model but they would need to be used in conjunction with standard-sized field plots. Standard-sized USLE and SLEMSA plots are large enough to represent the complete process of sheet and rill erosion. They are also large enough to allow the effect of a range of agricultural and conservation practices to be measured. The use of standardized plots and methodologies, that both these models have been based on, would allow knowledge gaps to be clarified and narrowed within the framework of research that has gone on before.

6.4 Recommendations

If the predictive abilities of these two models are so variable, the question remains how they can be used to reduce soil loss in Mberengwa. Both the USLE and SLEMSA were originally designed to quantify soil loss associated with specific commercial farming practices. The USLE, in particular, is used to make recommendations to U.S. farmers about field management practices that, if followed, have been demonstrated to reduce soil erosion.

Both models have been used in the developing world (and elsewhere) at small scales in an attempt to show the distribution of potential soil erosion over a large area. Using these models in ways and locations they were not designed for is partially due to:

a) the urgent and widespread problem of soil erosion in many parts of the world, and;

b) lack of time and resources to refine models suitable for SSLI agriculture under tropical conditions.

If the existing models are to be of use to a community of farmers (and not just planners at the national level), they must be shown to work. They also must be used at a scale where individual fields and associated soil types can be identified (at least 1:50 000). However, both models require that an impressive series of assumptions be made before they can be applied at the local level as this study has done, or at the national level, as others continue to do.

A single model, used at the national level or for a small region of subsistence agriculture, may give the impression that a fairly clear picture of the extent of soil erosion is being shown. Because using two models for the same region leads to such conflicting results, the conclusion becomes inescapable that too many assumptions have had to be made. In addition, both models do little to predict soil removal by wind or the relationship between soil, water and wind erosion. While soil loss due to water probably accounts for greatest volumes, wind erosion becomes increasingly important as vegetative cover is removed.

If at this time, neither model can be used in its entirety, perhaps parts of them can. Because overpopulation problems of the Zimbabwean communal lands are so extensive, the soil erosion hazard is extreme. Stocking (1972) states that for continuous areas of degraded soil combined with extensive defoliation, slope may be the most significant variable needed to identify the distribution of soil loss.

If in the future this is shown to be the case, recommended conservation practices have already been tied to existing slope angles by Zimbabwean agricultural agencies (Stocking & Elwell, 1986). For slopes of 0-2% no contour ploughing is normally necessary (slope percentage expresses the ratio of height gained to distance travelled). For slopes of 2-6% with good cover crops, contouring and some small physical works such as storm waterways are recommended. For steeper slopes of 6% and greater, contouring plus more elaborate land use planning measures (crest roads, lined waterways, diversions etc.) are necessary. Contour ploughing and contour bunds which do not always exactly follow the contour are presently the extent of mechanical conservation practices within the study area. The slope portion of either model could be used to locate agricultural fields within Mberengwa with slopes of 6% and greater which probably require more extensive conservation measures (see Figure 20).

Finally, two ideas contained within the models provide guidance as to which direction future efforts should take to preserve soil in Mberengwa.

