Soil erosion prediction under changing land use on Mauritius

by

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Abstract

More than one half of the total area of Mauritius Island (1844 km^2) is under intensive cultivation, mostly sugarcane. Since the sugarcane industry is currently facing tremendous economic constraints, sugarcane cultivation may be diversified into other agricultural types such as vegetables, pineapple and forestry. Increasing concern about the sugarcane industry and the consequences of agricultural diversification, necessitated the application of soil loss prediction models within a GIS framework. Modelling of the potential soil loss in the *Rivierre Des Anguilles* catchment (RDAC) is undertaken to understand the extent to which soil erosion is affected by different land use types or agricultural systems. Although most of the RDAC is covered with sugarcane (62%), a wide range of landforms, micro-climates and soils exist, making the catchment representative of southern catchments in Mauritius.

The study integrates GIS techniques with two empirical soil loss models: The Revised Universal Soil Loss Equation (RUSLE); and The Soil Loss Estimation Model of Southern Africa (SLEMSA). Both models, as well as the GIS application termed Soil Erosion Assessment using GIS (SEAGIS), are used to investigate average annual soil loss from the catchment under key management practices. Using data on soil erodibility, rain erosivity, topography and land cover, soil loss can be estimated under different management options for cropland (sugarcane, intercropped cane, vegetables, banana and tea) and natural vegetation (scrub and forest). RUSLE is additionally used to predict soil loss for the catchment under potential crop diversification scenarios including, vegetables, pineapple and forest. Using the

empirical soil loss models in conjunction with a GIS, it is possible to compile soil erosion prediction maps of the RDAC under current and future conditions.

Although soil loss in the catchment varies significantly, models show a similar trend in mean soil loss rates of the cropping systems. Rates are generally highest on steep slopes (>20%) with high rainfall (2400 mm) along the river valley and upper catchment area (above the 400 contour line). Predicted soil loss results, however, indicate a strong inverse relationship with vegetation cover. Very high soil loss values (more than 80 $t.ha^{-1}.yr^{-1}$) are attained under vegetables, moderate values (13 to 20 $t.ha^{-1}.yr^{-1}$) under intercropped cane, low (10 $t.ha^{-1}.yr^{-1}$) or very low (less than 2 $t.ha^{-1}.yr^{-1}$) under sugarcane, very low (4 $t.ha^{-1}.yr^{-1}$) to moderate (16 $t.ha^{-1}.yr^{-1}$) ratings under banana plantations, very low (less than 1 $t.ha^{-1}.yr^{-1}$) to high rates (41 $t.ha^{-1}.yr^{-1}$) under tea plantations, and low rates (less than 10 $t.ha^{-1}.yr^{-1}$) for natural vegetation. SLEMSA, however, predicts high erosion rates (27 $t.ha^{-1}.yr^{-1}$ to 59 $t.ha^{-1}.yr^{-1}$) under natural vegetation, since the model is not developed for use in natural conditions.

Crop diversification will have a considerable influence on soil erosion. RUSLE predicts a mean soil loss of 42 $t.ha^{-1}.yr^{-1}$, 20 $t.ha^{-1}.yr^{-1}$, and 0.2 $t.ha^{-1}.yr^{-1}$ under vegetables, pineapple, and forest, respectively. When compared to current conditions, the mean soil loss for the catchment will double under pineapple (increase by 100%), and quadruple under vegetables (increase by 300%). Results indicate that no appreciable erosion damage will occur in the RDAC if converted to forested land.

Results provide considerable information regarding soil loss under potential land use change. The study also improves the understanding of factors governing erosion in Mauritius, which is important in the targeting of research and soil conservation efforts. Landowners and the government can use results to promote farming systems that do not degrade land resources.

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Chapter 1: <u>Introduction</u>

The land resource base of Mauritius is limited due to the islands relatively small size of 1844 km^2 and growing population (Proag, 1995). Soils previously classified by Arlidge and Wong You Cheong (1975) as unfit for agriculture are now being bulldozed, de-rocked and irrigated by overhead systems. More than one half of the total area of Mauritius is under intensive cultivation, mostly sugarcane, including areas that have slopes of 30 percent or more. Water erosion can be severe in the tropics, especially from marginal lands with steep slopes and poor soil structure (Yu *et al*. 2001). A limited number of studies (*e.g*. Atawoo and Heerasing, 1997; Kremer, 2000; MSIRI, 2000) indicate that one of the most important types of land degradation in Mauritius occurs by loss of topsoil. Although sugarcane is considered a soil conserving crop (Proag, 1995), Kremer (2000) states that soil erosion under sugarcane is prevalent on highly erodible soils and steep slopes. Furthermore, a possibility exists that sugarcane cultivation might be diversified into other agricultural systems, since the sugarcane industry is currently facing tremendous economic constraints (Mauritius Sugar Syndicate, 2001). The problem is compounded by an increasing shortage of labour coupled with rising production costs and lower sugar prices (Julien, 1995; Ministry of Agriculture and Natural Resources, 1999; MSIRI, 2000). In order to attain a certain degree of self-sufficiency in food production, the government has emphasized a need for the promotion of agricultural diversification (Jahaweer, 2001). The flourishing export market for exotic agricultural and horticultural products reinforces this demand. It is postulated that the diversification of sugarcane fields into other agricultural systems will place increasing strain on land resources leading to further soil degradation.

In order to select appropriate conservation measures and land management strategies, the identification and quantification of erosion sources is necessary (Dickinson and Collins, 1998). Prediction technology used for estimation of soil loss is regarded as a suitable tool in depicting the nature of the factors governing erosion (Morgan, 1995). Empirical soil erosion models continue to play an important role in soil conservation planning (Liu *et al*., 2000), and to assess the distribution and extent of erosion in catchment areas. Numerous qualitative studies on soil erosion on catchment scale have been done (*e.g*. Edwards and Owens, 1991; Wallace, 1997; Trustrum *et al*., 1999; Smithers *et al*., 1997; Smith *et al*., 2000), however, there remains a general lack of quantitative information under tropical conditions. Furthermore, nothing is known regarding the potential rate of soil loss under crop diversification for Mauritius.

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1.1 General aim and objectives

In this context the main objective of the study is to estimate the average annual soil loss due to water erosion under current conditions and to predict the outcome in terms of soil loss under future conditions, should diversification of agricultural systems come to pass. A specific catchment (*Rivierre Des Anguilles*) is used for this purpose. The study aims to achieve an understanding of the extent to which soil losses are affected by the erosion factors, particularly land use. Therefore, the study anticipates improving the understanding of factors governing erosion in Mauritius, which is important in targeting of research and soil conservation efforts. Some essential concepts are outlined before specific aims and objectives are listed.

1.2 Soil erosion as central concept

Soil erosion is related to a wider concept termed soil degradation. Loss of topsoil is only one of the major soil degradation problems confronting agriculture throughout the world and includes physical, chemical and biological deterioration (Dardis *et al*., 1988). Research has shown that soil degradation includes loss of organic matter, decline in soil fertility, the breakdown of soil structure, changes in salinity, and acidity (Haynes, 1997). Forces leading to soil degradation include deforestation, intense cultivation and overgrazing of vulnerable land, pollution, and poor soil and water management. All these forces reduce the productive capacity of the soils.

Rain erosion is one of the categories of soil erosion. Other erosion agents include ice, wind and streams, and are referred to as glacial erosion, eolian erosion and fluvial erosion respectively (Morgan, 1995). Rain erosion is defined by Bergsma *et al*. (1996: 117) as: "The rate of soil loss expected in the near future, due to rain erosion, depending on the combined and interactive effects of all erosion hazard factors: climate, relief, soil profile, present erosion, land use and vegetation, and cultivation system". Rain erosion processes include removal or detachment or entrainment, transport and deposition of soil particles. According to Nearing (1990) the total soil loss for any time period is a function of two distributions: one for the resistance of the cover and soil factors that change daily and the distribution of the rainfall events for the time period. Understanding and predicting soil erosion requires knowledge of how these key soil and plant parameters change with time, and how these changes influence soil erosion. Empirical models are, therefore, required for predicting soil loss under a wide range of conditions.

1.3 Model selection

Two models whose primary function is the estimation of rainfall erosion were considered. According to Smith *et al*. (1999) the most widely applied soil loss models are the USLE, its improved version the Revised Universal Soil Loss Equation (RUSLE) version 1.04 (Renard *et al*., 1994), and the Soil Loss Estimation model of Southern Africa (SLEMSA) (Elwell, 1976). The RUSLE version 1.04 and the SLEMSA are utilised in this study.

RUSLE was selected due to the model being one of the most technically advanced and showing potential for use in other parts of the world, including developing countries (Lane *et al*., 1992). Furthermore, the flexibility of the RUSLE model proved to be advantageous for application on a catchment scale (Smith, *et al*., 2000). RUSLE is especially useful for simulating a series of "what if" scenarios. Hence, soil erosion rates, of current and future conditions, of different cropping systems can easily be estimated and compared (Renard *et al*., 1994).

In addition, SLEMSA was selected since it was developed in southern Africa, and it gives promising soil loss results with limited data[1] (Rydgren, 1996). Both the RUSLE and SLEMSA are commonly used in the Southern African region (see discussion on page 122 and 123). The simplicity, or rather manageability, of both models makes them attractive to many users particularly for adding quantification to assessments of soil erosion risk.

1.4 Catchment selection

As noted above, the study aims at estimating the average annual soil loss under current and potential future conditions in the *Rivierre Des Anguilles* catchment (RDAC). The catchment is chosen because of its diversity in landscape profiles, and particularly for its well differentiated and diverse land use pattern. Similar to most southern catchments of Mauritius, the RDAC runs from sea level up to an elevation of about 650 m.a.sl. near the highest point on the island (860 m.a.sl.). Consequently, landscape profiles of the RDAC have a wide range of rainfall patterns (Proag, 1995) and variable slopes (Ordinance Survey, 1991), making it representative of southern catchments. In addition, the RDA catchment falls within an important agricultural area, especially the coastal - and lower inland sloping plains, and contains three of the most

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[1]. Information from personal communication with Prof. A. S. Claasens, Department of Plant Production and Soil Science, University of Pretoria, 7 August 2001.

important soil groups in Mauritius (Arlidge, & Wong You Cheong, 1975). The flat to gently undulated slopes below the 400 m contour line with deep and fertile Latosols, have almost no limitations to intensive crop production. The RDAC, therefore, can be classified as a land system that is highly suitable for cultivation, currently and potentially. It is an appropriate study area in which the soil erosion rates of important land use types can be assessed; and importantly, to assess the impact in terms of soil erosion under future diversification of agricultural systems. A detailed environmental description is provided in chapter 2.

1.5 Rationale

There is much scope internationally for research in the prediction of soil erosion under specific conditions or scenarios. The ability to predict soil erosion impacts of various land uses and management practices before they are implemented allows land managers to select the most suitable alternatives for preventing or reducing soil loss. According to Smith *et al*. (2000), soil loss modeling, in which available input data and appropriate soil loss models are used together with GIS technology, can be used to screen feasible development alternatives. Empirical soil loss models have been applied in many parts of the world and are relatively simple to use (Smith *et al*., 1999). However, prediction models do not yield true deterministic results of real erosion rates (Morgan, 1995). Empirical models, such as the RUSLE and SLEMSA, are based on identifying statistically significant relationships between assumed important variables. Variables such as chemical properties of the soil are not accounted for. Therefore, estimated soil loss rates need to be verified before they can be used with confidence in quantitative interpretations. Caution should be taken when interpreting quantitative results because spatially distributed results, especially within catchments, have not been validated.

Nonetheless, according to Rydgren (1996), prediction models used wisely are useful tools for comparisons between different agricultural systems. Morgan (1995) notes that for some purposes, such as comparing the effect of different cropping systems, it may be enough for a model to predict realistic percentage differences in erosion between the systems without giving absolute values. Smith *et al*. (2000) suggests that initial results could still be used to identify trends in soil loss rates, which can then be used to steer future research and validation studies. Although results obtained in the study may be subject to error, it is postulated to be very useful in terms of soil loss comparisons between current and possible future conditions. Such results, however, should be interpreted as probabilities rather than deterministic values (Stocking, 1995). Yet, results of this kind give land managers the ability to predict soil erosion impacts of

various agricultural systems before they are implemented, and to select the most suitable alternatives for preventing soil loss. Additionally, the quantitative approach of the study involves the comparison of soil loss values or rates with what is considered acceptable. Subsequently, cropping systems leading to unacceptable soil erosion rates have to be reconsidered or eliminated. Soil erosion records and predictions provide that kind of information. Unfortunately, few records of soil loss rates and totals are available in the tropics, including Mauritius.

1.6 Soil loss modelling in concept

Kremer (2000) provided a qualitative assessment of the soil erosion rate in Mauritius under sugarcane. The principles of the USLE were used in a GIS framework to obtain erosion risk maps. According to the maps, the erosion hazard is high when the canopy cover of sugarcane is low. These results however remain speculative since ratoon cane, when harvested, does not leave the soil bare.

The Mauritius Sugar Industry Research Institute (MSIRI) studied the effect of storms of different intensity on runoff and sediment transport in sugarcane fields in Mauritius using a rainfall simulator. Along the cane rows, very little runoff and erosion occurred. On bare interrows the soil loss rate averaged low values between 0.2 and 5 $t.ha^{-1}.yr^{-1}$ at a rainfall intensity of 90 $mm.h^{-1}$. According to the results it appears that there is a threshold rainfall intensity of about 60 $mm.h^{-1}$ above which erosion starts to occur (MSIRI, 2000). The study, however, was limited to a few sugarcane fields on two soils (Low Humic Latosols and Dark Magnesium Clay) with slopes varying from 7 to 13% and thus, although valuable data, has limited application to other areas on the island.

Soil erosion has long been recognized as an important process in steep valleys of tropical islands (Lo *et al*., 1985; Cooley & Williams, 1985). On Hawaii, Calhoun and Fletcher (1999) estimated with the USLE that the 55.5 km^2 Hanalei watershed in the tropical Kauai Island loses a total of 4800 ± 5600 tons of sediment per year (140 ± 55 $t.km^{-2}.yr^{-1}$). Also in Hawaii, McMurtry *et al*. (1995) calculated lower sediment yields (2630 $t.yr^{-1}$ or 61.2 $t.km^{-2}.yr^{-1}$) in a 42.9 km^2 canal of Oahu Island. The lower sediment yield for the canal of Oahu Island is contributed to a drier climate and the canal being more urbanized than the Hanalei watershed of Kauai Island. Despite its smaller size (32.6 km^2), the RDAC is comparable to the above noted catchments in terms of its volcanic originated geology and tropical climate.

The RUSLE (*e.g.* Biesemans *et al.*, 2000; Smith *et al.*, 2000; Wang *et al.*, 2000; Busacca *et al.*, 1993; Renard *et al.*, 1991) and SLEMSA (*e.g.* Schulze, 1979; Hudson, 1987; Paris, 1990; Rydgren, 1996) has been applied on catchment scale in many areas of the world. These studies demonstrate that the RUSLE and SLEMSA are capable of adequately modelling soil loss under different land use, despite being applied to conditions beyond its database. RUSLE in particular, is capable of adequately modelling soil loss in a wide range of conditions, including tropical regions. Results from the studies noted above indicate that both models signify a similar trend in soil loss rates between land use types. For example, using the USLE and SLEMSA, Rydgren (1996) determined soil and nutrient losses under different management options in catchments of Lesotho, South Africa where poorly conserved cropland loses on average (6-7 t.ha^{-1}) up to six times more soil than the well conserved cropland (1-2 t.ha^{-1}). Prediction models are described below while their application is considered further in Chapter 5 on page 121.

1.7 Model descriptions

1.7.1. RUSLE

Smith, *et al.* (2000) describes the Revised Universal Soil Loss Equation (RUSLE) as a software version of an improved Universal Soil Loss Equation (USLE), which draws heavily on USLE data and documentation. The RUSLE is an erosion model designed to predict the long term average annual soil loss carried by runoff from specific field slopes in specified cropping and management systems including rangeland (Renard *et al.*, 1994). The model groups the many influences on the erosion process into five categories including climate, soil profile, relief, vegetation and land use, and land management practices. These categories are well known as the erosion factors, R, K, LS, C and P, respectively. Descriptions of each factor follow under Chapter 3: Methodology and terminology. The product of these factor values gives the expected soil loss in t.ha^{-1}.yr^{-1}, depending on the dimensions used in the climate and soil factor. The equation is (Renard *et al.*, 1994):

$$A = R.K.L.S.C.P \qquad\qquad (1.1)$$

where:

- A is the computed spatial average soil loss and temporal average soil loss per unit area, expressed in the units (t.ha^{-1}.yr^{-1}) selected for K (in t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}) and for the period selected for R = EI$_{30}$ (where E is in MJ.ha^{-1}.mm^{-1} and i is in mm.h^{-1});

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- R is the rainfall runoff erosivity factor which is the rainfall erosion index calculated as an average annual value;

- K is the soil erodibility factor which is the soil loss rate per erosion index unit for a specified soil as measured on a standard plot (22.1 m in length of uniform 9% slope in continuous clean tilled fallow);

- L is the slope length factor which is the ratio of soil loss from the field slope length to soil loss from a 22.1 m length under the same conditions;

- S is the slope steepness factor which is the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under the same conditions;

- C is the cover management factor which is the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow; and

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

Changes to the original USLE include the following (Renard, *et al*., 1994; Morgan, 1995):

- The RUSLE incorporates more data ranging from different crops to forest and rangeland erosion;

- a new procedure for computing the C factor value through the multiplication of various sub-factor values reflecting prior land use, surface cover, crop canopy, surface roughness and soil moisture;

- the support practice factor P has been expanded to consider rangelands, contouring, strip cropping and terracing; the development of a seasonally variable K factor, including correction for rock fragments in the soil profile, as well as the development of an alternative regression equation for volcanic tropical soils;

- modifications to the LS factor to take account of the susceptibility of the soils to rill erosion; and

- revisions to the R factor values in the USA.

RUSLE also incorporates more vegetation data than the USLE, and includes process based calculations to add or change data from its original database. The most significant RUSLE improvement is its increased flexibility, which allows for modelling of a greater variety of

systems and alternatives (Yoder and Lown, 1995). The RUSLE is alleged to show acceptable trends in erosion rates for even minor changes in management systems (Smith *et al.*, 1999) which increases its usefulness as a conservation planning tool for potential development scenarios.

1.7.2. SLEMSA

SLEMSA was developed largely from data from the Zimbabwe highveld to predict the mean annual soil loss arising from sheet erosion under different farming systems and has since been adopted throughout the countries of Southern Africa. The structure of SLEMSA is similar to that of the (R)USLE using similar parameters. SLEMSA consist of three submodels K, X and C to account for soil erodibility (F) and rainfall energy (E) representing the soil loss from bare soil, slope steepness and length, and crop types and cropping practices, respectively. Tillage or management effects are accounted for in the soil factor K. The equation is (Elwell, 1976):

$$Z = K.C.X \tag{1.2}$$

where:

- Z is the predicted mean annual soil loss in $t.ha^{-1}.yr^{-1}$;
- K is the mean annual soil loss in $t.ha^{-1}.yr^{-1}$ from a standard field plot 30 x 10 m with a slope of 4.5% and for a soil of a known erodibility rating F (discussed under methodology) under a weed-free bare fallow;
- C is the ratio of soil lost from a cropped plot to that lost from bare fallow;
- X is the ratio of soil lost from a plot of 30 m length L and slope percent S, to that lost from the standard plot with a 30 m length and 4.5% slope.

The main differences between the RUSLE and SLEMSA include the following:

- Despite the differences of the model equations, both models take the same soil erosion factors into account;
- RUSLE is a computerized model while SLEMSA is manually operated;
- RUSLE requires more input data, such as rainfall intensity data and vegetation parameters for determination of the soil erosion factor values C and R;
- SLEMSA input values, particularly the erodibility factor F, are determined more subjectively than RUSLE input values;

- RUSLE allows for a wider range of conditions and input data that can be manipulated making the model more flexible and dynamic than SLEMSA.

1.8 Using empirical soil loss models in a GIS environment

Empirical models can also be used in a spatial context by means of a geographical information system (GIS) (*e.g.* Flacke *et al*., 1990; Busacca *et al*., 1993; Desmet and Govers, 1996; Mitasova *et al*., 1996; Pretorius and Smith, 1998). Soil erosion assessment using a GIS as a support tool is more and more commonly used in catchment scale studies (*e.g.* Dikau, 1993; Wallace, 1997; Cochrane and Flanagan, 1999; Engel, 1999). Using soil loss models in a GIS environment enables the production of soil erosion hazard maps on a catchment scale and allows for the classification and spatial visualization of erosion potential. The visualization approach assists soil conservationists to identify areas with severe soil erosion hazard within a catchment. Dickinson and Collins (1998) describe a GIS-based approach to predict the effects of land use change on soil erosion from limited data. Other strengths of GIS in this type of work are the ability to integrate and analyse soil erosion data from disparate sources, and to simplify further analysis (Wallace, 1997). If data on soil, land use and the topography are available, specific soil erosion factor values can be assigned to each land unit so that soil losses can be predicted using a simple overlay procedure (Desmet and Govers, 1996). There is also great potential to compare results with other models (Bergsma *et al*., 1996). Comparisons are used for extrapolation of relationships to wide areas, with data bases used for storage and manipulation into GIS. The ease of manipulating data within a GIS also enables a quick evaluation of divergent land use scenarios. The GIS-based application used in the study is referred to as SEAGIS (Soil Erosion Assessment using GIS), developed by the DHI (1999). A brief description of the application and its operation follows below and in Chapter 3 on page 54.

1.8.1. SEAGIS (Soil Erosion Assessment using GIS)

As stated above, SEAGIS is a GIS-based application for simple erosion risk assessments (DHI, 1999). The application is developed as an ArcView GIS extension and requires Spatial Analyst. SEAGIS is based on the same empirical models used in the study: (R)USLE and SLEMSA, including the Morgan, Morgan, and Finney model (Morgan *et al.*, 1984). SEAGIS determines soil erosion through processing and creating a series of images that represent the erosion factors in the above models. Digitized maps of each of the soil erosion factors are produced from existing maps and digital data, using Arcview 3.2. SEAGIS comprises two

different terms for describing soil erosion; source erosion and transported erosion. The study, however, focused only on source erosion, which applies to the soil eroded from each grid cell.

Since no measured soil loss data from runoff plots exists in the RDA catchment, the study is restricted to the application and comparison of RUSLE and SLEMSA together with Arcview 3.2 software and SEAGIS. With the support of GIS techniques, several "what if" scenarios can be analyzed, and finally, assist during the planning of suitable crop diversification. Subsequently, the planner has the opportunity to prevent irreversible impacts and to plan remedial actions or land use change scenarios. To attain the need for quantitative data on soil loss under current and potential future conditions, certain aims and objectives had to be pursued.

1.9 Aim and objectives

Firstly, the study aims to obtain an understanding of the extent to which soil loss is affected by the soil erosion factors, especially land use. Therefore, the nature of the factors governing erosion and the distribution and extent of erosion in the catchment will be assessed. Until now the RUSLE and SLEMSA have not been applied in Mauritius. First order estimates of the soil loss of representative land units will be obtained using the RUSLE and SLEMSA in a GIS framework. In the process, specific data requirements of the models will be taken into account. Moreover, the study is an attempt to predict the consequences in terms of soil erosion under potential future conditions in the RDAC. Using the RUSLE in a GIS, it is possible to estimate the soil loss for different future scenarios, given information on the mean and variability in vegetation parameters. Results will be used to consider development alternatives and unacceptable practices leading to high rates of soil erosion.

The study is also aimed at providing a point of departure for future modelling efforts, insight on data collection and, for certain situations, provides measured values for some model input data. The study forms part of a large scale land evaluation survey on Mauritius, performed by the Agricultural Research and Extension Unit (AREU) of Mauritius. The aim will be achieved through meeting the following objectives:

- Recognition and subdivision of the RDAC into areas termed land units.

- Determination of representative values of the governing soil erosion factors for each land unit, including rainfall erosivity, soil erodibility, slope gradient, slope length, vegetation or land use type and conservation practices.

- Estimation of average annual soil loss values of current land use types, using the RUSLE and SLEMSA.

- Summation of soil loss values to give a total soil loss value for the RDAC.

- Soil loss prediction for three potential crop diversification scenarios for the RDAC including, vegetables, pineapple and forest.

- Comparison between current and future soil loss estimations.

- Comparison of soil loss to values or rates what is considered acceptable (soil loss tolerance).

- Theoretical model evaluation with respect to their applicability to the catchments of southern Mauritius.

1.10 Project outline

Following the overview of soil loss modelling above, Chapter 2 presents the general environmental setting for Mauritius. A more specific description is given for the RDAC. Chapter 3 describes the methodology followed to achieve the objectives mentioned above. The measurement techniques for determining the input values for the data required by the RUSLE and SLEMSA, are discussed according to the submodel components or soil erosion factors. Subsequently, Chapter 4 gives the results including, soil erosion factor maps and average annual soil loss maps obtained from the two models. Results are also compared for descriptive purposes. Chapter 5 provides a detailed discussion of the results and justifies the outcomes of the parameters and their importance in terms of the environment and agriculture of Mauritius. Finally, a summary given in Chapter 6 concludes the study.

Chapter 2: <u>Site description</u>

2.1 Location

The island of Mauritius is situated between latitudes 19º 58.8' S and 20º 31.7' S (north to south distance approximately 50 km) and longitudes 57º 18.0' E and 57º 46.5' E (east to west distance approximately 61 km) in the Indian Ocean, approximately 800 km east of Madagascar (Figure 2.1). The island has an area of 1844 km^2 (Batchelor and Soopramanien, 1993), and has a highest altitude of 860 m a.s.l. near Chamarel in the south.
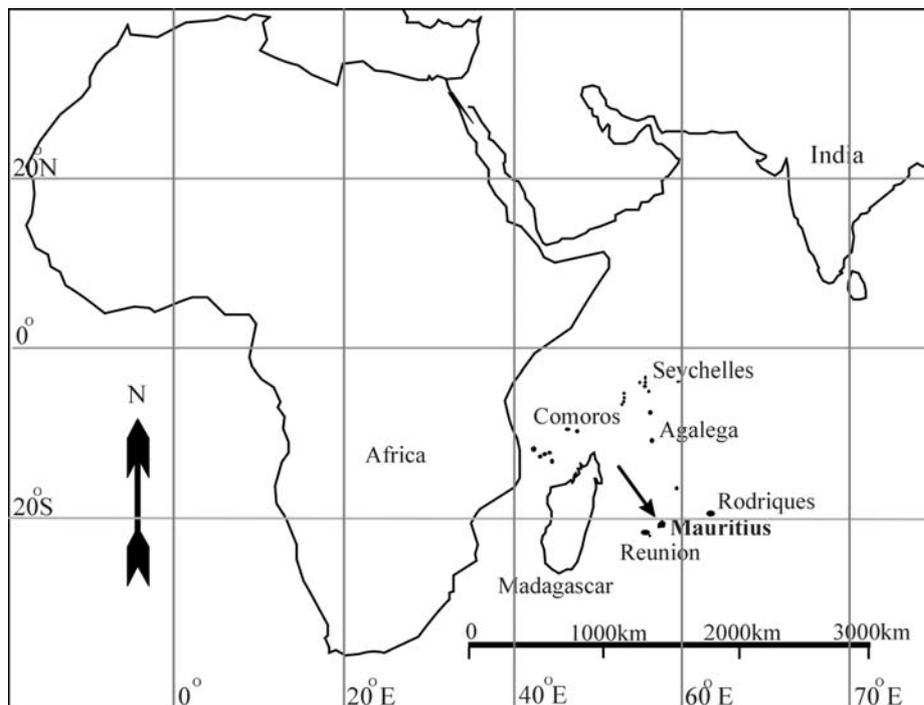
Figure 2.1:   Location map of Mauritius (after Saddul, 1996).

2.2 Geology

Mauritius is entirely of volcanic origin, except for the coral formations of the reef as well as extents of alluvial deposits at the coast. The geological history of Mauritius and its volcanism is well documented (*e.g.* Sentenac, 1964; McDougall and Chamalaun, 1969; Baxter; 1973). Saddul (1995) described the geology of Mauritius according to a geological chronology with four main stages (Figure 2.2) as follows:
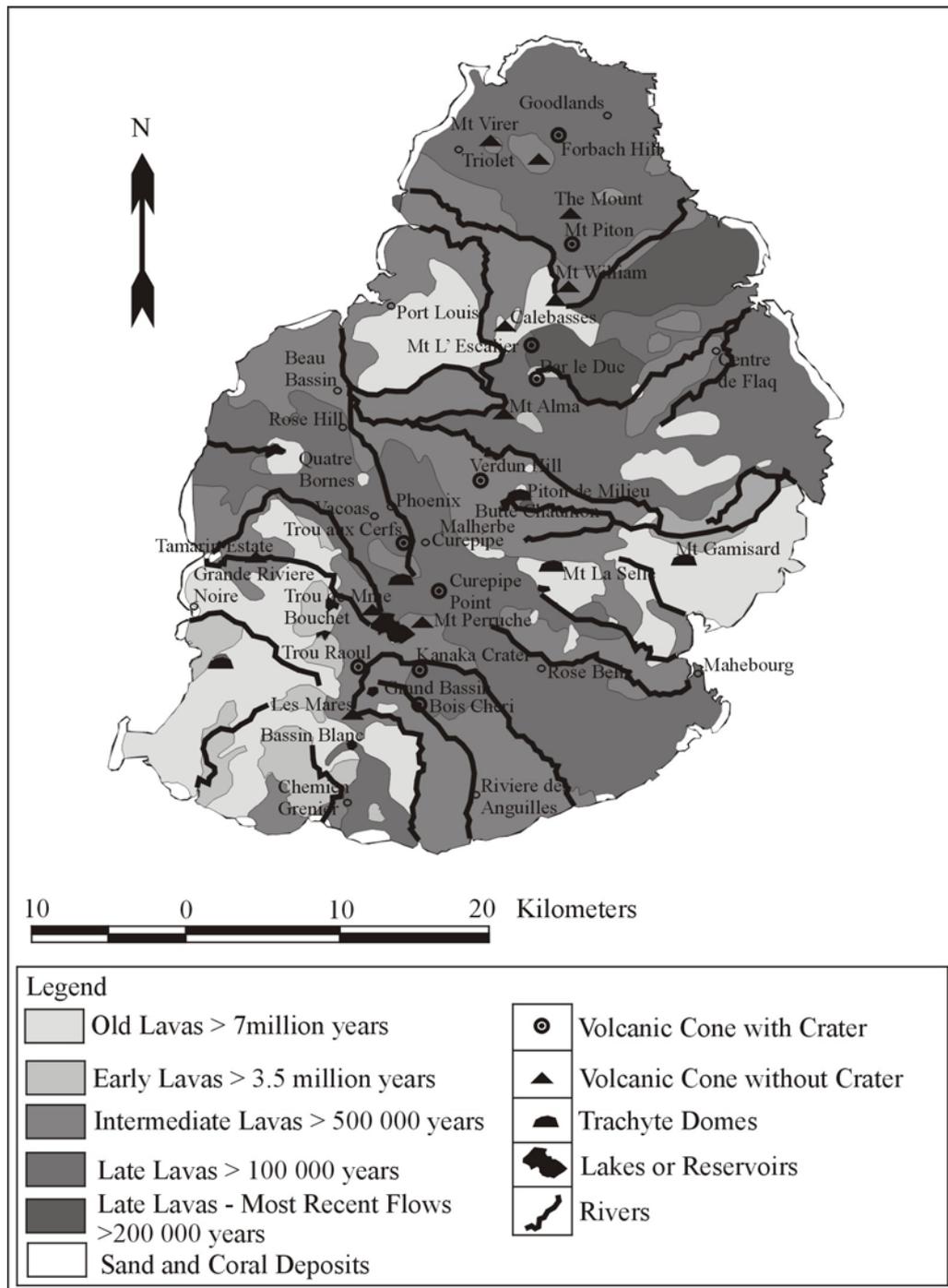
Figure 2.2:   Geological map of Mauritius (after Saddul, 1995).

The Breccia Series caused the emergence of the island from 10 M.Y. to 7.8 M.Y. ago. This series lies at the base of the subsequently formed features and displays an abundance of scoriaceous materials, layers of ochre-coloured tuffs, alternating with layers of volcanic ash, and brecciated flows of alkali basalts and oceanites.

During the Old Lava Series from 7.6 M.Y. to 5 M.Y. B.P., most lava from the Breccia Series was covered by a "shield" consisting of picrite-basalts, olivine basalt, basalts rich with feldspars, andesites such as hawaiites and mugearites, and endogenous domes of trachyte. Although the strato-valcona of the Old Lava Series has been largely eroded, its remains form the major mountain ranges of the island. Features belonging to the Old Lava Series are absent in the centre of the island and can be explained by the formation of a central caldera about 5 M.Y. B.P.

Volcanic eruptions between 3.5 M.Y. to 1.7 M.Y. B.P. are known as the Early Lava Series. The Early Lava consists mostly of compact olivine basalts along fissures and vents, exposed only in the south west of the island.

Between 0.7 M.Y. to 0.1 M.Y. ago the Recent Lava Series, also termed the Late Lavas, covered 70% of the island and also correspond to the last volcanic activity of the island. They comprise a series of flows from 1 to 8 m thick, of generally highly vesicular olivine basalt, often with coarse grained doleritic textures. Scoriaceous zones are common at the top and base of flows. Earlier flows of the Early Lava Series, termed the Intermediate Lavas, were emitted from 700 000 to 500 000 B.P. These lavas erupted from a chain of some 20 vents of which Curepipe Point is the largest and the highest (685 m). Intermediate Lavas are compact and contain many crystals of olivine. The more vesiculated Most Recent Lavas, dates back from 0.1 M.Y. to 0.2 M.Y. and are distinguishable from the Intermediate Lavas (Saddul, 1995).

Along the coast, relict features such as sedimentary formations are not volcanic in nature, but related to the formation of coral reefs. These formations can be mainly observed along the southwestern and south eastern coasts. Sandy beaches and sand dunes border the coast along approximately 20% of the coastline.

2.3 Topography

According to Parish and Feillafe (1965) the island of Mauritius has three distinct topographic patterns connected with the age of the parent lava. The oldest lavas gave rise to the mountain ranges. These were followed by the Intermediate Lavas of the Younger Volcanic Series with gently rolling topography and deeply incised rivers with terraces and stabilized gullies. The Early Lavas are characterised by many rocky areas with an almost complete absence of surface drainage, dominated by the vents that gave rise to them.

Proag (1995) describes the topography of the island as central uplands which are surrounded by mountain ranges, isolated peaks and plains forming a bowl with chipped rims, filled with younger lavas. The island consists of a variety of undulating central uplands, with a mean elevation between 300 to 400 m, rising to about 600 m in the south. Outside the old caldera, plains were deposited during a series of lava flows mentioned above. Younger volcanic formations produced most of the central uplands. These flows are the products of small volcanoes situated on the wide, low median ridge running across the island from southwest to northeast. Eroded relics of the rim of the bowl protrude above these younger volcanics as a discontinuous ring of mountain ranges with rugged peaks. Without any well marked delimitation, the central uplands merge into the coastal plains. Even towards the coast, slopes are in general gradual and are only steep for short distances. Figure 2.3 shows two island profiles from SSW to NNE, and NNW to SSE.
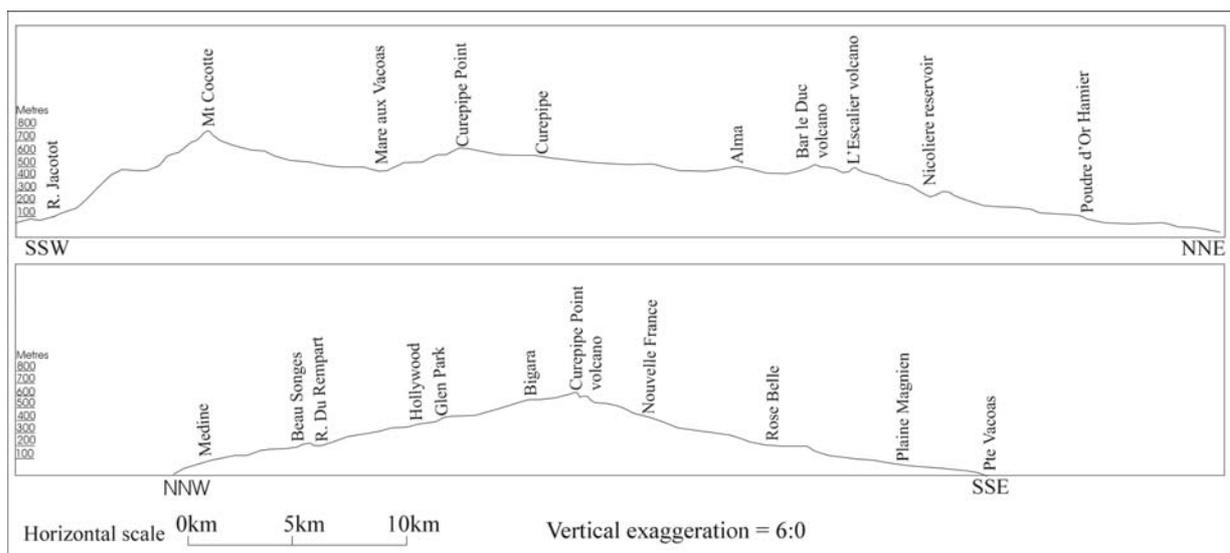
Figure 2.3: Island profiles from SSW to NNE, and NNW to SSE (after Saddul, 1996).

2.4 Geomorphological domains

Mauritius is classified into five geomorphological domains (Saddul, 1995).

The Mountain Environment formed by massive flows of the Old Lava Series, which forms a discontinuous ring encircling the central uplands. The mountain complex has been classified into three main mountain ranges: The Port Louis-Moka-Long Mountain Range, the Bambou Mountain Massif, and the Black River–Savanna Mountain Complex. These are narrow escarpments with peaks reaching 600-860 m a.s.l. Some of the mountain walls have slopes exceeding 80%, while the slope angles decrease to only 5% at the base.

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The Central Uplands comprises mostly land within the caldera of the island, which has been filled and raised by post caldera flood lavas above the 320 m contour. This region unfolds a suite of topographical units ranging from a flat to subdued plateau-like topography to the undulating and gently sloping (8-13%) relief that merges into the coastal lowlands of the east.

The Southern Highlands also classified as the domain of the Early Lavas, comprises all land above the 500 m contour. The topography is characterized by a multi-form segment of slopes that are convexo-concave.

The Recent Lava Plains, including the coastal plains and inland slopes, lie below the 200 m contour. These plains represent a surface topography that is low and undulating with slopes between 2 – 13% and vast expanses of rocky surfaces. Finally, the Coastal Environment includes sandy beaches, rocky coastline and coral reefs just below or above sea level (Saddul, 1995).

2.5 Climate

Saddul (1995), and Proag (1995) describes the climate of Mauritius as humid, subtropical and maritime due to its location at 20º S latitude, small size, lack of extreme elevations and distance to continents. Variations in temperature and rainfall from one region to another allow subdivisions of the island into subhumid, humid, and superhumid zones. The subhumid zone is restricted to low altitudes on the western coast and the northern plains where the total rainfall is less than 1250 mm. The humid region occurs at intermediate elevations on the western and northern coasts with rainfall between 1250 mm and 2000 mm, and on the lowlands of the eastern coast where the rainfall is less than 2500 mm. The superhumid region lies above 450 m on the west coast and above 400 m on the east coast where rainfall exceeds 2000 mm. In the humid regions, rainfall and evaporation are in balance while evapotranspiration exceeds precipitation in the subhumid regions. The relative humidity has an average value of 80%, remaining relatively constant throughout the year.

In general, the island experiences two seasons. The warm and rainy summer season extends from November to April, whereas the cool and comparatively dry winter season extends from May to October. Mean annual air temperature for Mauritius is 22ºC. July is the coolest month with temperatures ranging from 16ºC (central uplands), to 22ºC (coastal). February is the warmest month with temperatures ranging from 20ºC (central uplands) to 28ºC (coastal).

Annual mean rainfall is 2120 mm of which 79% was recorded in the rainy season (Proag, 1995). According to Rughooputh (1997) annual rainfall can vary from as low as 750 mm *(e.g.* Albion station at the west coast) to well above 4000 mm *(e.g.* Arnaud station on the central plateau). Therefore, rainfall markedly increases from the coast to the interior. As a result, the island has been subdivided into 10 rainfall zones with altitudinal intervals (widths) of approximately 100 m. Thus, rainfall zone 10 is situated along the coast between sea level and the 100 m contour line, whereas rainfall zone 9 is situated between the 100 and 200 m contour lines *etc.* Figure 2.4 shows the average monthly rainfall (from 1961 to 1997) for the ten rainfall zones of Mauritius (Kremer, 2000).
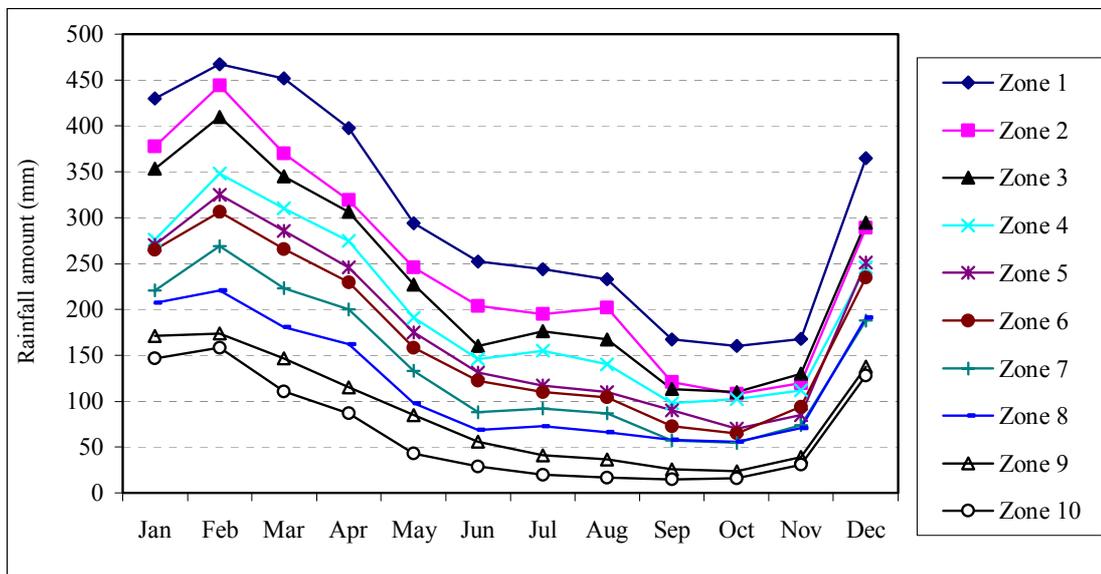
Figure 2.4:   Average monthly rainfall for the ten rainfall zones of Mauritius
                (after Kremer, 2000).