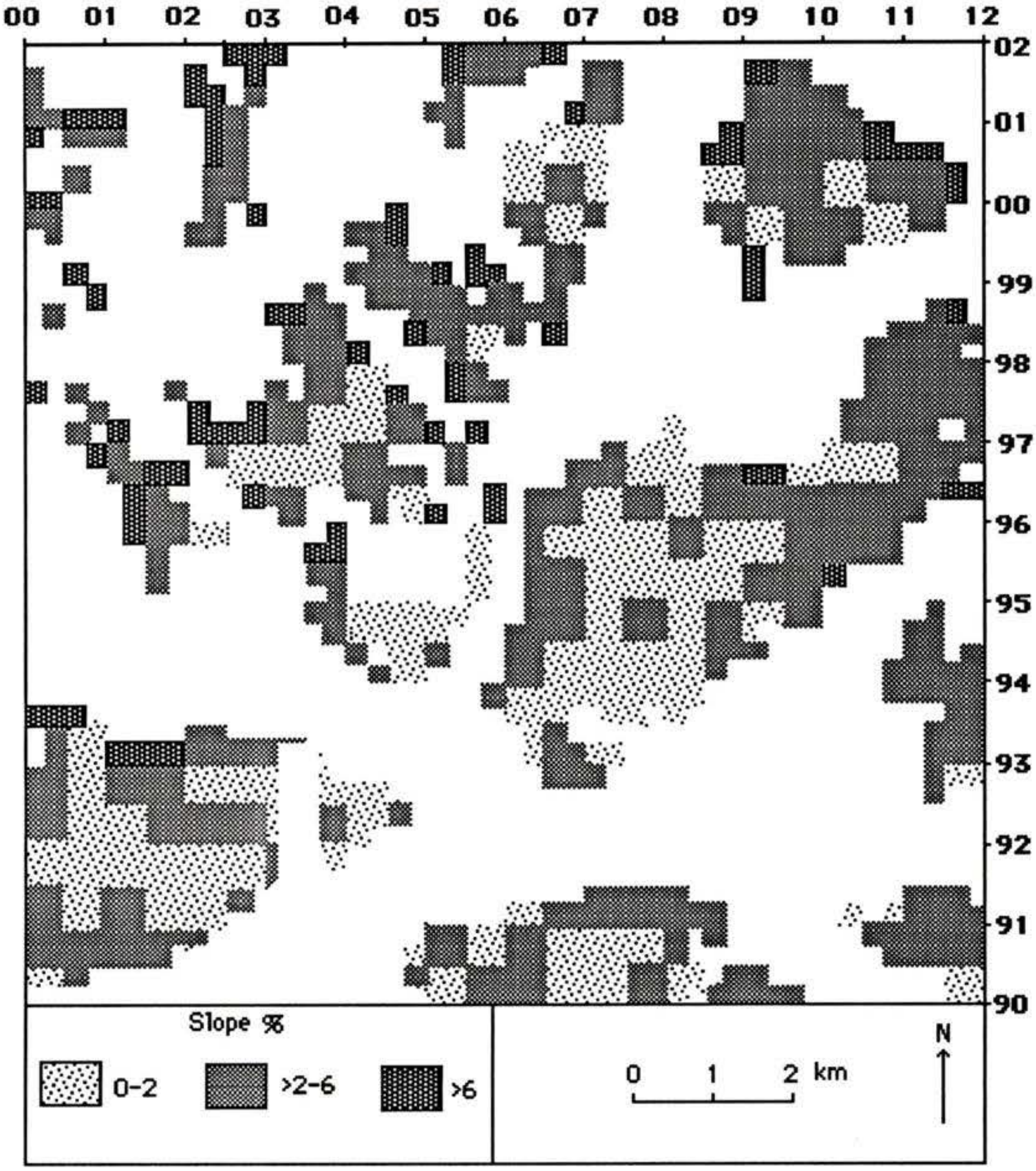
- The SLEMSA model's emphasis on the importance of plant cover in reducing the energy of convectional rainfall.

- The erodibility of soil in the USLE model and its direct relationship to organic matter content.

Efforts to prevent soil moving down slope in Mberengwa often focus completely on mechanical solutions. Extension workers try to encourage farmers to use their oxen to plough parallel to the contour or to spend time building and maintaining contour bunds. However, ways should also be found to maintain and rebuild soil organic matter content and to increase the amount of plant residue available for use as a protective mulch. This will both reduce erodibility and increase soil fertility which will lead to increased plant cover. Conservation practices which lead to increased yields are practices that the subsistence farmer will actively support if they are not too labour-intensive or costly.

This study started with the premise that SLEMSA and the USLE could be used to identify trouble areas where limited resources could be directed to slow soil loss. This project was initiated to address the need for a simple way of organizing information in the developing world where large numbers of farmers live in dispersed and remote locations. Because of the number of assumptions that have to be made and the variability of results, neither model can yet be used to accurately identify exactly what is happening where. Both models reveal that there is the potential for great amounts of soil loss in tropical areas of subsistence agriculture and both provide insights into what parameters need to be studied to prevent the loss of soil that so many depend on.