The dry season is dominated by moderately cool and dry south easterly trade winds, whereas the rainy season is dominated by warm and humid south easterly trade winds with speeds in the range of 1-25 knots. Occasionally, tropical cyclones produce high velocity winds and gusts with a maximum recording of 278 km.h^{-1} on the island (Luk *et al.*, 2000).

An average of four cyclones develop in the southwest Indian Ocean each summer. The cyclonic period extends from November to May. During the last century 68 have reached and affected Mauritius. Some of the most devastating cyclones that caused severe damage on Mauritius are listed in Table 2.1 and their trajectories shown in Figure 2.5. The average rainfall during tropical cyclones is 245 mm, but variations are large. Tropical cyclones are an important climatic factor that are of considerable importance to agricultural production in

Mauritius (Proag, 1995). The 1999 sugarcane crop was the lowest since 1960 when the island was hit by two severe cyclones in succession. However, during tropical cyclone-free summers, there is usually a rainfall deficiency and drought conditions prevail in the subhumid zone.

Table 2.1:   Severe tropical cyclones from 1945 to 1994 (after Mauritius Meteorological Services, 2000).

Year	Date	Cyclone name	Rainfall (mm) at Vacoas	Rainfall (mm) at Plaisance	Highest gusts (km.hr^{-1})
1945	16 Jan	No name	Not available	Not available	156
1960	16-20 Jan	*Alix*	654	336	200
1960	25-29 Feb	*Carol*	508	320	256
1961	20-25 Dec	*Beryl*	746	381	171
1964	17-20 Jan	*Danielle*	795	350	219
1967	11-14 Jan	*Gilberte*	451	121	142
1975	05-07 Feb	*Gervaise*	533	260	280
1979	21-23 Dec	*Claudette*	295	125	221
1980	24-28 Jan	*Hyacinthe*	1030	1011	129
1983	23-26 Dec	*Bakoly*	397	134	198
1987	12-14 Feb	*Clotilda*	489	296	103
1989	27-29 Jan	*Firinga*	409	172	190
1994	09-11 Feb	*Hollanda*	494	213	216
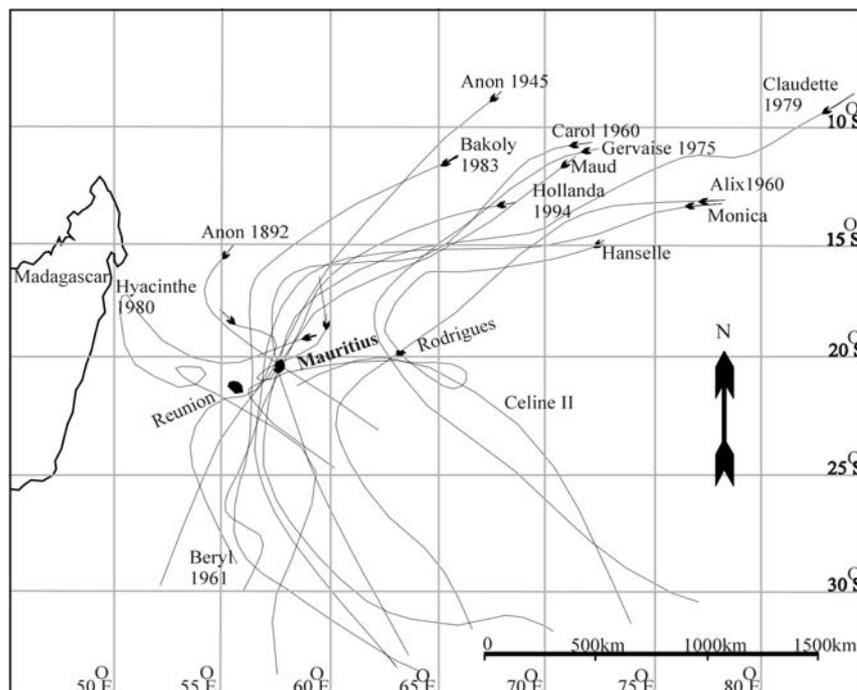
Figure 2.5:   Trajectories of severe tropical cyclones from 1945 to 1994 (after Luk *et al*., 2000).

2.6 Pedology

Close similarity between parts of the Hawaiian Islands and Mauritius as regards geology, climate, soils and cropping have led to the adoption (Parish and Feillafe, 1965; Alridge and Wong You Cheong, 1975; and Willaime, 1984) of a classification system (Cline, 1955) used for the soil survey of Hawaii. The classification is given in Appendix 1, which also indicates a tentative correlation with units of the FAO/UNESCO (1970) World Soil Map and with the United States Department of Agriculture's system of classification (U.S.D.A., 1960). Figure 2.6 illustrates a diagram portraying the soil types of Mauritius in relation to their age or developmental stage (Pears, 1985 cited in Proag, 1995: 21).
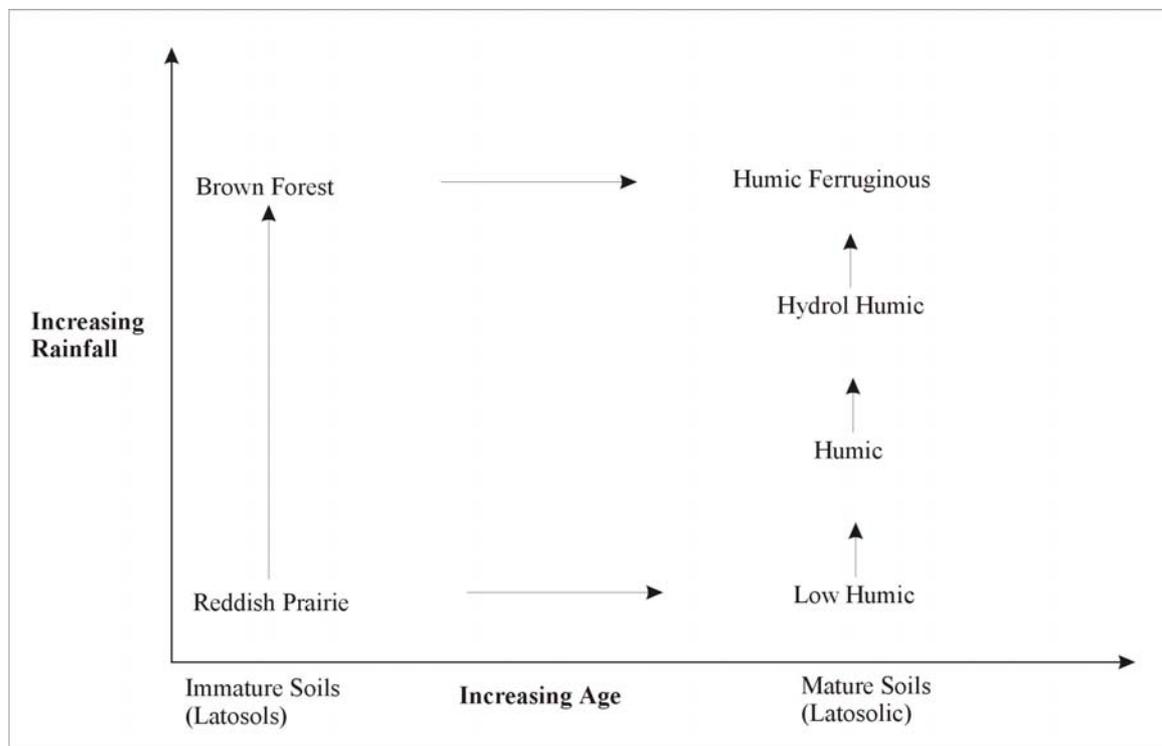
Figure 2.6:   Soil types of Mauritius in relation to age or developmental stage (after Pears, 1985 cited in Proag, 1995: 21).

Boundaries between soil groups are diffuse, and have been differentiated by chemical rather than morphological criteria. Soils of Mauritius developed almost exclusively on olivine basaltic lavas or highly vesiculated basaltic lavas (Proag, 1995). Due to the basaltic origin of Mauritian soils, no series subdivisions occur (Parish and Feillafe, 1965; Alridge and Wong You Cheong, 1975; Willaime, 1984). The agriculturally important soils of Mauritius are

subdivided into two main groups: mature ferralitic soils or latosols, and immature latosolic soils.

Mature Latosols originate from highly weathered basaltic lava rock. These soils are subdivided into Great Soil Groups, which are further subdivided into families, each of which represents an area of fairly uniform climate and topography. Soils at the study site, the *Rivierre des Anguilles* catchment (RDAC), fall within the Latosol group. Further discussion of the soils in the study site follows on page 30.

By way of contrast, Latosolic soils have minerals that are still in the process of weathering, characterized by the presence of angular clasts and gravel of vesicular lava. The Latosolic soil group is subdivided into Zonal, Azonal and Intrazonal soils.

Zonal soils have developed principally on the Intermediate Lavas under a mean annual rainfall ranging from less than 1000 mm to over 5000 mm (Parish and Feillafe, 1965). Intrazonal soils developed on the Late- and Older Volcanic Series under conditions where the effects of climate (rainfall ranging from 1000 – 5000 mm) and vegetation are masked by local factors of environment such as relief, drainage and composition of parent material. Azonal soils have little or no profile development, apart from some accumulation of organic matter in the surface horizon. Further discussion of these soil groups can be found in Parish and Feillafe (1965), Alridge and Wong You Cheong (1975), and Williame (1984).

The natural soil fertility of Mauritius is low because of a deficiency in nitrogen, phosphate and potash (Proag, 1995). Soil fertility decreases with increasing rainfall and age of the parent material. Furthermore, rainfall increases with elevation, and therefore, a vertical zonality of fertility exists that is correlated with the vertical zonality of Mauritian soil. For example, the Latosolic Reddish Prairie soils are less fertile at high rainfall levels with excessive drainage and shallow depth, than Humic Latosols occurring at low rainfall levels and limited drainage.

2.7 Land use

Although in recent years the Mauritian government has been promoting a policy of agricultural diversification, sugar remains by far the most important agricultural crop on the island (Proag, 1995). Just over 50% of the total land surface is under sugarcane cultivation. That is 87% of the island's cultivable land, averaging an annual cane production of ±71.56 t.ha^{-1}, giving an average sugar yield of ±8 t.ha^{-1} (MSIRI, 2000). The total annual sugar production is

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approximately 650 000 t with its bulk output being exported to European countries (Batchelor and Soopramanien, 1993). The four major sugarcane varieties include R 570, M 3035/66, M 695/69 and M 1658/78 (MSIRI, 2000).

Apart from the sugar industry, other forms of agriculture are on a relatively small scale. Except for tea and forestry, alternatives to sugarcane are limited to the production of vegetables, tobacco, fruits such as pineapple, patches of banana, and scattered litchi, - mango, - papaya, and some citrus trees. Vegetables and mixed crops mostly include potatoes, tomatoes, groundnuts, maize, rice, onions, and a wide variety of green vegetables. Patches of tea plantations occur on the interior around the Central and Southern Uplands. Approximately 57 000 ha (31%) of land in Mauritius is classified as forest and scrub (Ministry of Agriculture and Natural Resources, 1999). The characteristics of land use are not discussed here. Further discussion of the land use in the *Rivierre des Anguilles* catchment follows on page 26.

The livestock industry at present, geared mainly to the production of milk, is largely in the hands of the small farmer. Livestock production including cattle, sheep and Javanese deer, is limited to marginal land (9000-10 000 ha) that is only suitable for pasture under *Herbe bourique*, *Stenotaphrum dimidiatum*, and Star Gras, *Cynodon nlemfuensis* (Proag, 1995).

2.8 The Rivierre Des Anguilles Catchment (RDAC)

Mauritius has been divided into 25 catchment areas, each corresponding to a main river and coastal zones drained by several streams or rivulets (Proag, 1995). Figure 2.7 gives the location of the various basins and their respective areas. The study site is known as the *Rivierre des Anguilles* Catchment (RDAC) and is chosen as a pilot test area to determine on-site soil losses under current and potential future conditions. Although most of the RDAC is covered with sugarcane, a wide range of landforms, micro-climates and soils exists, which combine to give a strikingly large number of different characteristics.

2.8.1. Geology of the RDAC

Most of the RDAC consists of Intermediate Lava plains with gentle seaward slopes, where sugarcane plantation dominates the landscape. The higher parts of the catchment consist of different geological units because of three geological features present in the southern mountain region (Saddul, 1995). First, a small part of the Old Lavas falls within the catchment boundary above the 600 m contour line. Second, a small section of Late Lavas in the upper catchment
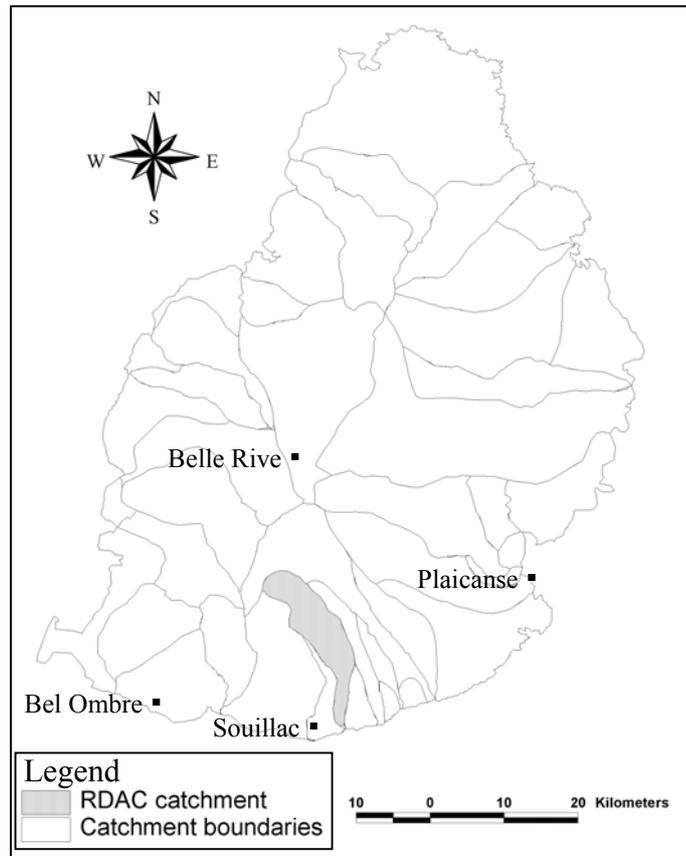
Figure 2.7:   Location of the various catchments and their respective areas, including the site known as the *Rivierre des Anguilles* Catchment (RDAC) (after Proag, 1995).

area falls between the 550 m and 600 m contour line. Third, the Intermediate Lavas erupted from 700 000 to 500 000 B.P. from a chain of some 20 vents of which *Kanaka* and *Grand Bassin* craters fall within the RDAC. The coastline is characterized by 30 m high cliffs from the Recent Lava Series, most of the time associated with a wave-cut platform, and without a coral reef.

2.8.2. Topography of the RDAC

Topography and drainage is shown is Figure 2.8. Arlidge and Wong You Cheong (1975) describes the topography of different land complexes in Mauritius. The lower humid plain (altitude 0 - 290 m a.s.l.) of the RDAC is almost flat to gently undulating. Above 250 m a.s.l the convex slopes average 4%, decreasing to an average of 2% towards the coast. The gradient steepens below 60 m a.s.l. Sloping tracts of land within this lower plain are rolling or moderately steeply sloping (8 - 20%), but grade to steep slopes (30% or more) along the river valley (Figure 2.9). The higher superhumid plain (altitude 245 – 455 m a.s.l.) is, in general sloping seawards. Slopes are almost flat to gently undulating (0 - 8%). However, some areas
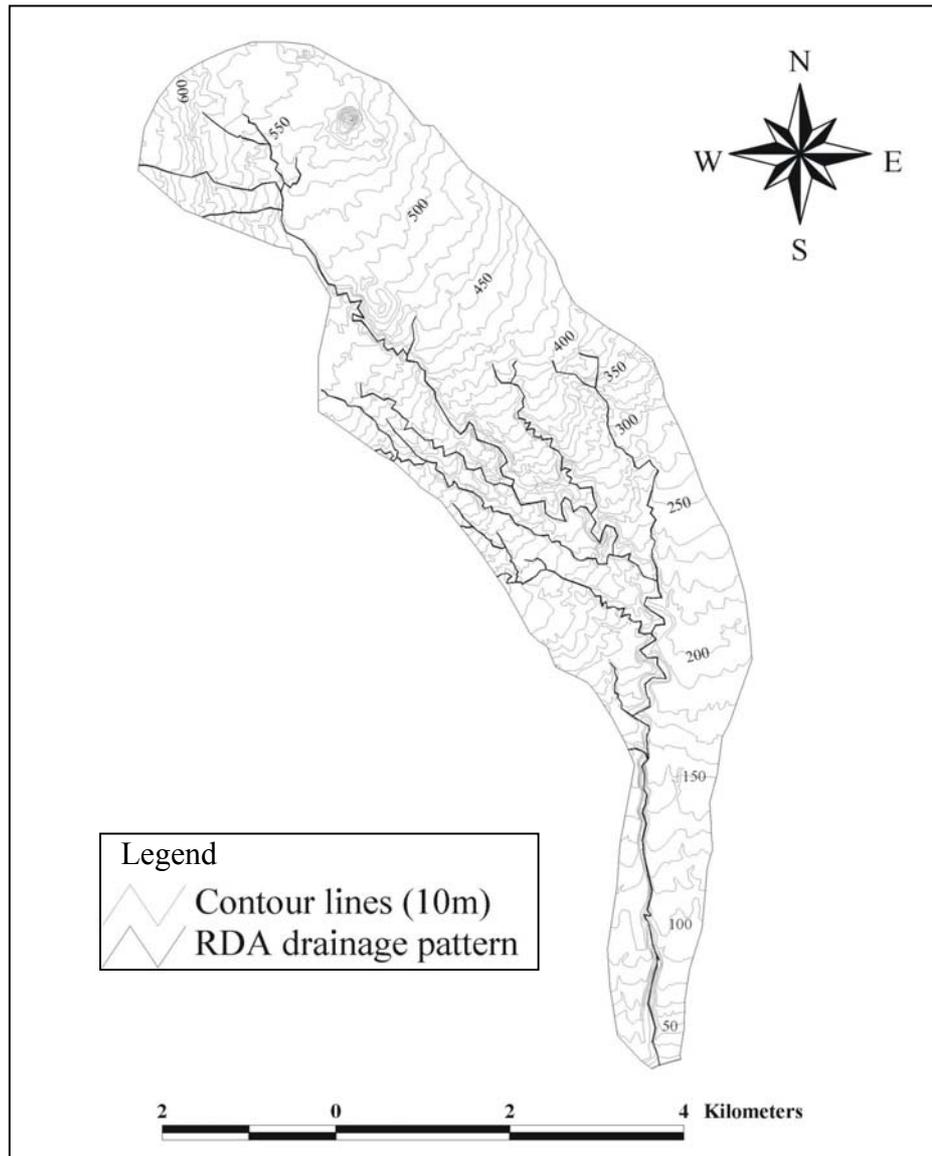
Figure 2.8:   Topography and drainage map of the RDAC (after Ordinance Survey, 1991).

Figure 2.9:   *Rivierre des Anguilles* valley.

Figure 2.10:   *Kanaka* crater.

grade to rolling or moderately steep slopes (20-30%). Slopes (above 600 m a.s.l.), at craters *Kanaka* (Figure 2.10) and *Grand Bassin,* are rolling to moderately steep (30%), hummocky and rough. The average slope steepness of the river is 4%. Figure 2.11 shows the longitudinal profile for *Rivierre des Anguilles*. Its highest elevation is approximately 640 m a.s.l.
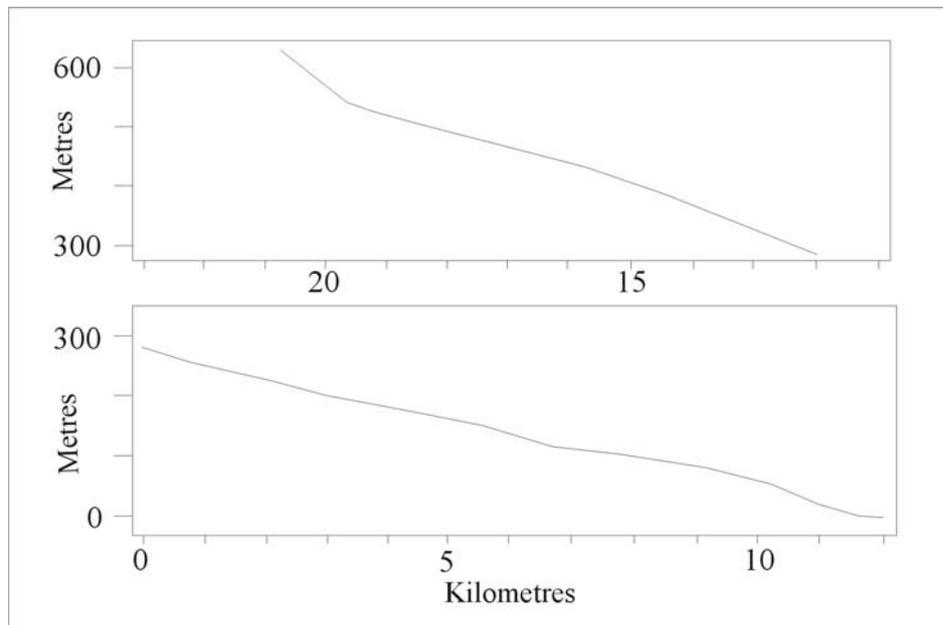
Figure 2.11:   Longitudinal profile for *Rivierre des Anguilles* (Source: Proag, 1995).

2.8.3. River characteristics

Rivierre des Anguilles is one of the twenty-five major rivers in Mauritius with a length of 14.9 km and a catchment area of 32.6 km^2. Because of the history of volcanism, which provided initial surfaces with a variety of ages, stream patterns of the RDAC are dense and diverse (see Figure 2.8). The river takes its source from the central uplands where first order tributaries feed into it at an elevation of 650 m between *Grand Bassin* and *Kanaka* craters. The river is a fourth order stream with rivulets that feed the main channel. From the elevated physiographic units it flows southeast towards the ocean picking its way through the small irregularities of the underlying volcanic surface. The river itself though not large, is deeply incised. Due to high rainfall, the near-surface water table, and the erodible base in the source region, the river incised the volcanics into a long deep valley. At 500 m a.s.l. the river incised to a depth of about 15 m, and more deeply at 200 m a.s.l., to a depth of 40 m. The final two kilometers incised the valley to a depth of 50-60 m. Just before the end of its course in the ocean, St. Aubin sugar mill uses its water for irrigation.

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Discharge and crest-stage data for the river are limited. According to the hydrograph in Saddul, 1995) for 1989 and 1990, *Rivierre des Anguilles* has a minimum flow (1-3 $m^3.s^{-1}$) for much of the year, and discharges large amounts of water (10-14 $m^3.s^{-1}$) only during heavy rainfall events. During extreme rainfall events, such as cyclones, the storm discharge can easily increase ten-fold.   It is mostly during these cyclone events that a large amount of sediment load including large boulders is transported downstream. Usually, a limited number of runoff peaks occur during the year from December to May. The low discharge season extends from June to November. According to Saddul (1995), river discharge and surface runoff in general is limited due to the high permeability of the geology and soil, which favours transfer of moderate amounts of precipitation to underground water. Although more research is needed in this topic, the study aims at estimating the sources and amount of soil loss. Calculation of discharge and sediment transport is considered beyond the scope of this study.

2.8.4. Climate of the RDAC

The RDAC experiences a succession of climates, due to differences in elevation, variations in exposure, and proximity to the coast (Rughooputh, 1997). The catchment faces the south easterly trade winds, and falls within the humid – and superhumid climatic zones. Figure 2.12 shows the mean annual rainfall pattern from 1951-1980, with a south to north gradient over the RDAC. The lower plains and slopes of the catchment are under the influence of a humid climate with average annual rainfall between approximately 1500 mm and 2000 mm. The upper catchment area has a superhumid climate which receives over 3000 mm of rainfall per year. Localized falls of high intensity occur during thunderstorms associated with unstable air mass movements. Mean temperature maps in Saddul (1996) show that July is the coolest month with a mean temperature of 16ºC at the interior and 22ºC at the coast. January is the warmest month with a mean temperature of 22ºC at the interior and 26ºC at the coast.
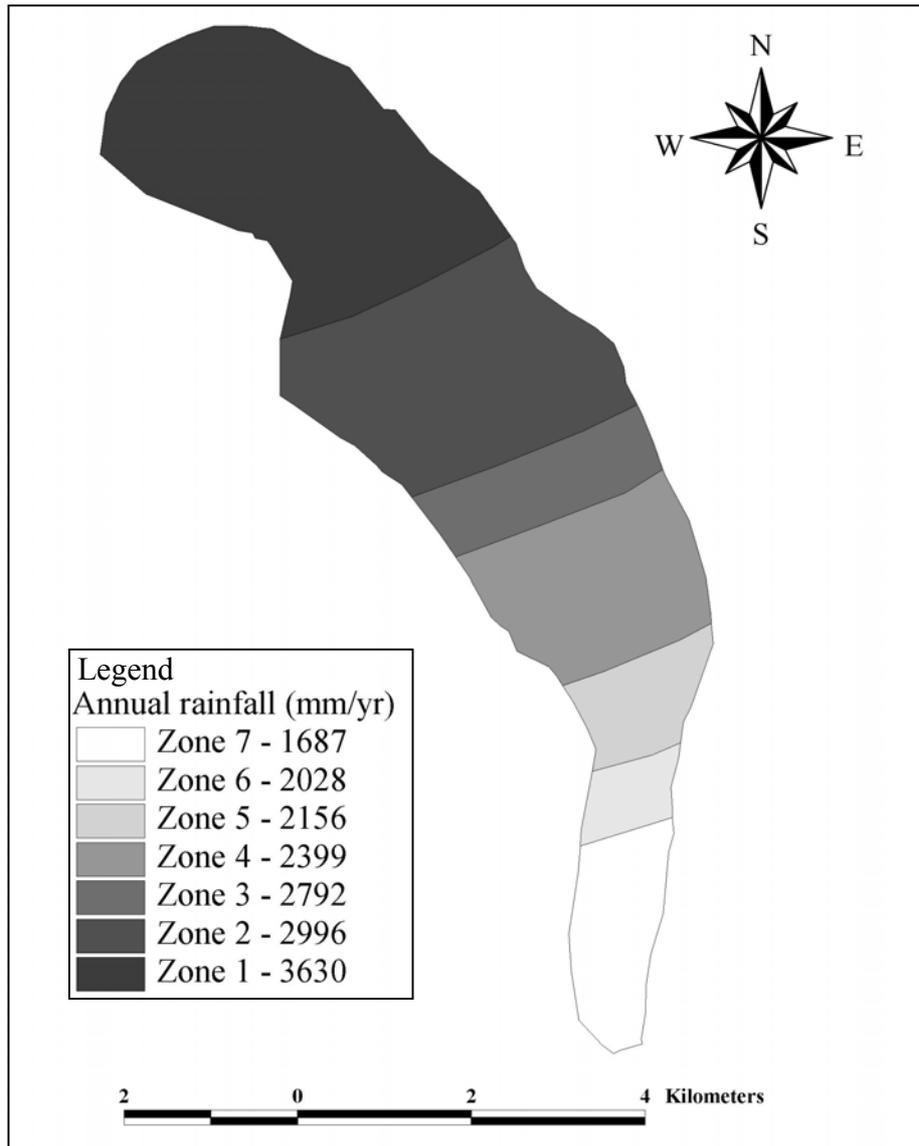
Figure 2.12:   Mean annual rainfall map of the RDAC (after Proag, 1995).

2.8.5. Land use of the RDAC

Figure 2.13 shows land use of the RDAC. Agricultural potential in the catchment changes significantly with altitude in relation to the succession of climates (Proag, 1995). Sugarcane covers 62% of the catchment on land below the 500 m contour line (Figure 2.14). However, small cane fields (1-2 ha) belonging to small-scale planters exist above the 500 m contour line. Crops are mostly confined to areas having an annual rainfall of less than 3000 mm. At lower altitudes, during the non-rainy period where rainfall does not exceed 1500 mm, cane requires irrigation. Most of the sugarcane in the catchment is ratoon-type cane replanted every ±7 years. When harvested, the root systems with mulch of the ratoon cane are left intact (Figure 2.15). In addition, buffer strips of perennial grass species, "Maguet" are planted on

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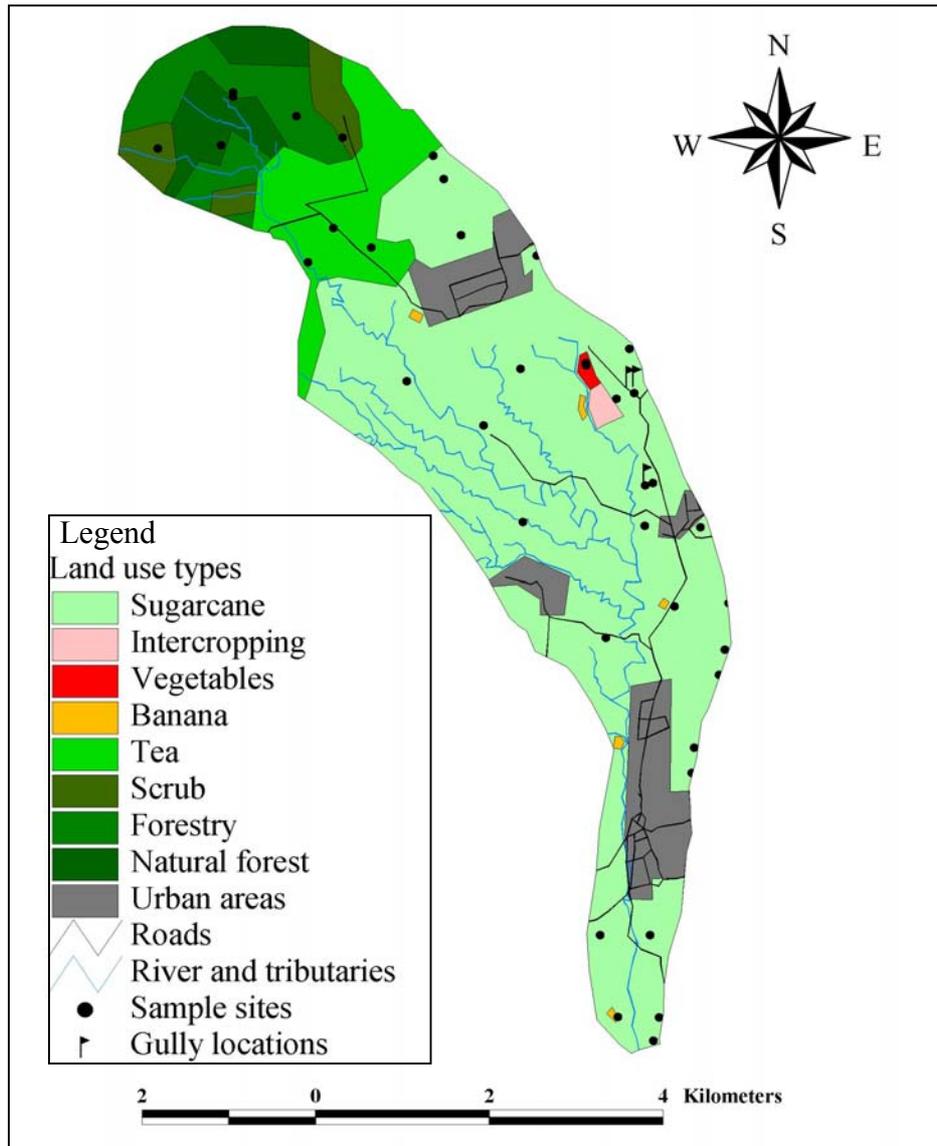
Figure 2.13:   Land use map and sample sites of the RDAC (after Saddul, 1996).

Figure 2.14:   Sugarcane (first growth stage).   Figure 2.15:   Stubbles and mulch after

harvest.

some of the sugarcane slopes (Figure 2.16).   These strips are permanent and not part of the crop rotation. Most of the land belongs to two sugar estates Britannia and Union St. Aubin. Small-scale planters at the upper catchment area own a very small, unknown percentage.

Approximately 22 ha of land is devoted to food and vegetable crops, either as purestand (Figure 2.17 and Figure 2.18) or as intercrop in sugarcane (Figure 2.19). Mixed cropping in the RDAC includes a proportion of small sugarcane plots next to the continual vegetable stand. Vegetables in the catchment mostly include potatoes, tomatoes, groundnuts, cucumber and sash quash. Banana plantations are scattered on mall patches of land ±1 ha each (see Figure 2.20). Some banana plantations are planted on very steep slopes (15-30%) of the *Rivierre des Anguilles* valley (Figure 2.21).

Figure 2.16:   Buffer strips of perennial grass (*Ophiopogon intermedius*).

Figure 2.17:   Pure stand vegetables (tomatoes).

Figure 2.18:   Pure stand vegetables (sash quash).

Figure 2.19:   Intercropping sugarcane with potatoes.

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Figure 2.20:   Small banana plantation on steep slope.

Figure 2.21:   Banana plantations planted on very steep slopes of the *Rivierre des Anguilles* valley.

The upper slopes or higher inland extension of the catchment are vegetated by tea plantations (Figure 2.22), scrub (Figure 2.23), and forest. Forested areas include natural forest (Figure 2.24) as well as forestry plantations (Figure 2.25). The natural forest may be regarded as subtropical montane rainforest, which extends upward onto steeper slopes of 30-40º and along the steep slopes of the *Rivierre des Anguilles* valley. Indigenous vegetation along the river, known as a "river reserve", is protected by the government. However, most of the indigenous vegetation is restricted to the Lithosols of the mountain ranges. The forest consists of large tree species such as ebony, *Diospyros tesselaria*, and a high proportion of *Sapotaceae* in the uplands (Proag, 1995). Scattered forestry plantations mostly including pine trees, *Pinus elliotti*, as well as other softwoods such as *Cryptomeria*, *Auracaria*, and *Junipeus* that are selectively felled. Ferns and epiphytes are abundant on the forest floor. The commonest scrubs are *Albizia lebbeck*, *Litsea glutinosa*, as well as *Eugenia* and *Acacia spp*. (Ramsamy, 1987). The coastal area of the catchment is characterized with littoral vegetation, with patches of Casuarina plantations where *Herbe bourrique*, *Stenotaphrum dimidiatum*, grow on the ground floor (Ministry of Agriculture and Natural Resources, 1999).

Figure 2.22: Tea plantation in the upper catchment area near Bois Cheri.

Figure 2.23: Scrub in the upper catchment area (encroached guava).

Figure 2.24: Indigenous forest trees.

Figure 2.25: Forestry plantation in the upper catchment area near Bois Cheri.

2.8.6. Pedology of the RDAC

Three soil groups are identified within the RDAC (Figure 2.26). All three Great Soil Groups that fall into the Latosol sub-order are found in the catchment. These include: Low Humic Latosols (LHL), Humic Latosols (HL) and Humic Ferruginous Latosols (HFL) (Parish and Feillafe, 1965; Proag, 1995). A description of the A - and B horizons of the soils in the RDAC follows.

The Low Humic Latosol (LHL) has been subdivided into four families that reflect differences from variations in rainfall and age of parent material namely: *Richelieu*, *Reduit*, *Ebene* and *Bonne Mere*, of which only the *Reduit* family occurs within the catchment. Soils belonging to the *Reduit* family occur in the subhumid and lower rainfall zone of the catchment, receiving

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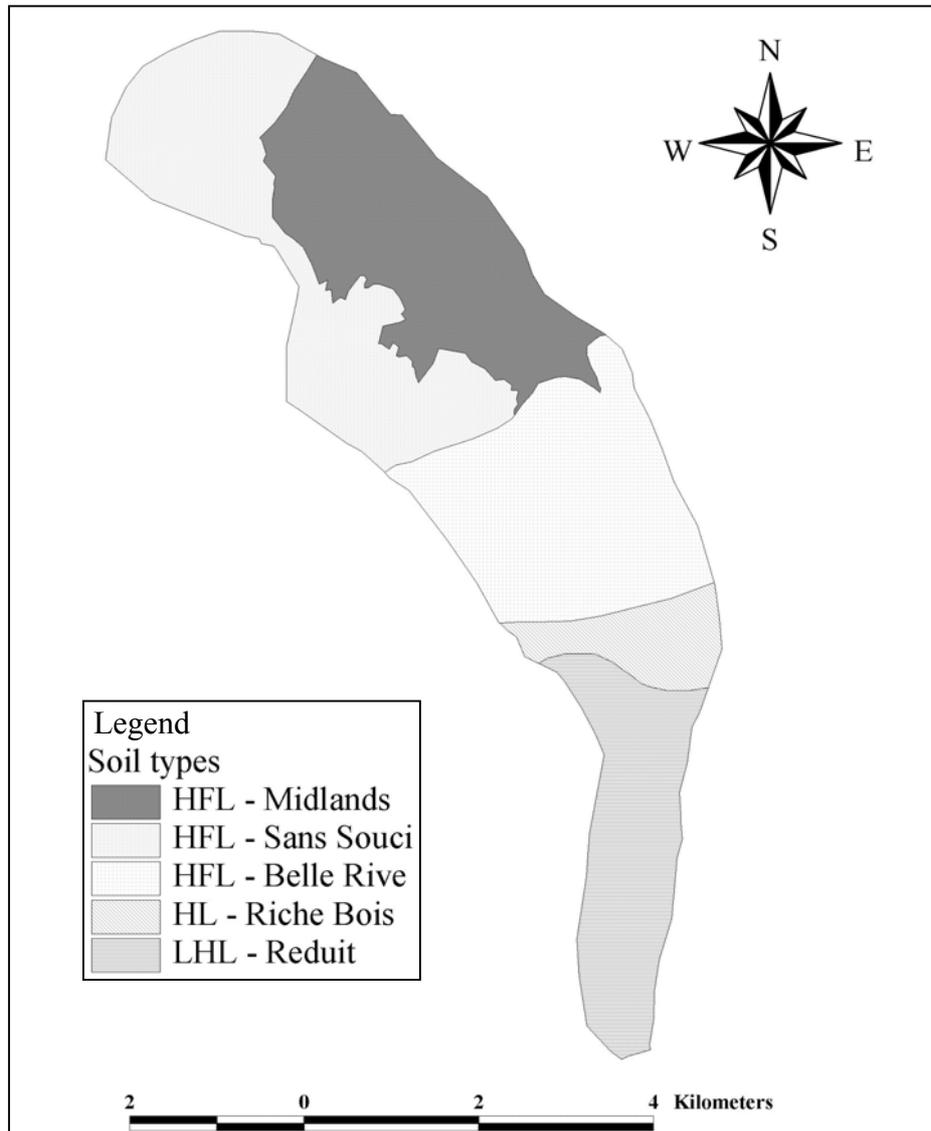
Figure 2.26:   Soil map of the RDAC (after Parish and Feillafe, 1965).

1500 mm to 2500 mm annually. Soil of the A horizon has a weak to moderately strong, medium to fine sub- angular blocky structure, whilst the friable B horizon is massive to weakly prismatic. The texture varies from red to brown silty clay to clay, over a red to reddish brown B horizon. Manganese dioxide is present in the soil profiles. These soils are deep to moderately deep with good internal drainage and fairly high base status (56%), whilst organic matter content is low (4.7%).

The Humic Latosol (HL) group has been subdivided into two families including: *Rosalie* and *Riche Bois*, of which only the *Riche Bois* family occurs within the catchment. As part of the HL group, the *Riche Bois* family represents a transitional group between the Low Humic Latosol (LHL) and the Humic Ferruginous Latosol (HFL). These soils occur within the humid

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and superhumid climatic zones of the catchment, receiving 1750 mm to 3750 mm annually. Structural development is weak although soils are friable throughout the solum. Soils are deep with a dark brown to dark yellow brown silty clay A horizon overlaying a dark brown to strong brown silty clay B horizon. No obvious individualization of concretionary nodules occur. The soils contain more organic matter (6.3%) than the LHL group, but silica and bases (32%) are more depleted.

Three of the four HFL families occur within the RDAC (Parish and Feillafe, 1965). These three families include *Belle Rive*, *Sans Souci* and *Midlands*, separated from each other on the basis of increasing amounts of concretions. All families occur within the superhumid climatic zone of the catchment where the average rainfall varies from 2500 to 5000 mm. Soils in this group are strongly weathered.