FIGURE 20:
THE DISTRIBUTION OF SLOPE % RELATED TO RECOMMENDED CONSERVATION PRACTICES



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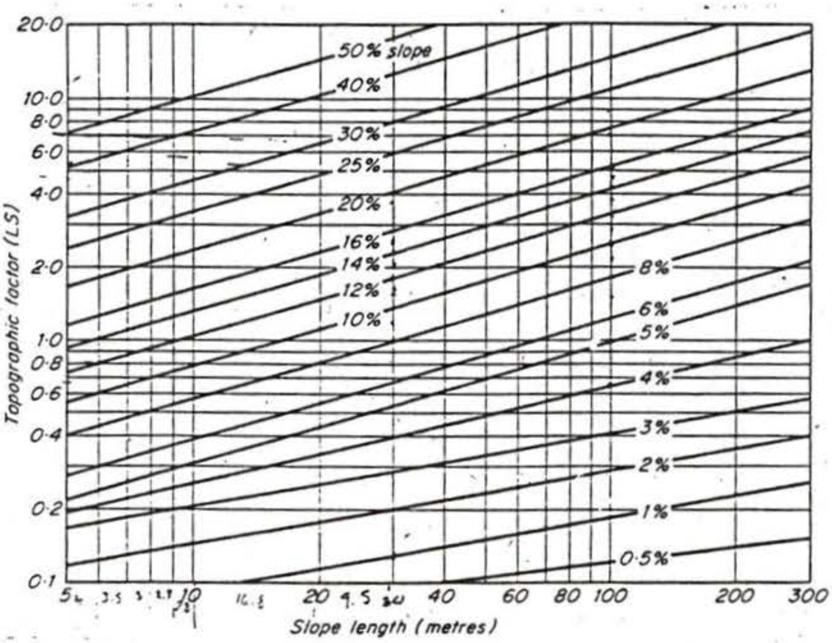
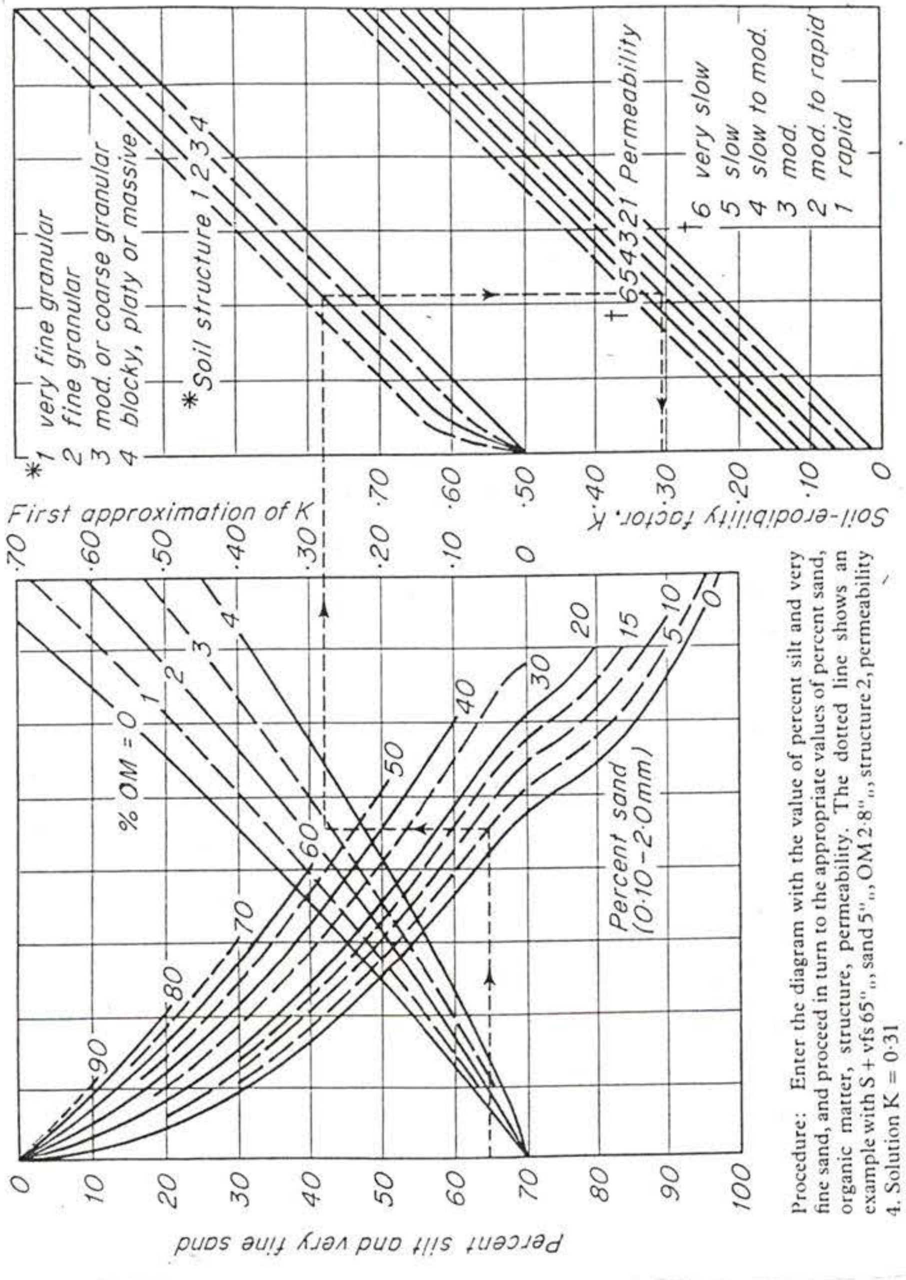
Appendix A: figure 1

USLE TOPOGRAPHIC RATIO (Hudson, 1981)



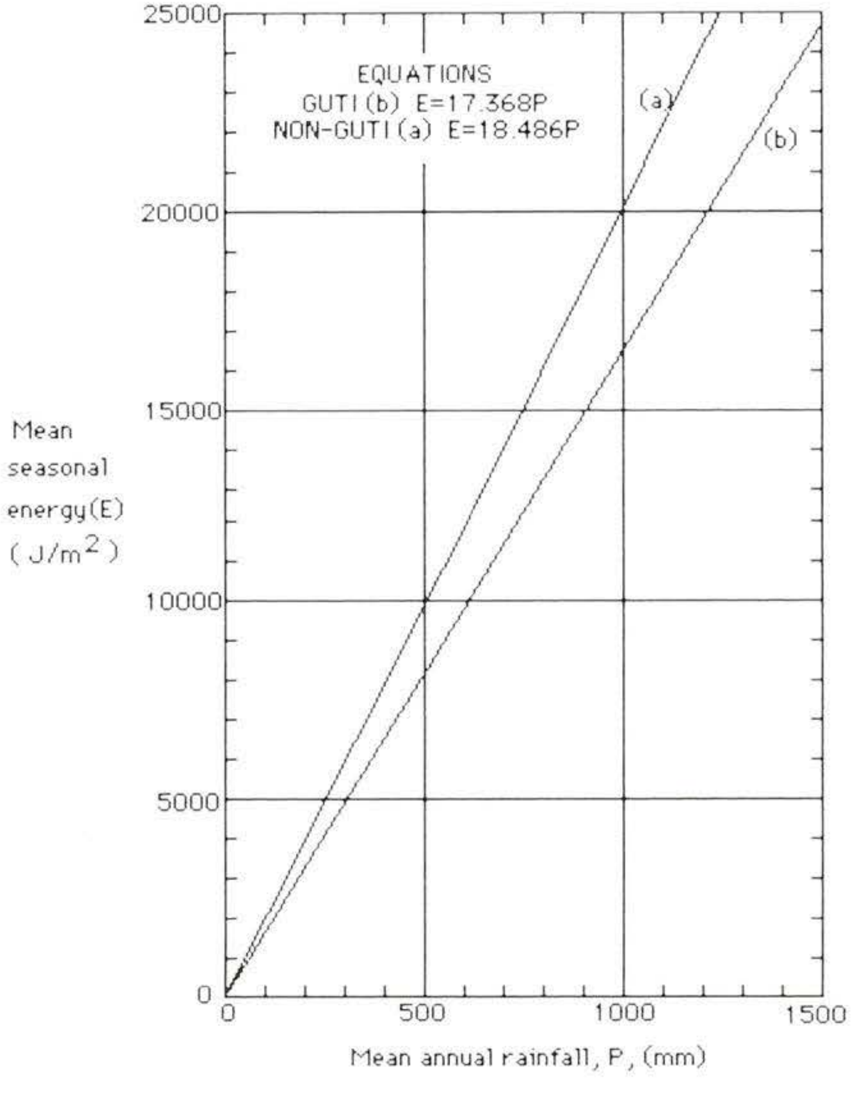
Appendix A: Figure 2

USLE SOIL ERODIBILITY (K) NOMOGRAPH (Hudson, 1981)