Soils of the *Belle Rive* family are situated in upper areas of the catchment receiving 2250 mm to 4000 mm rainfall. The A horizon has a coarse granular structure overlaying a weak and friable B horizon breaking into fine granular peds. Soils have a brown to dark brown, silty clay loam A horizon containing some ferruginous concretions. The B horizon is a yellowish red to reddish brown silty clay. Organic matter averages 6.9%, and base saturation is low (10%). Due to a compact subsoil, drainage is fairly inadequate. However, the *Belle Rive* family is the most suitable of the HFL soils for cane production (Parish and Feillafe, 1965; Alridge and Wong You Cheong, 1975).

The *Sans Souci* family is intermediate in both chemical and physical characteristics between the *Belle Rive* and *Midlands* family. These soils occur in the rainfall zone from 3250 mm to 4500 mm. The A horizon is a dark yellowish brown sandy clay loam, overlaying a reddish brown silty clay B horizon. The structure of the surface is a strong crumb, whilst the subsoil is compact, breaking into medium crumb to fine sub-angular blocky. The surface horizon of the profile contains a high percentage (20% - 40%) of iron oxide concretions. Due to the shallow and compact subsoil, drainage is poor. Organic matter is high averaging 8.6% (Parish and Feillafe, 1965; Alridge and Wong You Cheong, 1975).

Soils of the *Midland* family also developed under the superhumid rainfall zone where rainfall ranges from 4000 mm to 5000 mm. The profile consists of a very dark greyish brown to dark brown sandy loam A horizon, over a yellowish-red silty clay B horizon. There is a high

amount (40%-80% by weight) of concretions in the topsoil. The physical properties of the topsoil are good due to the concretions, but the B horizon is very compact. The surface structure is coarse granular over a massive blocky subsurface breaking into fine sub-angular blocky peds. The base saturation is less than 10%. Although the organic matter is high (10.4%), these soils are poor in nutrients, particularly once the natural vegetation is removed. Infiltration rate is good, in the A horizon, but the compact B horizon restricts drainage and root development (Parish and Feillafe, 1965; Alridge and Wong You Cheong, 1975).

2.8.7. Erosion features in the RDAC

Gullies in the catchment are limited to only three locations (Figure 2.13) within sugarcane fields (Figure 2.27 and Figure 2.28). Their dimensions and characteristics are described in Chapter 4 on page 92. Other features of soil erosion such as subsurface erosion were not noticed in the catchment during field observation. Rill erosion seems to be limited along very steep slopes under banana and sugarcane cultivation. It is postulated that most of the soil loss in the RDAC occur due to sheetwash. The following chapter explains the methodology followed for predicting soil loss in the catchment under different land use.

Figure 2.27:   Small gully in sugarcane field.

Figure 2.28:   Larger gully in sugarcane field.

Chapter 3: <u>Methodology and terminology</u>

3.1 Application of the RUSLE and SLEMSA soil loss models

GIS techniques were integrated with two empirical soil loss models: the Revised Universal Soil Loss Equation (RUSLE); and the Soil Loss Estimation Model of Southern Africa (SLEMSA). Both models were used to group the many influences of the erosion process into five categories including climate, soil type, relief, vegetation and land use, and land management practices. When using the RUSLE, the categories are known as the erosion factors, erosivity (R), erodibility (K), slope steepness (S) and slope length (L), crop management factor (C), and support practice factor (P). The product of these factor values gave the expected soil loss in $t.ha^{-1}.yr^{-1}$ (A), depending on the dimensions used in the climate and soil factor. The RUSLE equation is (Renard *et al*., 1994):

$$A = R.K.L.S.C.P \tag{3.1}$$

SLEMSA is similar in structure to that of the RUSLE using similar parameters. The model consist of three submodels K, X and C to account for soil erodibility (F) and rainfall energy (E), slope steepness and length, and crop types and cropping practices, respectively. Tillage or management effects are accounted for in the soil factor K. The equation is (Elwell, 1976):

$$Z = K.C.X \tag{3.2}$$

Background theory and the equations used in soil loss calculations using RUSLE and SLEMSA are fully described in Renard *et al*. (1994) and Elwell (1976), respectively. For both models, several measurement techniques are followed to develop the required input data. Measurements necessary to determine the soil erosion factor values for the RUSLE, followed by SLEMSA, are described in this chapter. GIS techniques, including the application termed SEAGIS, are also described. Finally, using data on soil erodibility, rain erosivity, topography and land cover, soil loss could be estimated under various cropping systems and land use.   In doing so, however, a few constraints had to be overcome:

- One of the complications for describing erosion by modelling is the spatial variation of land characteristics;
- The soil erosion factors are to a greater or lesser extend inter-related;
- Not all remote areas of the catchment could be measured;

- Due to limited field time on the island field measurements could not be taken over the course of a year as normally required by the models;

- Erosion modelling had to be conducted for areas with limited data;

- Since no measured soil loss data from runoff plots exits for the *Rivierre des Anguilles* catchment (RDAC), the study was restricted to the application and evaluation of soil loss estimation techniques, and not on the validation of the prediction results.

The methodologies described below were applied to overcome above mentioned limitations.

3.1.1. Land units

Due to spatial variation, the RDAC was subdivided or classified according to landscape profiles or land units. Land units refer to subdivisions of land that shows variations in geology, soil type, microclimate and land-use or vegetation cover. The catchment was subdivided into 37 land units by means of GIS techniques. Land units were derived and integrated by means of overlaying a rainfall zone map, a soil map, and a land use map. The topography has been treated separately by means of digital terrain modeling so that the complex nature of the topography may be fully accounted for. This was done for modeling purposes and to collect representative values for factors governing soil loss. A further discussion of these procedures follows on page 48.

For each land unit, average values of the factors considered by the selected soil loss models (RUSLE and SLEMSA), were determined. The methodology for obtaining these factor values (erosivity, soil erodibility, topography, land use or cover management and conservation practices) is discussed below. Arcview 3.2 facilitated the prediction of soil loss in a spatially distributed manner, using the Spatial Analyst and SEAGIS extensions. Subsequently, erosion rates were assessed within each individual land unit. All land units together represent the catchment. Finally, a range of vegetation data types (pineapple, vegetables and forest) was incorporated to provide soil loss results for potential crop diversification scenarios.

3.1.2. Measuring averages

For countries such as Mauritius, where detailed information for computing soil erosion factor values does not exist, Morgan (1995) suggests the calculation of average annual values. In addition, the RUSLE and SLEMSA were developed to estimate long-term mean annual soil loss and should not be used to predict erosion from individual storms. According to Renard *et*

al. (1994), rainfall fluctuations and vegetation variability tends to average out over extended periods. Therefore, mean annual soil loss predictions on a catchment scale were made.

3.1.3. Qualitative/quantitative assessment

According to Van Lanen (1992) the problems of error and uncertainty can be solved to some extend by using empirical models in so called mixed qualitative/quantitative assessment procedures. Therefore, the RUSLE and SLEMSA were used as qualitative screening tools to identify areas prone to erosion, and also to give approximate quantitative outcomes. With such an approach, areas with a high erosion hazard can be targeted with more detailed investigations (Smith *et al*., 1999).

3.1.4. Reliable soil erosion factor values

For use in the tropics, it is necessary to make a few important assumptions in developing input data for soil loss models such as the RUSLE and SLEMSA (Manrique, 1993). The most important assumption was to accept that EI_{30} is a reliable indicator of rainfall erosivity for use in the RUSLE. The methodology followed to estimate the erosivity factor is described on page 37. Likewise, the soil erosion factors (K, C, and P values) were representative for each individual soil family and land use.

3.1.5. Using constant values

Soil erosion factors are to a greater or lesser extend inter-related. For example, the support practice component, P, combines the influences of rainfall (R), soil type (K) and slope (LS). Recognising the need to simplify this complex relationship between individual factors, some input values had to be kept constant. Appendix 2, and 4 provide all the input values required in the models.

3.1.6. Published literature

Since it was not possible to take field measurements throughout the year, it was necessary to ascertain how conditions change with time, by means of other sources of literature. Research elsewhere has provided methods of obtaining at least approximate values of soil erosion factors. These sources are discussed below and include: SLEMSA and RUSLE databases; vegetation studies; a soil map; an annual rainfall map; a topographic map; and a land use map. However, results from prediction equations are of questionable value when used with handbook derived equation factors. Therefore, erosion factor values for all the soil types,

microclimates, slopes and main land use types were obtained from mostly field and laboratory measurements, only to be supplemented by several theoretical tables, figures and maps. For example, a land use map was used to provide the spatial distribution of cropping systems, but the input values for determining C and P factors of the RUSLE were mostly obtained from the field. Likewise, a soil map was used to provide the spatial distribution of the soil types, and the input values to determine the K factor were obtained in the laboratory. Certain data, such as methods and time of operations (*e.g.* planting and harvesting), were obtained from local farmers during fieldwork.

Although there is no simple procedure for estimating soil erosion potential in a catchment, empirical methods such as the RUSLE and SLEMSA do meet most of the requirements for initial planning (Mander *et al*., 1993). According to Wallace (1997), much research has been carried out on the components of the soil erosion factors, making their application more relevant to local conditions. For this reason the RUSLE and SLEMSA were deemed applicable for use in this exercise. Therefore, using available input data and an applicable soil loss model, estimates of the soil loss of representative landscape profiles in catchment areas were obtained. With these methods soil erosion factors can be estimated from physical properties of the climate, topography, soil and vegetation. The methodology of determining the input values for the data required by the RUSLE and SLEMSA, are discussed according to the submodel components (soil erosion factors).

3.2 Determining the RUSLE erosivity factor R

Erosivity is the ability of rainfall and runoff to cause soil detachment and transport (Lal & Elliot, 1994). The ability of rain or the rainfall energy to cause detachment and transport, is partly the result of raindrop impact, and partly due to the runoff that rainfall generates. The rate and drop size distribution are both good indications of the energy load of a rainstorm. Therefore, the erosivity of a rainstorm is attributed to its kinetic energy, a parameter easily related to rainfall rate or even total amount. Wischmeier and Smith (1978) developed a relation between soil loss and a rainfall parameter termed EI_{30}. The latter is a product of the total kinetic energy (E) of the storm multiplied by its maximum 30-minute intensity (I_{30}). The term I_{30} is calculated as twice the greatest amount of rain falling in any 30 consecutive minutes.

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The energy of a rainfall event for which rainfall intensity data are available, is calculated by applying the following equation:

$$E = 0.199 + 0.0873 \log_{10}(i) \tag{3.3}$$

where E is the total kinetic energy in $MJ.ha^{-1}.mm^{-1}$ for an event; i is rainfall intensity in $mm.h^{-1}$. A rainfall event is taken as a period of rain during which more than 12.5 mm (0.5 inch) rainfall, separated from any other periods of rain by more than six hours. Showers of less than 12.5 mm are included only if 6.3 mm (0.25 inch) or more falls in 15 minutes. The sum of the EI_{30} values for a given period is a numerical measure of the erosive potential of the rainfall in that period. Therefore, annual values of EI_{30} were obtained by summing EI_{30} values for all events during the period in question. In these terms, the rainfall erosion index R, is then the average annual total of the storm EI_{30} values.

3.2.1. Calculation of rainfall intensity

The lack of EI_{30} input data in the catchment is the biggest impediment in the application of the RUSLE. However, Bergsma *et al*. (1996) state that values of the rainfall erosivity index (R) for the RUSLE can be determined experimentally for a series of storms. In the study, R was calculated from selected stations for which rainfall intensity data were available. In the absence of automatic raingauges in the RDA catchment, only limited intensity data from weather stations close to the catchment could be retrieved. The intensity data was used to determine EI_{30} from 1995 to 1997 for the following weather stations relatively close to the catchment: *Belle Rive*, *Bel Ombre*, *Plaicanse*, and *Souillac* (see Figure 2.7 on page 22). Only *Belle Rive* is situated in the northern interior, while the other stations are situated close to the coast. In addition, intensity data from *Plaicanse* for a cyclone event in December 1996 were used to calculate its EI_{30}. EI_{30} values calculated from these intensity data were compared to estimated R values using the modified Fournier Index (discussed below). However, as already stated above, rainfall intensity data for Mauritius and the RDAC are incomplete and available for only short periods of time. Unpredictable short time fluctuations in the levels of variables such as rainfall make R factor estimations substantially less accurate (Renard *et al*., 1994).

3.2.2. Estimation of RUSLE erosivity factor R

Wischmeier and Smith (1978) stress the value of EI_{30} as a long term average annual factor. The R factor should account for cyclical effects and random fluctuations. Therefore,

precipitation data should be analyzed for consistency over a much longer period (*e.g.* 20 years).   In the absence of long term rainfall intensity data for the RDAC, an alternative procedure for estimating R was adopted. In the study, average monthly rainfall values had to be used to calculate the R factor of each rainfall zone in the RDA catchment. Long term, monthly rainfall data were obtained from several weather stations around Mauritius (Mauritius Meteorological Services, 2000). The R factor was derived from monthly rainfall data between 1960 and 1990.

Several studies (*e.g.* Bols, 1978; Kinell, 1981; Smithen, 1981; Lo *et al.*, 1985; Hudson, 1987; Yu *et al.*, 2001) involve the use of estimation techniques to obtain EI_{30} values. Empirical studies on the erosivity of rainfall patterns in Mauritius, were tested by Atawoo and Heerasing (1997). The results indicate that the Fournier Index (1960) modified by Arnoldus (1980) gives a close approximation to calculated rainfall erosivity (R) values for *Curepipe, Vacoas* and *Plaisance* in Mauritius. In addition, the index has been used to compile erosivity maps for Africa and the equator by the FAO. In this study, due to insufficient rainfall intensity data, the R factor values for each of the rainfall zones were estimated using the modified Fournier's Index developed by the FAO (Arnoldus, 1980):

$$R = 0.0302 \text{ x } (RI)^{1.9} \tag{3.4}$$

where $RI = \sum (MR)^2/AR$, MR is monthly rainfall in mm, and AR is annual rainfall in mm.

The approach, however, does not account for seasonal distribution of rainfall erosivity. For use in RUSLE the erosivity database involves a mean seasonal distribution of the R-factor ($\%EI_{30}$) to permit weighting of the soil erodibility value and especially of the cover management factor.   In assessing erosion the magnitude of the R factor and its seasonal distribution must be addressed in relation to the cropping system. In the absence of automatic rain gauges in the RDAC, the mean seasonal distribution had to be derived from mean monthly rainfall values. $\%EI_{30}$ was derived using a linear relationship between rainfall energy and monthly rainfall. To facilitate these calculations, an assumption was made that rainfall energy correlates with rainfall amount on a monthly basis.   In the case of tropical rainshowers, Bergsma *et al.* (1996) reports that rainfall amount can be a good index of rainfall energy. Yu (1998) demonstrated that on a monthly basis, a power function relating storm erosivity to rainfall amount worked well for the Australian tropics. Van der Linden (1983) estimated storm

erosivity in the tropics of Java, Indonesia using similar correlations. Therefore, it is believed that for the purposes of the study, estimates based on monthly rainfall were adequate. In this regard it is postulated that the RUSLE may be applied to Mauritius.

3.2.3. Creating an erosivity map

Finally, the mean annual rainfall map provided by Proag (1995), was used to classify the catchment into rainfall zones. The catchment falls within 7 of the 10 rainfall zones of Mauritius. Subsequently, the mean annual rainfall map and estimated R values were used to create an erosivity map of the RDAC in ArcView 3.2. It is important to note the fundamental need for reliable estimates of EI_{30}, which can only be met by local research. Calculated values of EI_{30} can be used to further investigate the seasonal distribution of rainfall erosivity and to facilitate use of soil loss models in assessing the protective value of crop systems.

Estimates of the remaining RUSLE factors are obtained from physical properties of the topography, soils, vegetation and management practices.

3.3 Identification and sampling of soils

A soil map of Mauritius at a scale of 1: 100 000 published by Parish and Feilafe (1965), was used to identify the different soil types within the catchment. Due to the variability between, as well as within soil types, attempts to select representative samples of soil types within the catchment was challenging. Sampling methods aimed at representing the five major soil families under typical field conditions within the catchment. For example, since more than 80% of the *Reduit* soil family is under sugarcane cultivation, all *Reduit* soil samples were taken from soil under sugarcane fields. Likewise, *Riche Bois* and *Belle Rive* soil samples were taken from soil under sugarcane fields. *Sans Souci* and *Midlands* soil samples, however, were taken from soil under natural vegetation and tea plantations, since both these soil families are mostly (>70%) covered by tea, scrub and forest. As a result, 6 to 9 soil samples (±500 g) were taken from each of the 5 soil families (see Table 3.1), from different sites with uniform topography and land use. Soil properties were determined from a total of 37 soil samples taken at the locations shown in Figure 2.13 on page 27. Also measured at these sample sites were the vegetation parameters for use in the RUSLE and SLEMSA. A further discussion of these procedures follows on page 44 and 51. Soil samples were analysed in the agricultural laboratories of the University of Mauritius. Soil erodibility usually refers to the topsoil (Bergsma, *et al*., 1996). Therefore, during fieldwork and laboratory analyses, only the topsoil

was sampled in order to determine its surface erodibility. Sampling and analysis procedures were done according to standard methods described in Goudie *et al*. (1990), unless referenced otherwise.

Table 3.1:   Number (n) of sampling points and analyses carried out for each soil.

Soil group	Low Humic Latosol (LHL)	Humic Latosol (HL)	Humic Ferruginous Latosol (HFL)		
Soil family	*Reduit*	*Riche Bois*	*Belle Rive*	*Sans Souci*	*Midlands*
Soil samples (n)	9	6	7	8	7
Particle size analysis (n)	9	6	4	3	3
Fine particle size analysis (n)	9	6	4	3	3
Aggregate stability (n)	5	5	5	5	5
Infiltration rate (n)	4	6	6	2	7
Bulk density (n)	9	6	7	0	7
Shear strength (n)	22	20	25	0	30
Organic matter content (n)	9	6	7	8	7
Moisture content (n)	9	6	7	0	7

3.4 Determining the RUSLE erodibility factor K

Soil erodibility accounts for the influence or response of soil properties on soil loss during rainfall events. Erodibility of a soil is designated by the soil erodibility factor, K for RUSLE. The K factor is a measure of the susceptibility of a given soil to particle detachment and transport (Wischmeier & Smith, 1978). The physical, as well as chemical soil properties and their interactions that affect K values are many and varied. For the determination of erodibility factors in the RDAC, several approaches were followed. For use in RUSLE, erodibility values were determined by means of physical measurements in the laboratory. These measurements are discussed below. The choice of appropriate measurements depends upon the relevance to processes that govern erosion under natural field conditions (Lal & Elliot, 1994). For tropical soils of volcanic origin, the RUSLE supplies the user with the relationship of El-Swaify and Dangler (1976 cited in Renard *et al*., 1994: 78):

$$K = -0.0397 + 0.00311x_1 + 0.0043x_2 + 0.00185x_3 + 0.00258x_4 + 0.00823x_5 \qquad (3.5)$$

where K is the soil erodibility factor expressed as $t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$. x_1 is the percentage unstable aggregates smaller than 0.25 mm; x_2 is the product of percentage modified silt (0.002 – 0.1 mm) and percentage modified sand (0.1 – 2.0 mm); x_3 is the percentage base saturation; x_4 is the percentage silt (0.002 – 0.05 mm); x_5 is the percentage modified sand (0.1 – 2.0 mm).

Thus, K is calculated according to the relationship of erodibility to soil properties for volcanic soils. The RUSLE also accounts for rock fragments on the soil. Rock fragments on the surface were treated as mulch in the C factor. Consequently, mean annual erodibility values were assigned to each of the soils of the catchment area, allowing a weighted average K factor to be predicted for each mapping unit. Erodibility values for each soil were classified according to the erodibility ratings (from low to very high) in Bergsma *et al*. (1996).   The soil erodibility map is shown in Chapter 4 on page 60.

3.4.1. Particle size analyses

As stated above, soil samples were drawn at 37 sites throughout the RDA catchment. Sieve analysis was carried out on 25 (due to limited field time) of the 37 soil samples (see Table 3.1), using a shaker and sieve stack with sizes ranging between 0.063 to 16 mm, on the Wentworth Scale (Briggs, 1997a). Thereafter the percentage of the total sample weight retained on each sieve was assessed. Graphs showing the cumulative percentage frequency of the size distributions were drawn. Data were transformed to an arithmetic normal distribution. Since the relative mass of fines is underrepresented in a sample, a logarithmic phi scale is used: $\Phi = -\log_2 d$, where d = sieve aperture diamater in mm. Thereby, plotting the cumulative percentage frequency distribution of sediment size with the logarithmic phi classes on the x-axis. Statistical methods, discussed by Till (1974) and Briggs (1977b), have been used for descriptive purposes. Statistical measures include the mean, skewness and sorting. The mean reflects the average particle size or weighted central point of the sample, whereas skewness and sorting describe the shape of the particle size distribution. Kolmogorov Smirnov Tests were included for comparison of different soils to distinguish statistically between particle distributions.