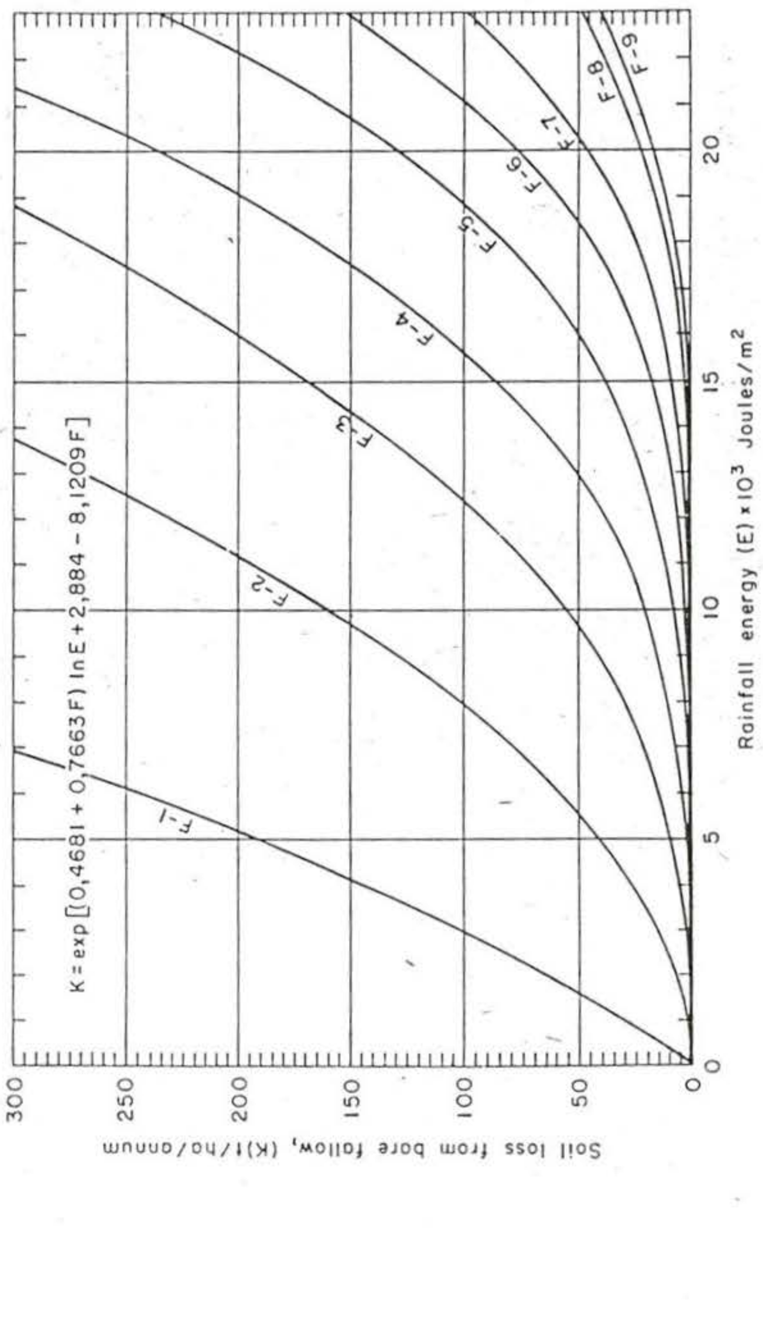


Procedure: Enter the diagram with the value of percent silt and very fine sand, and proceed in turn to the appropriate values of percent sand, organic matter, structure, permeability. The dotted line shows an example with S + vfs 65%, sand 5%, OM 2·8%, structure 2, permeability 4. Solution K = 0·31