3.4.2. Fine particle analyses

Fine particle analyses and wet sieving were carried out on 25 (due to limited field time) of the 37 soil samples (see Table 3.1) to obtain erodibility results for use in RUSLE. The pipette method was used to perform fine particle analyses. The pipette is used to remove a definite volume and thereby concentration of particles in a settling suspension.   Thereby an approximation of fine particles is obtained based upon its settling velocity, governed by Stoke's Law: The velocity of fall of a sedimentary particle through a viscous medium (e.g. water) is directly proportional to its diameter Goudie *et al*. (1990).

3.4.3. Aggregate stability

The degree of water stable aggregation is also used as a general indicator of soil erodibility. RUSLE requires determination of the unstable aggregate size fraction in percent less than 0.250 mm. A classical and still most prevalent procedure for testing the water stability of soil aggregates is the wet sieving method. Wet sieving was carried out on 5 samples of each soil type (Table 3.1).   Soil aggregates was sieved and subjected to simulated rainfall in a standardised manner described by Hillel (1982).   The fractional oven dried mass remaining after 10 minutes was determined.

3.4.4. Measuring additional indices of soil erodibility

In conjunction with the analyses to determine soil erodibility, the following analyses of samples were also taken into account:

- Infiltration of water into the soil is a key process in runoff and erosion. The depth of water entering the soil per minute was measured in the field by flooding an infiltration ring with a known volume. Water uptake was measured until the water head lowered at a constant rate, also known as the infiltration rate or infiltration capacity (Finlayson and Statham, 1980).   Infiltration measurements were attained using similar representative techniques described on page 40.   Infiltration rates were determined from each soil family from sites with uniform topography and land use (Table 3.1). Between 2 and 7 measurements were repeated at each site. As a result, infiltration rates were determined from 22 of the 37 sample sites shown in Figure 2.13 on page 27.

- Organic matter content data were obtained from Parish and Feilafe (1965). Data were verified by measuring organic matter contents using a furnace. Organic matter contents were determined by weighing a sample of the soil and then placing the sample in a furnace at a temperature of $600\,°C$ for 24 h and reweighing. Results were obtained from the 37 soil samples as described on page 40; locations indicated in Figure 2.13 on page 27.

- Information on the soil structure for each soil family was obtained from the Mauritius soil map (Parish and Feilafe, 1965).

- The availability of erodible material also depends on the resistance to splash and scour detachment; the soil's shear strength. A shear vane was used to test the shear strength of the topsoil. This was done by recording the maximum torsion force exerted by the soil on symmetrical intersecting blades, inserted 1 cm deep into the topsoil. Between 20 and 30 shear vane tests were performed on 4 of the 5 soil families (Table 3.1).

- Bulk density was measured by the core technique discussed in Briggs (1977a). Between 6 and 9 samples were collected from 4 of the 5 soil families in the RDAC (Table 3.1). Samples were collected by hammering a core tube with a known volume into the soil. Samples were oven dried and weighed. The bulk density of the soil was measured as the ratio of its mass to its volume:

$$\text{Bulk density} = \text{Weight (g) / Volume (cm}^3). \tag{3.6}$$

- The moisture conditions in the soil affect infiltration rates and the erosion process. Between 4 and 6 soil samples of 4 soil types (Table 3.1) were weighed and dried in an oven at a temperature of 105-110°C and reweighed. Consequently, a total of 29 samples were oven dried to determine the moisture contents during November and December.

- Additional input values including the base saturation and consolidation, needed for the soil erosion models were obtained from the literature (references given with the results). Chemical and mineralogical properties were not further investigated in the study. A quantitative discussion is given by Parish and Feilafe (1965), and Williame (1984).

3.5 Measuring land use characteristics for the RUSLE

Of all hazard factors the cover management code is the most important soil erosion factor (Crosby *et al.*, 1981; Renard *et al.*, 1994; Garland, 1995; Evans, 2000). The effect of plant cover is dominant over the effect of rainfall, slope and the soil profile. Not only does it represent conditions that can be managed to reduce erosion, but it also represents the changes in land use if crop diversification has effect. Therefore, a realistic estimate of the C factor is essential if soil loss results are to be of any practical value. The following method was used to obtain crop cover measurements.

A land system approach similar to that developed by Smith *et al*. (2000) was used. The main land use types or cropping systems within the RDAC were identified (Saddul, 1996).   In addition, small plots (the vegetable – intercrop – and banana plantation) were georeferenced by means of GPS and GIS techniques. Some of these crops were of different varieties and used in different management scenarios. However, the variety of crops that were tested in this study represent the main agronomic practices within the RDAC. For modeling purposes, the catchment was subdivided into the following land use types: Frequently disturbed land use types (sugarcane, intercropped sugarcane, and a vegetable stand); and Infrequently disturbed land use types (banana plantations, tea plantations, scrub, forested land and urban areas). For the purposes of the study, forested land included natural forest and forestry plantations within the RDAC.

Field measurements aimed at representing the 8 major land use types within the catchment. As a result, 4 to 5 sites for each land use were selected for measurement.   A total of 37 measurements were made at the sites mentioned above (Figure 2.13 on page 27).   When studying the annual crop cover effect on erosion, the type of crop and its growth stages were considered. The main stages for plant cover and its interception for rainfall are: (1) the harvest - soil preparation – planting stage; (2) the first growth stage; (3) the second growth stage; and (4) the mature growth stage. Differences in their effect on erosion were expressed by the cover factor C.   The cover factor was calculated by weighing the growth stage cover factors according to the relative erosivity of the respective growth stages, and then summed to produce the average annual C factor. A more detailed discussion follows.

3.5.1. Determining RUSLE soil loss ratios (SLR)

The C value is not only a function of plant cover, but also a function of the distribution of erosivity.   The seasonal development pattern of the canopy is important because rainfall erosivity also follows a seasonal pattern. In order to arrive at an average annual C factor the growth habit of crops must be estimated over the season. Therefore, C factor values can also be described as weighted averages of soil ratios that relate the soil loss at a given condition at a given time. By definition, the soil loss ratio (SLR) is an estimate of the ratio of soil loss under actual conditions to losses experienced under clean-tilled continuous fallow. Soil loss ratios vary during the year as climate, soil and cover conditions change. To relate the canopy effect to seasonal rainfall erosivity distribution by the RUSLE method, the year is divided up into various crop stages, as noted above.

The RUSLE uses a subfactor method to compute the SLRs for frequently disturbed crops. SLRs were calculated in the RUSLE according to the mean distribution of erosivity in the catchment during a year. The subfactor relationship is given by the equation:

$$SLR = PLU \cdot CC \cdot SC \cdot SR \cdot SM \qquad (3.7)$$

where PLU is prior land use, CC is crop canopy, SC is surface cover, SR is surface roughness, and SM soil moisture. Each subfactor contains cropping and management variables that affect soil loss. The combination of information from these variables includes residue cover, canopy cover, canopy height, surface roughness, below-ground biomass, prior cropping, soil moisture and time. Thus, vegetation parameters needed for modeling of the C factor were estimated for each frequently disturbed land use type. Characteristics or input values for each crop and its growth stages requested by the models have been summarized in Appendix 2, 3 and 4. In addition, these values were assigned in the RUSLE based on the date of operation. Subsequently, each of these subfactor parameters were assigned a value, which were multiplied within the RUSLE to yield an SLR. Thus, the erosion control effectiveness of a crop was determined on the basis of four crop stage periods and the amount of erosive rain (EI%) expected during each period as a ratio of the soil loss from continuous fallow. To compute C, the RUSLE weighted each of these calculated SLR values by the fraction of erosivity (EI_{30}), associated with the corresponding time period. Finally, these values were combined into an overall C factor value.

The methodology above describes the circumstance under which RUSLE is used for normal cropping rotation, in which the crop system is disturbed repeatedly during one or more years. The RUSLE also provide for the situations of a single disturbance, or no disturbance (infrequently disturbed). For areas such as forest – scrub – banana – and tea plantations, the parameters used in computing SLR values are relatively constant (Renard, *et al*., 1994). In these cases, it seems to be adequate to calculate a C factor based on a single average SLR representing the entire year. The results for infrequently disturbed crops, however, do not reflect changes in the climate's erosive potential throughout the year.

3.5.2. Literature

Most of the C factor values for the RDAC were derived from fieldwork. In order to obtain initial information, most of the vegetation parameters, such as canopy cover and fall height,

were measured for every crop system in the RDAC. However, since it was not possible to take field measurements throughout the year, it was necessary to ascertain how crops changes with time by means of other sources of literature. As a result, it was still possible to describe typical vegetation patterns.

Although the RUSLE has computer routines for many tillage operations and crops, these databases do not contain the compilation of factors for all of the crops cultivated in Mauritius. Additional vegetation database sets for sugarcane, intercrop and vegetables had to be implemented. Furthermore, there was insufficient crop information (*e.g.* crop residue, root mass *etc*.) to use the RUSLE methodology for possible future cropping systems. Instead, the C factor value for pineapple was obtained from Roose (1975 cited in Bergsma *et al*., 1996: 87); Elwell (1976); Cooley and Williams (1985); McPhee & Smithen (1984). The C value for vegetables was estimated by using a combination of field data and the RUSLE database of similar crops (Biesemans *et al*., 2000).

Field measurements and subsequent RUSLE computations needed to include the average soil loss for multicrop systems. A small section of sugarcane fields are intercropped with vegetables such as potatoes and tomatoes. In the RUSLE, this information had to be combined to reflect the total values of the combined crops.

All the vegetation data were integrated into vegetation database files, termed cover management systems. These database files contain information regarding the dates of all operations, implements used, and the number of years in rotation. The effects of the different implements on the land were compiled by means of the RUSLE operations database. The different types of operations and there effects are shown in Table 1 and Table 2 in Appendix 3, respectively. To value the crop management input data above, Appendix 3 includes the classification codes used in the RUSLE database. These include the cover management code (Table 3), the soil hydrological classes (Table 4), and the surface cover function known as the b-value code (Table 4).

3.6 Determining the RUSLE support practice factor P

The dimensionless support practice factor P, takes into account the effect of special management practices. Of all the erosion factors, values for P are the least reliable (Renard *et al*., 1991). This is due to the difficulty in identifying subtle characteristics in the field.

P values represent broad, general effects of practices such as contouring. In RUSLE, the available sub-factors are contour farming, terraces, strip cropping and buffer strips (Renard *et al*., 1994). These practices principally affect erosion by modifying runoff. It is therefore noteworthy that the runoff index is computed during the calculation of P. The index is a measure of the percentage of available precipitation that will be seen as runoff, and is a function of soil type, soil structure, surface condition and surface cover. The RUSLE also includes an approach for addressing soil loss through the "frequent - and infrequent disturbed" P factor options.

Information on the most common support practices for the RDAC (contouring and buffer strips) were collected during fieldwork and supplemented by other sources of literature (see Table 11 in Appendix 2). Factor values for contouring is a function of ridge height, furrow grade and climatic erosivity (EI_{30}). Ridge height refers to the average height of the contour ridges for each crop. Furrow grade refers to the lateral slope angle of contour ridges for each crop. The RUSLE also account for buffer strips, which are strips of vegetation acting as a buffer to initiate deposition of eroded sediments. Factor values for buffer strips are a function of their physical vegetation parameters, such as its width and its location in relation to the slope. The information was deciphered into an operations database defining the effects of field operations on the soil, crop and crop residues. All operations included in the calculations of P values are listed in Table 4 in Appendix 2. P values for use in RUSLE were calculated as a product of subfactors for the two individual support practices. For example, the average ridge heights for contour ridges of a specific crop were added, for which the programme calculates a total average P value. The RUSLE model similarly evaluated the effectiveness of buffer strips in trapping sediment and reducing erosion. For other land uses where no conservation practices are applied, the P factor has a deterministic value of 1.

3.7 Determining the RUSLE topography factors LS

In theory, the erosion slope length (L) should be considered as the distance from the point of origin of overland flow to the point where the slope (S) decreases enough that deposition begins or the runoff water enters a well-defined channel (Wischmeier and Smith, 1978). For areas with complex slopes, measurement of slope length is problematic. The reasons are the variation in erosion slope length according to the type of rain, the antecedent moisture conditions, and flow zone of the surface and subsurface flow (Bergsma *et al*., 1996). According to Desmet and Govers (1996) manual determination of slope length fails for

topographically complex areas because it is unable to capture the convergence and divergence of the real topography. Although profile determination must generally be carried out in the field, the preferred method of slope measurement on catchment scale is by using a large scale topographical map (Morgan, 1995). To determine the topographic factor at catchment scale an automated procedure is required. Digital terrain modelling is an essential method of determining the topographic factor for use in soil loss studies at catchment scale (Flacke *et al.*, 1990). In the case of a complex slope morphometry, digital terrain modelling intends to improve limitations of the LS factor (Dikau, 1993). In principle, digital terrain modeling allows for the calculation of all contributing unit areas so that the complex nature of the topography may be fully accounted for. Other advantages include the speed of execution and objectivity. Modelling approaches to derive the LS factors on a regional scale are also described by Cochrane and Flanagan (1999) and Engel (1999).

For this study, the data source for the LS factor was a topographical map (Ordinance Survey, 1991) of the island at a scale of 1: 25 000 showing contours at 10 m intervals. The map was used to create a digital elevation model (DEM) in Arcview 3.2. The DEM has been constructed by digitizing the contours encompassing the catchment for the purpose of slope calculation and categorization. Slope gradients were calculated using digital terrain modeling routines in Arcview 3.2. The resulting image contains units of slope gradient in percentages classes adopted from Bergsma *et al.* (1996). Using the SEAGIS application, slope length was calculated as the downslope horizontal length of each cell. In the process, the LS slope factor values were computed. A slope map and a LS factor map were extracted from the DEM using the following equations (Renard, *et al.*, 1994):

$$L = (\lambda/22.13)^m \tag{3.8}$$

where L is the slope length factor; λ is the length of slope (in m); and m is $\text{\ss}/(1+\text{\ss})$, where $\text{\ss}$ is the ratio of rill erosion to interrill erosion. Values for $\text{\ss}$ can be computed from:

$$\text{\ss} = (\sin\theta/0.0896)/[3.0(\sin\theta)^{0.8} + 0.56], \tag{3.9}$$

where θ is slope angle. For slopes shorter than 15 feet (4.5 m):

$$S = 3.0(\sin\theta)^{0.8} + 0.56 \tag{3.10}$$

where S is the slope gradient factor. Otherwise:

S = 10.8sinθ +0.03 for a slope steepness less than 9%, or

S = 16.88sinθ + 0.03 for a slope steepness greater than 9%.

In addition, an average slope gradient and LS factor were determined for banana plantations using an Abney level, and to make field checks on steep (25–40%) to very steep (40-60%) slopes. Resulting values were needed for the calculation of the P factor values by the RUSLE.

3.8 Determining SLEMSA input values

SLEMSA (Z = K.C.X) uses similar parameters as the RUSLE including a soil factor K, a canopy cover factor C, and a slope steepness and length factor X. The soil factor K accounts for soil erodibility F and rainfall energy E, as well as, tillage or management effects. Although SLEMSA uses similar parameters to the RUSLE a notable difference between these two models is the definition of K as the rate of soil lost per unit of erosivity. In SLEMSA the K factor is dependent on rainfall energy, to which it is exponentially rather than linearly related, as well as the dimensionless soil erodibility index F. Furthermore, SLEMSA treats the soil erosion factors as separate entities. This is an advantage over the RUSLE where interactions between model components can cause complications.

3.8.1. Determining the SLEMSA soil factor K

As stated above, the factor K accounts for soil erodibility (F) and rainfall energy (E). F values, which have to be provided by the user, should reflect all factors that influence the soil's runoff properties and resistance to detachment. Soil characteristics or erodibility are also altered by management practices. Therefore, the management practices such as tillage, subsurface drainage and crop rotation were also considered when determining the F value. Initially, basic soil values were determined by considering texture. Initial values were then adjusted according to local management practices. The erodibility value F was, therefore, modified according to management practices that influence soil properties. Table 1, 2 and 3 in Appendix 4 show the factors that this indexing system takes into account. Using the F values, values of K are derived from the equation (Elwell, 1976):

$$\ln K = b \ln E + a \tag{3.11}$$

where a = 2.884 – 8.1209 F; and b = 0.74026 – 0.09436 a; and

$$E = 9.28 P – 8.838 \tag{3.12}$$

where E is mean annual rainfall energy in $J.m^{-2}$, and P is mean annual precipitation in mm.

E represents the kinetic energy of the raindrops on striking the soil or vegetation. For the estimation of the rainfall energy factor E, SLEMSA uses mean monthly rainfall figures. Mean seasonal rainfall energy is derived from relationships between annual kinetic energy and mean annual rainfall from SLEMSA (Elwell, 1976). Calculation of the K factor is shown in Table 4 in Appendix 4.

3.8.2. Determining the SLEMSA slope factor X

Using the SEAGIS application, an image for the SLEMSA slope factor, X, was produced. The X factor map were extracted from the DEM using the following equation (Elwell, 1976):

$$X = L^{\frac{1}{2}}(0.76 + 0.53 S + 0.076 S^{2})/27.6 \tag{3.13}$$

where X is the topographic ratio; L is the ground slope length in m; and S is the slope percent. The slope factor for SELMSA was also computed in SEAGIS, using the same DEM used to compute the LS factor in RUSLE.

3.8.3. Determining the SLEMSA cover management factor C

The C factor is calculated as follows (Elwell, 1976):

$$C = (2.3 – 0.01 i)/30 \text{ when i is less than 50\% or} \tag{3.14}$$
$$C = \exp (-0.06 i) \text{ when i is more than 50\%}$$

where i is the percentage rainfall energy intercepted by the different crop stages (% rainfall x % cover).

It should be noted that rainfall and its intensity is greater in the summer months. This is taken into account when the protective value, i, of the crop cover is estimated. C values are calculated by multiplying the seasonal cover or crop stage value representing i with the

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corresponding average rainfall in millimeter, and dividing the sum of these monthly products by the average annual rainfall. Results indicate the percentage of annual rainfall intercepted by the crop. Interception values for the crops of the RDAC are shown in Table 5 of Appendix 4.

Finally, information from other studies conducted in Africa (Appendix 5) was used as a comparison for evaluating the derived RULSE and SLEMSA land use factor values for the RDAC.

By means of GIS techniques, the various combinations of the factor values for erosivity, erodibility and land use; effectively form the 37 land units and criteria depicted in Table 4 in Appendix 4. Table 4 also displays the SLEMSA calculations for determining the soil factor K. Once the stochastic distribution of every parameter was determined, the spatial distribution and data of each soil erosion factor were digitized into a GIS (Arcview 3.2) as themes. The soil erosion themes could then be treated as variables in the algebraic calculations for RUSLE and SLEMSA. With the information obtained from the procedures above, average annual soil losses over a wide range of conditions were derived.

3.9 Estimating and mapping soil erosion rates

As stated in previous studies, prediction models are interfaced with a GIS (*e.g.* Flacke *et al*., 1990; Busacca *et al*., 1993; Desmet and Govers, 1996; Mitasova *et al*., 1996; Pretorius and Smith, 1998; Breetzke, 2004). Using the RUSLE and SLEMSA in a GIS environment enables the production of a catchment map classified according to the erosion hazard of the main land use types. Figure 3.1 illustrates a diagram showing the basic GIS procedures that have been followed in the study.

The initial stage was to produce mapped information on four physical systems: climate, soil, crop and topography. Data were used to produce thematic maps for each soil erosion factor for use in RUSLE and SLEMSA. This lead to the digitizing of data on the erosivity, erodibility, topography, cover management and support practice. Thus, digitized maps for each of the soil erosion factors were produced from maps and digital data, using Arcview 3.2.

a)   RUSLE equation: A = R.K.L.S.C.P
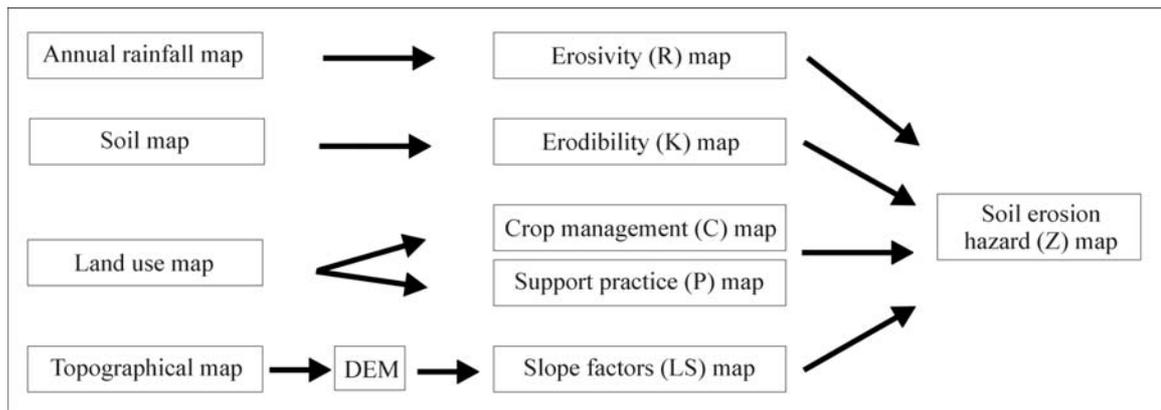
b)   SLEMSA equation: Z = K.C.X
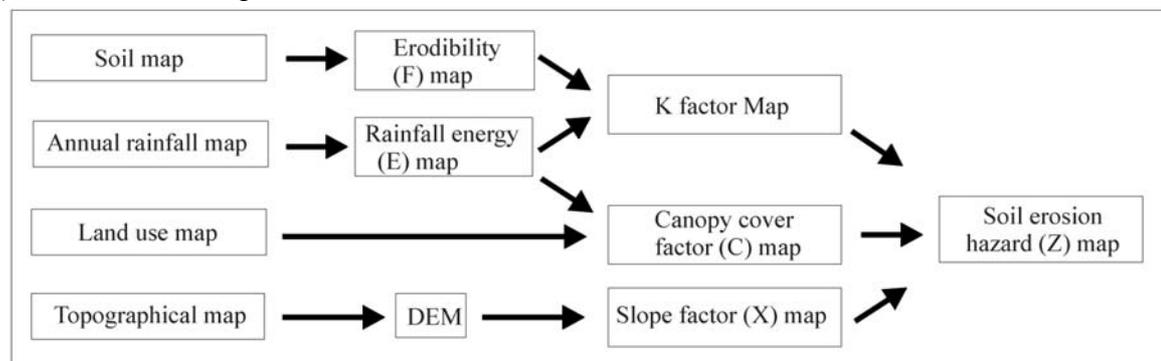
Figure 3.1:   Basic GIS procedures followed in the study for:

a) the RUSLE; and b) the SLEMSA.

Each of the 37 land units comprises of unique soil erosion criteria. These different soil erosion areas were derived and integrated by means of overlaying a rainfall zone map, a soil map, and a land use map. Topography has been treated separately by means of digital terrain modeling. Thereby, the complex nature of the topography was fully accounted for. Erosion factors were added as attributes to the each of the maps or themes mentioned above. For example, the land use map was used to add the C factors as an attribute field. Likewise, the soil map was used to add the K factors as an attribute field. After digitizing and rasterizing all factor maps and erosion information within Arcview 3.2, the soil erosion for each pixel was determined by multiplying the factors with the map calculator. Calculations were done using capabilities available within the spatial analyst extension.

Finally, these criteria have been used to estimate the soil loss for each land use. Soil loss is simply the product of each soil erosion factor. The mean predicted soil loss value (in $t.ha^{-1}.y^{-1}$) per land use was determined and multiplied by its area in hectares. Total soil loss for each land

use was determined by multiplying the mean unit value by the area (hectares). The sum of these results, of each land use, gives a single soil loss value for the whole catchment. According to Wischmeier (1976), the sum of soil loss estimates of land facets in a drainage area or catchment, approximates the amount of soil removed from its original position in the total catchment. Thus, soil loss is the amount of sediment lost from a specific area expressed as an average rate for the land unit in t.ha^{-1}.yr^{-1}. Subsequently, mean soil loss values for each land unit were computed and displayed by means of GIS techniques. Maps showing the results of each of the models have been produced and shown in chapter 4.

3.10 Soil erosion assessment using GIS (SEAGIS)

SEAGIS utilizes Arcview 3.2 for the preparation of input map data and for map display (DHI, 1999). The same maps and information on rainfall, soils, land use and topography was used within SEAGIS to determine soil erosion for each pixel. SEAGIS performs its calculations on the existing (R)USLE, SLEMSA and Morgan, Morgan and Finney (Morgan *et al.*, 1984) of which the former two models were selected for the study. The application offers the user several ways for calculating erosion factors. The minimum input data needed are a mean annual rainfall grid calculated from a formula (in this case the modified Fournier Index), a soil map with erodibility interpretation, a digital elevation model and a land cover map. SEAGIS allows the user to "add empirical values" already measured. The same input values were used as used above. For example, after classifying the land cover class in SEAGIS (crops and natural grassland, or dense pastures and mulch), the C factor is set using RUSLE derived input values (cover), for each land use in the land use theme. Within SEAGIS a grid for each of the RUSLE erosion factors (R, K, SL, C and P) were created. The grid themes for each SLEMSA factor (K, X and C) were determined by similar means within SEAGIS. After creating all the sub-factor grids, source erosion grids (for RUSLE and SLEMSA) with annual soil loss in t.ha^{-1}.yr^{-1} were made. Therefore, SEAGIS can be described as a GIS-based application that estimate soil loss using the same principles as the existing empirical models mentioned above. It was therefore interesting to compare results computed by SEAGIS that is GIS-based, to the initial results where GIS was used only as a helping tool (for visualisation of results).

SEAGIS comprises of two different terms for describing soil erosion; source erosion and transported erosion. The latter have the function of calculating the delivery index and sediment yield. However, no attempt was made to calculate the delivery index because: (1) calculation requires additional datasets; (2) calibration of thresholds for transport and

deposition is very subjective (Dickinson and Collins, 1998); (3) and delivery ratios can be extremely variable and site specific (Bergsma *et al*., 1996). The study focused only on source erosion, which applies to the soil eroded from each grid cell. Thus, the source erosion was estimated by use of the RUSLE and SLEMSA.

3.11 Identification and measurement of gullies

Both the RUSLE and SLEMSA do not directly account for gully erosion. For a more inclusive record of the erosion hazard, significant permanent erosion features such as gullies in the catchment were investigated. The term gully erosion process can be defined whereby water concentrates in narrow channels and over short periods removes the soil to depths, ranging from 30 cm to 20 m (Bergsma *et al*., 1996). Gullies are deep enough to interfere with, and not be obliterated by normal tillage techniques. Three gullies were located in the catchment. After ground surveys, the surface forms of these gullies were mapped using geomorphological mapping techniques described in Williams and Morgan (1976), and Cooke and Doornkamp (1990). The role of gullies in the catchment is considered further in Chapter 5 on page 116.

3.12 Prediction of soil erosion rates for future land use change

Two kinds of soil erosion maps have been compiled: An actual or current soil loss map; and a potential or future soil loss map. Each of the two maps are expressed in quantitative terms and defined into soil loss classes adopted from Bergsma *et al*. (1996). The soil losses from three potential land cover scenarios were added using RUSLE. The decision for using the RUSLE was based on the application and performance of the two models, under different conditions (discussed in Chapter 5 on page 121).

Three cropping systems are recognised to be relevant to the immediate and near future development opportunities in Mauritius.   These are forestry and/or natural vegetation, vegetables, and pineapple (Jawaheer, 2001) [2]. According to the land resources and agricultural suitability map of the MSIRI (Arlidge and Wong You Cheong, 1975), and the suitability of sugarcane lands for potato and tomato (Jhoty *et al.*, 2001), land of the RDAC is either suitable or at least conditionally suitable for other food crops. Therefore, potential crop systems were assumed to cover the whole catchment, except existing urban areas.   The three possible future

[2]. Information from personal communication Mr. M. A. Atawoo, Agricultural Research and Extension Unit of Mauritius, University of Mauritius, 3 November 2001.

cropping systems including, forestry and/or natural vegetation, vegetables, and pineapple were simulated according to RDAC conditions. Thus, real climate – soil – topographical – and crop data from the catchment, were loaded into the RUSLE. Only the C and P erosion factors were modified to represent the three potential scenarios (crop systems). The C factor for pineapple was based on published values due to being absent in the RDAC. Soil loss results for all three potential cropping systems are estimated according to the scenarios given above.

Once all the images are created, it is possible to identify areas of high erosion potential. Cropping systems and land use change scenarios that result to the greatest soil erosion are identified. In the absence of any other quantitative information on soil erosion for Mauritius, the results are compared to similar studies conducted elsewhere. In addition, theoretical evaluations of empirical models done by several authors under different conditions are discussed in Chapter 5 on page 121. The discussion is based on the application and performance of the two models including SEAGIS, under different conditions.

Chapter 4: <u>Results</u>

In this chapter results from the methodologies followed in chapter 3 are presented. First of all, results include all input data necessary for determining the erosion factor values required by: (1) The Revised Universal Soil Loss Equation (RUSLE); (2) The Soil Loss Estimation Model of Southern Africa (SLEMSA); and (3) The Soil Erosion Assessment using GIS (SEAGIS) application. Second, model outputs are displayed by means of soil erosion prediction maps, tables and graphs. These results focus on the mean and total soil loss for each land use within the *Rivierre des Anguilles* catchment (RDAC). Finally, soil loss values computed for potential cropping systems are displayed by means of soil erosion prediction maps, tables and graphs for comparative purposes.

Input data required for each of the soil erosion factor values of the RUSLE (A = R.K.L.S.C.P) are given below. The RUSLE input data and results are categorised according to the soil erosion factors including erosivity (R), erodibility (K), slope steepness (S) and slope length (L), crop management factor (C), and support practice factor (P).

4.1 RUSLE erosivity results

A map of mean annual erosivity (R) shows a south to north gradient over the RDAC (Figure 4.1). The erosivity map clearly indicates that R increases with altitude, corresponding with the amount of rainfall. The lowest estimated R value is 619 MJ.ha^{-1}.mm.hr^{-1} at the coast, whereas the upper catchment area is characterised by the highest calculated R value of 2139 MJ.ha^{-1}.mm.hr^{-1}. This area also has the highest average annual precipitation of 3630 mm. The highest estimated R values are found above the 450 m contour line, covered mostly by tea, forest and scrub.

4.1.1. Rainfall intensity (EI$_{30}$) results

Measured erosivity values (EI$_{30}$) obtained from limited rainfall intensity data from *Plaicanse*, *Bel Ombre* and *Belle Rive*, are shown in Table 4.1. Although the measured erosivity results in Table 4.1 are, on average, slightly lower than the erosivity results given above in Figure 4.1, results correspond. Results indicate that erosivity is low at the coast and increases substantially towards the interior. Correspondence of these erosivity results supports the use of the modified Fournier index that seems to be appropriate for use in the study. The R value
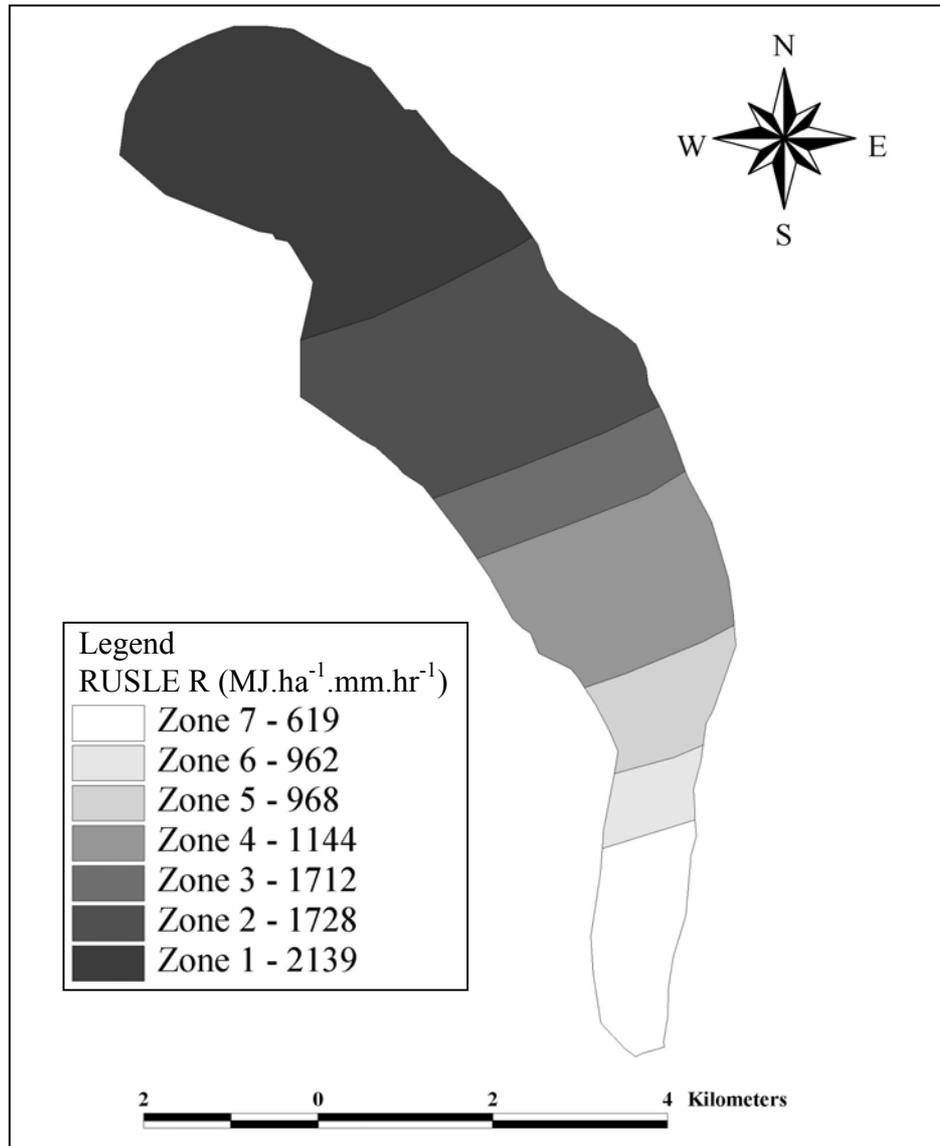
Figure 4.1:   Mean annual erosivity (R) for the rainfall zones of the RDAC.

Table 4.1:   Measured EI_{30} values in $MJ.ha^{-1}.mm.hr^{-1}$.

Town	Location	Year(s)	Erosivity (EI_{30}) $MJ.ha^{-1}.mm.hr^{-1}$
Souillac (coastal)	57° 31' E, 20° 31' S	1997	1367
Plaicanse (coastal)	57° 40' E, 20° 26' S	1995-1996	416
Bel Ombre (coastal)	57° 25' E, 20° 30' S	1995-1996	407
Belle Rive (interior)	57° 33' E, 20° 16' S	1995-1996	1453

calculated from intensity data for Souillac (1367 $MJ.ha^{-1}.mm.hr^{-1}$), however, does not correspond well with the estimated R value (619 $MJ.ha^{-1}.mm.hr^{-1}$). According to Renard *et al.* (1994) unpredictable short time fluctuations in rainfall levels makes R factor estimations substantially less accurate. Another possible reason for this could be the occurrence of a

cyclone during 1997. The implications of extreme events such as tropical cyclones are further discussed in Chapter 5 on page 97.

4.1.2. Erosivity of a tropical cyclone

Calculated EI_{30} results obtained from intensity data from a single cyclone event in Plaicanse during December 1996, are shown in Table 4.2. The cyclone generated approximately 176 mm of rain over a 10 hour interval. EI_{30} from the storm event exceeded 1100 MJ.ha^{-1}.mm.hr^{-1}.

Table 4.2:   Calculated EI_{30} results obtained from intensity data from a single cyclone event in Plaicanse during December 1996.

Duration (min)	mm	I (mm.hr^{-1})	LogI	0.0873logI	E (MJ.ha^{-1}.mm)	E (MJ.ha^{-1})
60	16.33	16.30	1.212	0.1058	0.2248	3.664
60	27.33	27.30	1.436	0.1253	0.2443	6.671
60	11.70	11.70	1.068	0.0932	0.2122	2.483
60	11.80	11.80	1.071	0.0935	0.2125	2.508
* 60	18.26	18.26	1.261	0.1101	0.2291	4.183
60	18.26	18.26	1.261	0.1101	0.2291	4.183
60	18.26	18.26	1.261	0.1101	0.2291	4.183
60	18.26	18.26	1.261	0.1101	0.2291	4.183
60	18.26	18.26	1.261	0.1101	0.2291	4.183
60	18.26	18.26	1.261	0.1101	0.2291	4.183

Total E = 40.43 MJ.ha^{-1}; I_{30} = 27.30 mm.hr^{-1}; Thus: EI_{30} = (40.43 x 27.30) = 1103 MJ.ha^{-1}.mm.hr^{-1}

* Due to the lack of rainfall intensity data, the assumption was made that an equal amount of rainfall (18.26 mm) came down during the last 6 hours of the cyclone event. Therefore, 110 mm of rainfall during the last 6 hours of the storm event was divided by 6 to obtain the rainfall intensity (I) in mm.hr^{-1}.

4.2 RUSLE erodibility results

Low to medium erodibility (K) values in the range of 0.074 to 0.147 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1} are common throughout the soils of the RDAC (Figure 4.2). The input data (texture, aggregate stability and percentage base saturation) necessary to determine the K values are shown in Table 4.3. The table shows the average and range, if available or applicable, for each of the erodibility input values mentioned above. Although not very obvious, the subsequent erodibility results tend to correspond with the input data. For example the *Sans Souci* and *Midlands* families of the HFL soil group, have higher K values (0.113 and 0.140 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1} respectively) than the *Belle Rive* family (0.074 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}) of the same soil group. The former two families have relatively high percentages of unstable aggregates (30 - 40%), whereas, the latter *Belle Rive* soil family has lower percentages (20%) of unstable aggregates, probably giving the relatively lower K value mentioned above. All three soil families share a base saturation value of 10%.
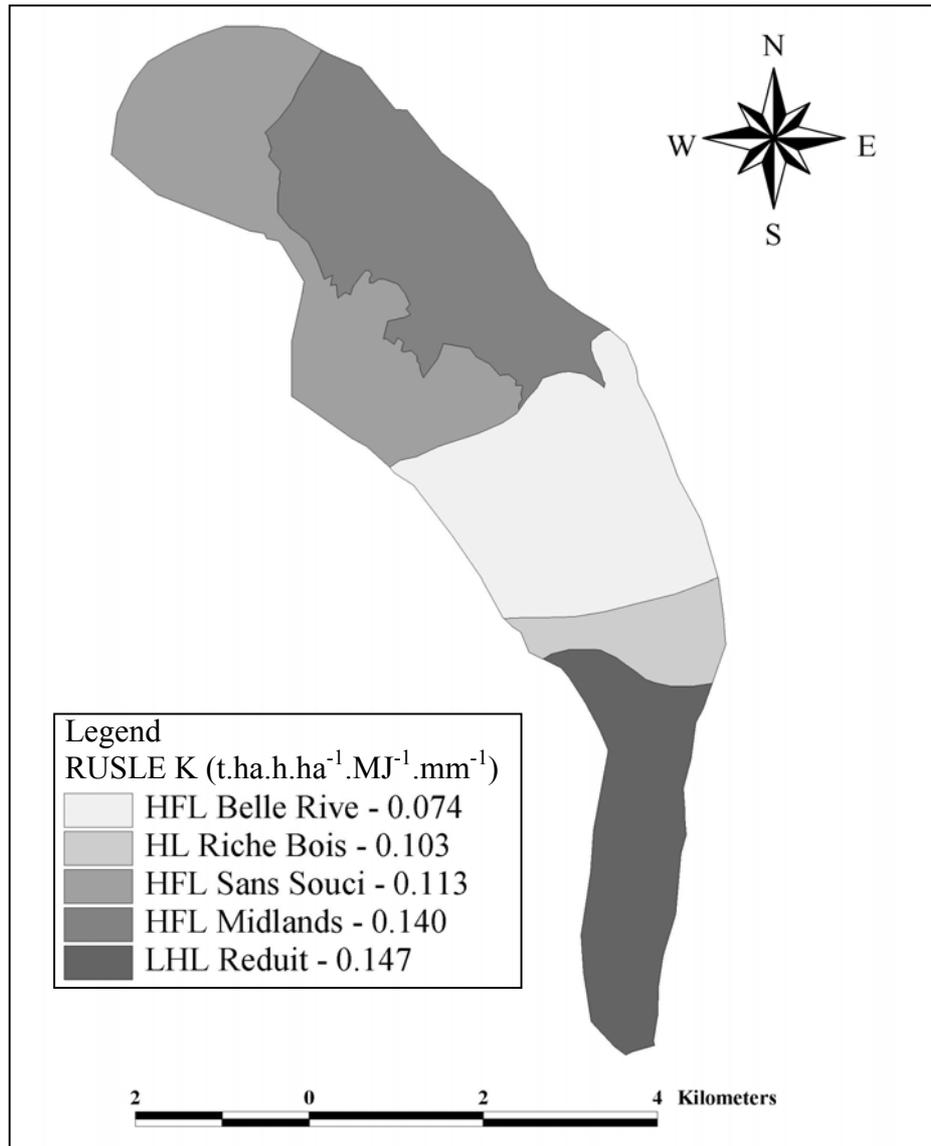
Figure 4.2:   RUSLE erodibility (K) for the soil types of the RDAC.