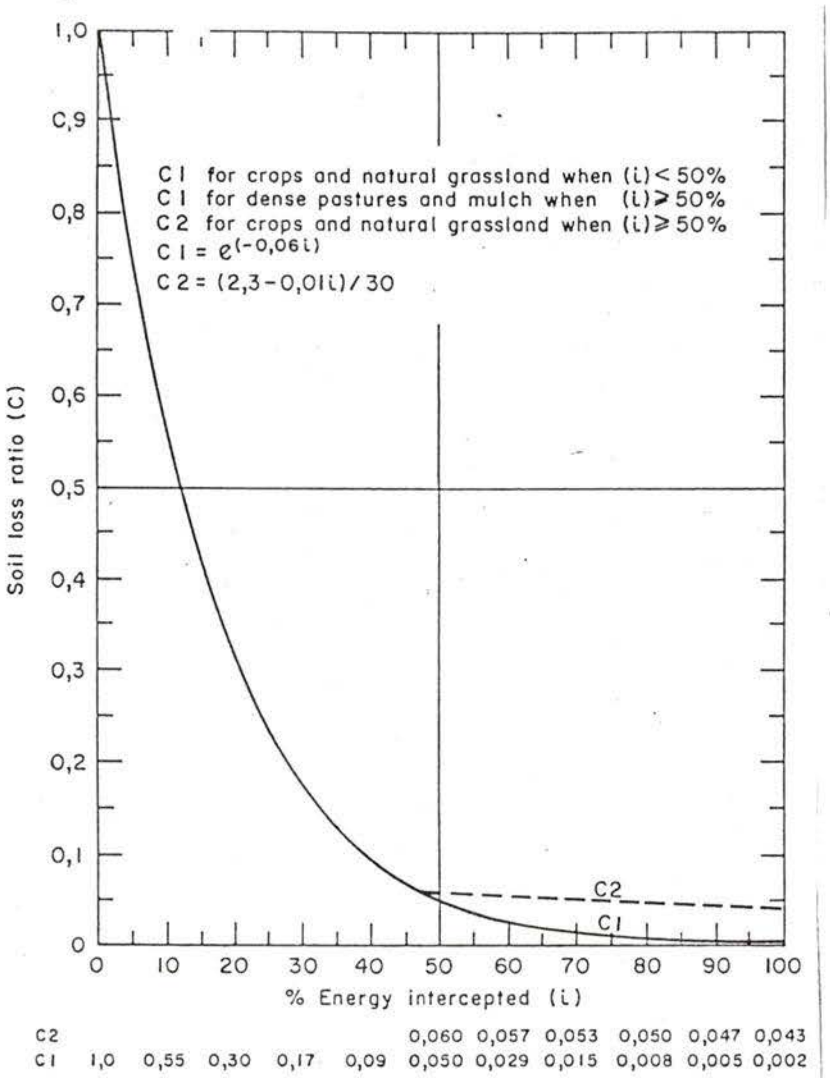
Appendix B: Figure 1:
SLEMSA EROSIVITY CALCULATION (E) (Elwell, 1984b)



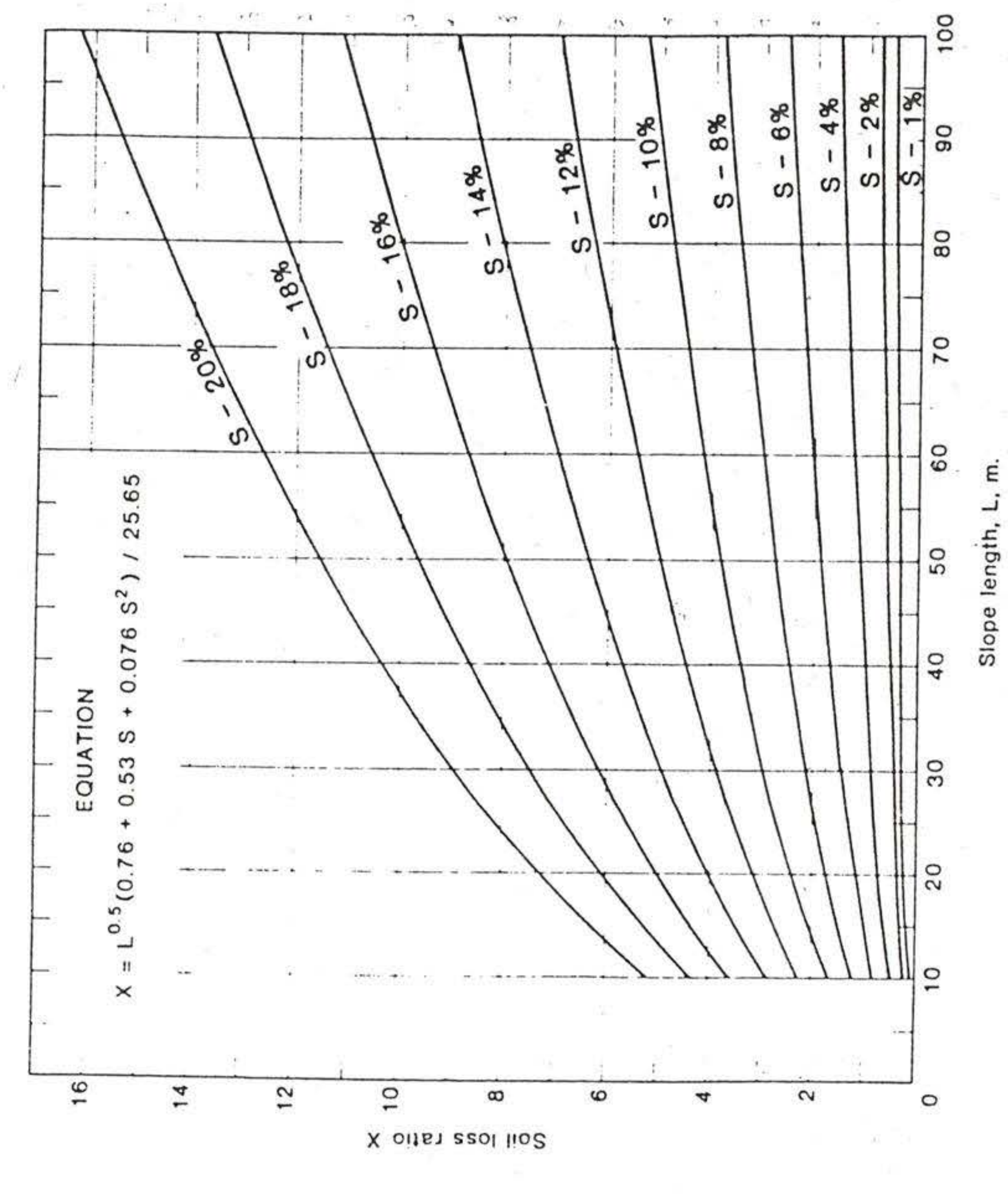
Appendix B: Figure 2
SLEMSA RELATIONSHIPS BETWEEN K,E, AND SOIL ERODIBILITY
(Elwell, 1984b)



Appendix B: Figure 3
SLEMSA CROP COVER MODEL (Elwell, 1984b)



Appendix B: Figure 4
SLEMSA TOPOGRAPHICAL MODEL (Elwell, 1984b)



Appendix B: Table 1: Selecting (F) Basic SLEMSA soil erodibility
(Elwell, 1984b)

		Texture of top soil		
Soil Group	Soil Family	A,X	B,C	D,E,F,G
Regosol	1K	4		
Lithosol	2	2	2.5	4
Vertisol	3B,3E,3X			5
Siallitic	4E		3.5	4
	4X			4
	4S			3.5
	4P,4M	3.5	4	
	4G	3		
Fersiallitic	5E		5.5	6.0
	5X			6.0
	5S		4	4
	5G	4	5	
	5P	4	4.5	
	5M	4.5		
	5F	4	5	
	5A	3.5	4	
Paraferrallitic	6G	4.5	5	
Orthoferrallitic	7E			7
	7S			5.5
	7G	5.5	6.5	6.5
	7M	5	6	
Sodic	8N	1	1.5	2

N.B. Where 2 or more values are given, the most commonly occurring soil is underlined.

Appendix B Table 1 continued:

Key to symbols:

Soil Group

1.	Regosol
2.	Lithosol
3.	Vertisol
4.	Siallitic
5.	Fersiallitic
6.	Paraferrallitic
7.	Orthoferrallitic
8.	Sodic

Texture

A	Sand
X	Loamy sand
B	Sandy loam
C	Sandy clay loam
D	Clay loams
E	Sandy clay
F	Clay
G	Heavy clay (vertisol)

Soil Family

A	Arenaceous
B	Basalt
C	Colluvium
E	Basic rocks
F	Micaceous rocks
G	Granites and coarse gneisses
h	Saline-sodic
K	Kalahari sand
M	Sandstones and quartzites
n	Weakly sodic
N	Strongly sodic
P	Fine-grained siliceous gneisses
S	Argillaceous sediments
U	Alluviums
X	Ultra basic rocks

Appendix B: Table 2:
Deviation of (Fm) from (F): (Elwell, 1984b)

(F= Fb ° the sum of the correction factors given below obtained from A + B + F or A + C + or D or E as appropriate)

Practice	Factor
A. Soil losses from the previous year	
- Less than 10 t/ha	0
- 10 to 20 t/ha	-0.5
- Greater than 20 t/ha	-1.0
B. Ridging practices	
B1 Crops on big ridges (not less than 200 mm high consolidated)	
- Flatter than 1% grades with tie ridges	+1.5
-Flatter than 1% grades without tie-ridges	+1.0
-Between 1 and 2% grades	0
- Over 2% grades	-1.0
B2 Crops on small ridges (less than 200 mm high unconsolidated)	
(The constriction of undersized ridges is not advocated!)	
-Flatter than 1% grades	-1.0
-Between 1 and 2% grades	0
-Over 2% grades	-1.0
C. Annual crops planted on the flat	
C1 Planting and ploughing directions	
- Operation "level" or "on-contour"	
- Operations at angles to the contour ridges	
C2 Tillage techniques	
- Plough (250 mm), roll and disc harrow to give a fine tilth, e.g. conventional tillage	0
- Plough (250 mm) and roll to give a rough tilth e.g. rough-conventional	+0.5
- Ripped to 300 mm and lightly disced to 80 mm, e.g. rip and disc	0
-Plough (250 mm), plant in strips of tilth made by the tractor wheels, leaving clods in the inter rows, e.g. wheel - track planting	+1.0
- No ploughing or discing with crop tine -planted e.g. zero tillage	-0.5
-Very fine powdery tilth, e.g. cotton tilth	-0.5
- Rip to 300 mm, cultivate and roll e.g. conservation - tillage	0

Appendix B: Table 2 (continued)

D. Fallows and leys (good management)	
- 1st year fallow or ley	0
-2nd year fallow or ley	+1.0
-3rd year and subsequent years	+ 2.0
- Permanent pastures and veld in good condition	+2.0
E. Perennial crops and orchards	
- No tillage and cultivated mechanically	-0.5
- No tillage and herbicide weed control	0
- No tillage and soil showing a marked improvement such as occurs under heavy mulch	+2.0
F. Irrigation	
- Light textured irrigated soils (sand and loamy sand topsoil)	-0.5
- Heavily fertilized and irrigated pastures	+3.0

Notes All practices are judged by comparing them to conventional tillage. If a practice either increases run-off, or reduces the soil's resistance to being broken down by raindrop action, it is given a negative rating. Conversely, practices which store water and resist detachment are given a positive rating.

The designer can interpolate between values if he is confident in his ability to do so.

Appendix B: Table 3: (i) Values for crops

Crop	Yield (kg/ha)	(i)% For emergence dates										
		1/S	15/S	1/O	15/O	1/N	15/N	1/D	15/D	1/J	15/J	1/F
Maize	500	14	16	18	18	17	15	12	10	7	4	2
	1000	18	21	23	23	22	20	16	13	9	6	3
	2000	24	27	29	29	28	25	21	16	12	7	4
	4000	34	38	42	42	40	36	29	23	17	10	5
	6000	43	48	52	53	51	45	37	29	21	13	6
	8000	50	56	61	62	59	53	43	34	24	15	8
	10000	55	63	68	69	66	59	48	38	27	17	8

VITA

Surname: BRYDEN Given Names: JOHN ANDREW

Place of Birth: VANCOUVER B.C, Date of Birth: June 17, 1949

Educational Institutions Attended:

University of Victoria	1988 to 1993
University of Calgary	1982 to 1985
Foreign Service Institute (Washington, D.C.)	1979
British Columbia Mining School (Rossland, BC)	1978

Degrees Awarded:

B.Sc. (Honours)	University of Calgary	1985

Honours and Awards:

National Science and Engineering Research Council Fellowship	1984-85

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Author [redacted]
(Signature)

John A. Bryden
(Name in Block Letters)

February 28, 1994
(Date)