The K value (0.103 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}) of the HL *Riche Bois* soil is similar to the K value (0.113 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}) of the HFL *Sans Souci* family mentioned above, despite dissimilar soil properties. For example, the former soil have relatively high silt contents (average 23.70%), but low percentages of unstable aggregates (15%); whereas the latter *Sans Souci* family has a lower average percentage of silt sized particles (10.02%), and a relatively high percentage of unstable aggregates (30%). These two soil characteristics seem to mutually be responsible for giving similar K values. Likewise, the LHL *Reduit* soil, with a K value of 0.147 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}, is comparable in erodibility to the HFL *Midlands* soil family. However, the above mentioned soils also differ in their percentage base saturation values. For example, the HL *Riche Bois* and LHL *Reduit* soil families have higher (32% and 56%) base saturation values than the HFL *Sans Souci* and *Midland* soil families (both 10%). The

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interrelationship of the erodibility factors seems to be more complex than simply comparing two soil properties or input values (see Discussion). Results of the following physical soil properties complement above mentioned erodibility results.

Table 4.3:   Input data necessary to determine RULSE erodibility (K) values.

Soil group	Low Humic Latosol (LHL)		Humic Latosol (HL)		Humic Ferruginous Latosol (HFL)					
Soil family	Reduit		Riche Bois		Belle Rive		Sans Souci		Midlands	
Range (R) & Average (A)	R	A	R	A	R	A	R	A	R	A
Unstable Aggregates (%)	-	15	-	15	-	20	-	30	-	40
Base Saturation (%) [1]	-	56	-	32	-	10	-	10	-	10
Silt sized particles (%)	19.24-28.02	24.11	22.41-25.06	23.70	22.20-30.11	26.10	7.01-15.22	10.02	14.23-15.00	14.06
Sand >100 microns (%)	3.33–8.78	5.54	3.77-7.76	5.48	3.60-7.11	4.80	-	4.44	-	4.07
Very fine sand (%)	2.09–5.31	3.20	2.13-5.17	3.39	2.70-4.47	3.17	2.00-3.00	2.52	1.50-2.50	1.97

1. Parish and Feillafe (1965).

4.2.1. Cumulative percentage frequency curves

Particle size distributions for each soil family in the RDAC are illustrated in Figure 4.3, while the particle size distributions for each sample are given in Appendix 6. Particle size distributions are presented as sigmoidal cumulative curves on a logarithmic scale, phi. Graphs depict the percentages coarser than a given grain size on a cumulative scale. The distributional shape for each soil is not noticeably different. However, according to the Kolmogorov Smirnov Test (Briggs, 1977b) (not shown) none of the different soil groups are from the same population. Statistical results (Table 4.4) show that all the soil groups are poorly to very poorly sorted, and positively or very positively skewed. The mean phi size varies between –0.79 and –1.08. The skewness and mean phi size of the HFL soils are slightly higher than the LHL soils.
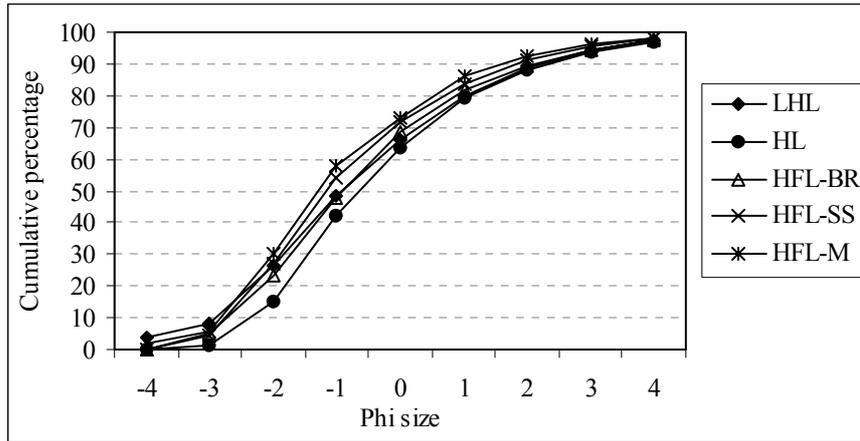
Figure 4.3:   Particle size distributions for each soil family in the RDAC.

Table 4.4:   Mean, skewness and sorting for each soil family in the RDAC.

Soil group	Soil family	Mean	Skewness	Sorting
Low Humic Latosol (LHL)	*Reduit*	-0.78	0.15	1.98
Humic Latosol (HL)	*Riche Bois*	-0.43	0.29	1.81
	Belle Rive	-0.76	0.26	1.80
Humic Ferrigenous Latsosol (HFL)	*Sans Souci*	-0.88	0.35	1.79
	Midlands	-1.07	0.35	1.70

4.2.2. Results of other indices of soil erodibility

Other indices of soil erodibility include infiltration rate, organic matter content, soil structure, shear strength, bulk density, and moisture content. These results are shown in Table 4.5. The table shows the average and range, if available or applicable, for each of the indices mentioned above.   A comparative description of the indices follows.

Infiltration rates for the each of the soils in the RDAC are shown according to the classification system adopted from Renard *et al*. (1994). In addition, graphs illustrating the infiltration rates are shown in Appendix 7. These results clearly illustrate that LHL soils have the slowest basic infiltration rate (7.5 mm.hr^{-1}). The HL *Riche Bois* soil family and the HFL *Belle Rive* family have slow to moderate infiltration rates of 15.00 mm.hr^{-1} and 20.00 mm.hr^{-1}, respectively. The *Midlands* and *Sans Souci* families of the HFL soilgroup have moderate to rapid infiltration rates of 24.15 and 36.50 mm.hr^{-1}, respectively.

The amount of organic matter in soils varies from 4.7% for the coastal LHL soils, to a significantly higher 10.4% for the inland *Midlands* family of the HFL soil group. It should be

Table 4.5:   Additional indices of soil erodibility (infiltration rate, organic matter content, soil structure, shear strength, bulk density, and moisture content).

Soil group	Low Humic Latosol (LHL)		Humic Latosol (HL)		Humic Ferruginous Latosol (HFL)					
Soil family	*Reduit*		*Riche Bois*		*Belle Rive*		*Sans Souci*		*Midlands*	
Range (R) & Average (A)	R	A	R	A	R	A	R	A	R	A
Texture	silty clay		silty clay		silty clay loam		sandy clay loam		sandy loam	
Infiltration rate (mm.hr^{-1})	5.00-7.50	7.50	7.00-42.00	20.00	8.65-27.00	15.00	11.00-60.00	36.50	5.00-55.00	24.15
Infiltration rate (very slow-rapid) [1]	Slow		slow-moderate		slow-moderate		rapid		moderate-rapid	
Soil depth [2]	deep – moderately deep		deep – moderately deep		deep		deep		deep	
Bulk density (g.cm^{-3})	0.74-1.15	0.98	1.05-1.60	1.13	0.70-1.94	1.10	-	-	0.60-1.51	0.93
Shear strength (kg.cm^{-2})	0.00-1.80	0.28	0.00-1.00	0.47	0.00-1.60	0.40	-	-	0.00-1.40	0.27
Organic matter content (%) [2]	4.7		6.3		6.9		8.6		10.4	
Structure [2]	fine granular – medium crumb		weakly crumb		weak coarse granular		strong crumb		coarse granular	
Moisture content Nov-Dec 2001 (%)	4.38-15.16	9.77	5.12-18.46	11.79	4.62-19.46	12.04	-	-	-	6.49

1. Infiltration rate classification adopted from Renard *et al*. (1994).

2. Parish and Feillafe (1965).

noted from the outset that the *Midlands* and *Sans Souci* families of the HFL soil group are mostly under forest, scrub and tea plantations.

Results in Table 4.5 indicates that the HL *Riche Bois* and HFL *Belle Rive* soils have slightly higher shear strengths (above 0.40 kg.cm^{-2}) compared to the other soils (below 0.30 kg.cm^{-2}) in the RDAC. The average shear strength readings of the HFL *Midlands* family were similar to those of the LHL *Reduit* family at 0.27 kg.cm^{-2} and 0.28 kg.cm^{-2}, respectively. Whereas the average shear strength readings of the HL *Riche Bois* and HFL *Belle Rive* families compare at 0.47 kg.cm^{-2} and 0.40 kg.cm^{-2}, respectively.

There seems to be a slight indication of correspondence between shear strengths and bulk densities. As expected, soils with relatively low shear strength also have a relatively low bulk density. The HL *Riche Bois* and HFL *Belle Rive* soil families with the highest shear strengths, have the highest bulk densities (1.10 g.cm^{-3} and 1.13 g.cm^{-3}, respectively). According to the results given above, these soils are also less erodible (0.074 and 0.103 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}). Moreover, the LHL *Reduit* and HFL *Midlands* families have lower shear strength values, corresponding with lower bulk density values (0.98 g.cm^{-3} and g.cm^{-3}, respectively). These soil families are more erodible (0.113, 0.140, and 0.147 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}) when compared to the former two soil families.

The average soil water contents determined at the time (November to December 2001) varied between 6.49% and 12.04% (Table 4.5).

No clear trend is noticed between the indices of soil erodibility given above. In general, it seems that soil with high percentages of unstable aggregates or a high silt content, have low bulk densities and shear strength, making it more erodible than its counterpart, for which the opposite is true. However, the results above do not always clearly illustrate the correspondence between the soil properties and soil erodibility. Results rather illustrate the interrelationship and complexity between soil properties and soil erodibility. These interrelationships may also be affected or determined by other soil erosion factors, such as the topography and land use described below.

4.3 RUSLE cover management input data

Land use data required for determining the C and P factor values for the RUSLE and SLEMSA are extensive and are therefore listed in Appendix 2 and 4, respectively. The data set for the RUSLE consists of input values for infrequently disturbed land use types, as well as data for frequently disturbed land use types. As stated in chapter 3, infrequently disturbed land use types for the RDAC include banana – tea – forest plantations and scrub. Frequent disturbed land use types include sugarcane, intercropped cane and pure stand vegetables. Results in Appendix 2 reveal the differences between infrequently disturbed land use types and frequently disturbed land use types.

Table 1 in Appendix 2 shows the input parameters describing the infrequently disturbed land use types. These input parameters are average annual values that do not vary significantly throughout the year and include the following: effective root mass (lb.ac^{-1}) in the top 4 inches (10 cm); percentage canopy cover, average fall height (ft); roughness for the field condition; number of years needed for the soil to consolidate; time since the last disturbance; and total percentage ground cover, including rock and residue.

Frequently disturbed land use types are characterised by a similar set of input parameters as mentioned above. Added to the frequently disturbed land use dataset are the date and type of field operations for each of the frequently disturbed crops (Table 4 in Appendix 2). However, these parameters change throughout the year, as shown in Table 5, 7 and 9 in Appendix 2. Changes in the vegetation are depicted according to four crop stages. The values are expressed in U.S. customary units for use in the RUSLE. The canopy cover, fall height and residue amount represent the most noticeable changes. For example the canopy and fall height for every crop increase in the first and second growth stages. The residue amount however shows a cyclical pattern. These patterns occur in relation to the field operations, together with the vegetation characteristics mentioned above. Such patterns are especially important for calculation of the cover management value, C.

4.3.1. Cover management factor results

Table 4.6 represents a list of the defined land covers and their related C factor values. Additionally, Figure 4.4 illustrates the distribution of the main land use types currently found in the RDAC, with their associated average C factor values. Only average data for each land use type is presented here.
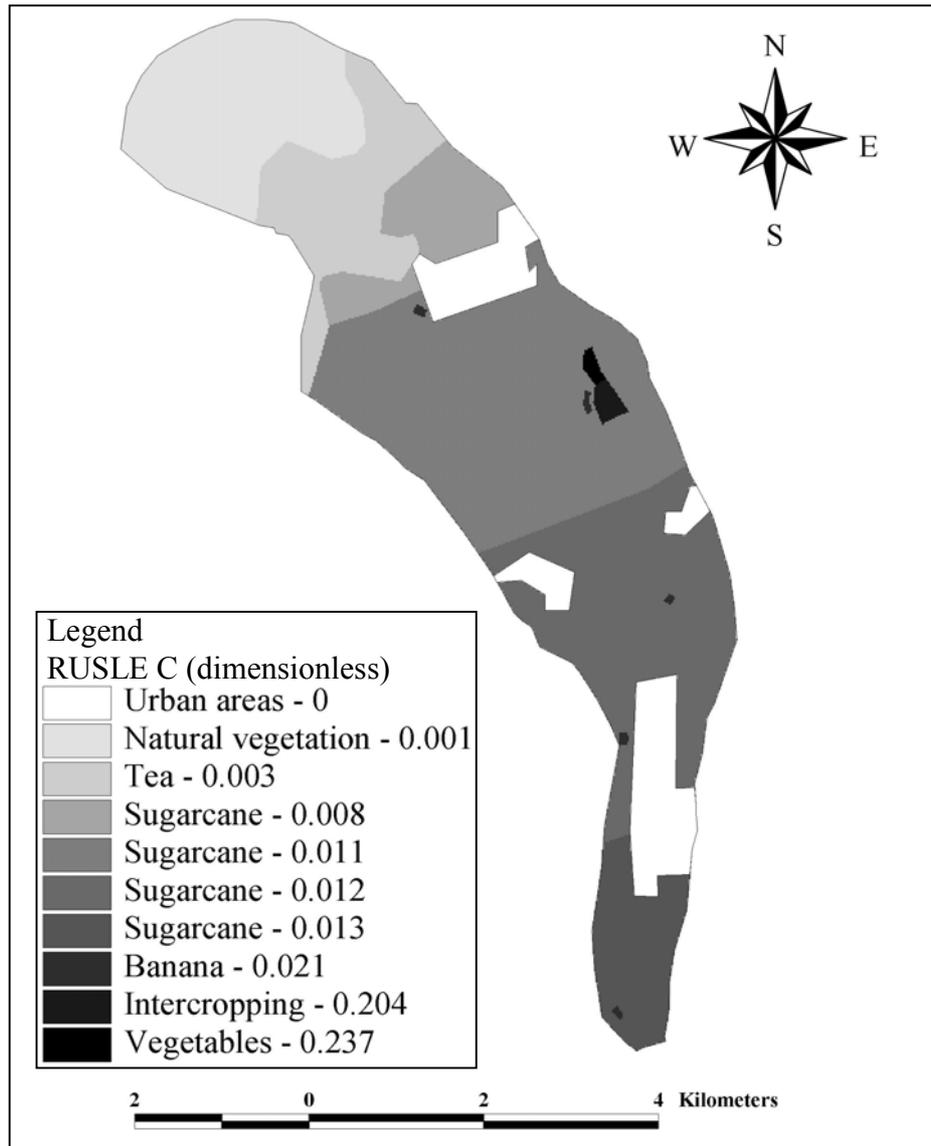
Figure 4.4:   RULSE cover management (C) map of the defined land use type in the RDAC.

Table 4.6:   RUSLE cover management (C) values (dimensionless) for each defined land
use type in the RDAC.

RUSLE Factor	Sugar-cane	Inter-crop	Veget-ables	Banana	Tea	Scrub	Forest	Urban	Pine-apple
C	0.0110	0.2043	0.2374	0.2140	0.0026	0.0010 [1]	0.0010 [1]	0.0000 [2]	0.3000 [3]

1. Approximate value obtained by comparison from: Roose (1975 cited in Bergsma *et al*., 1996: 87);
   Elwell, (1976); Wischmeier and Smith (1978); Donald (1997).

2. Urban areas are assumed to have complete cover, and assigned to a value of 0.

3. Approximate value obtained by comparison from: Roose (1975 cited in Bergsma *et al*., 1996: 87);
   Elwell (1976); McPhee & Smithen (1984); Cooley and Williams (1985 cited in El-Swaify *et al*., 1985: 509).

In the light of these results, scrub and forested areas in the upper catchment have the lowest C values (0.0010), followed by tea (0.0026), sugarcane (0.0110), banana (0.2140), intercrop (0.2043), and vegetables (0.2374).   The highest C values are ascribed to the frequently disturbed land use types, whereas the lowest C values are ascribed to the infrequently disturbed land use types. No cultivation of pineapple is currently taking place in the study area. The C value for pineapple, established from literature sources, is the highest at 0.3000.

4.3.2. Soil loss ratios (SLR)

The average soil loss ratios (SLR) of the three frequently disturbed land use types; sugarcane, intercropped cane, and vegetables, are displayed in Figure 4.5.
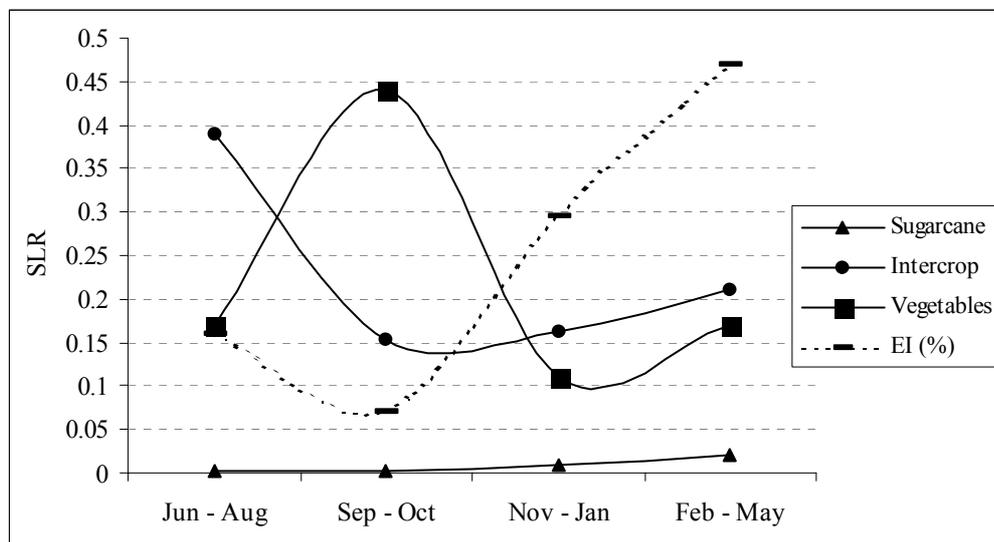
Figure 4.5:   The average soil loss ratios (SLR) of the three frequently disturbed land use types; sugarcane, intercropped cane, and vegetables.

Average SLR values for these crops are displayed according to four crop stages. This graph illustrates the changes in soil loss due to the effect of the erosivity factor as a percentage of EI_{30} throughout the year. In other words, SLR varies according to the effect of different crop stages in correspondence with EI%. High C values are expected early in the growing season when the SLR values are high, but are much lower when crops reach full canopy. In general, the peak canopy cover for sugarcane and intercropped cane range from the second growth stage (November to January) to the mature growth stage (February to May). The peak canopy values range from 75-100% and 70-90%, respectively. Vegetables are harvested and replanted

twice a year. Therefore, vegetables have a peak canopy cover of between 60-75% in April, and again in November.

The SLR for sugarcane is low throughout the year, varying from 0 (2 x 10^{-3}) to 0.02. The crop experiences a slight increase in its SLR as rainfall and EI% increase over the wet summer months from November up to May. Intercropped cane seems to correspond well with EI%. This crop begins with a relatively high SLR of 0.39 during the harvest - soil preparation – and planting season in June through to August. As crop establishment takes place between September and October, SLR values decrease substantially. The SLR value finally increases to a value of 0.21 in correspondence with an increasing EI%. Vegetables start off with a relatively low SLR (0.17) in the dry winter months between June to August. Thereafter, vegetables experience a substantial increase (0.17 to 0.44) in the SLR from September to October, despite the decrease in EI% during the same time period. Towards November, as the crop grows and establishes, the SLR drops back to a much lower value of 0.11. When EI% increases to its highest (47%) over the rainy season, SLR increases slightly to 0.21. November to May covers a significant period of the erosive rains.   During this period, SLR values for every crop increase.

4.4 RUSLE support practice input data

Table 2 in Appendix 2 shows the input data for estimating the P value of infrequently disturbed land use types. These input parameters are average annual values and do not vary significantly throughout the year. The input parameters required for determining P are not applicable to scrub and forested areas. A value of 1 is assigned for scenarios with no support practice. The input parameters for banana and tea plantations include the following: the furrow grade in percent; a description of the micro topography as the equivalent slope in percent; a hydrology class; the cover at disturbance and at soil consolidation; a roughness code at disturbance and at consolidation; the number of years since the last disturbance; and the number of years for the soil to consolidate.

As with the crop management factor C, input parameters for determining the P value differ slightly for frequently disturbed land use types. These parameters change throughout the year, as shown in Table 6, 8 and 10 in Appendix 2. The changes of the parameters are also depicted according to four crop stages. Values are expressed in U.S. customary units for use in the RUSLE. Ridge height represents the most noticeable changes. For example, ridge height for

all crops is high after soil preparation and planting. After tillage the ridge height decreases towards the mature growth stage. It is established that P varies mostly according to the ridge height of contour farming, and where no tillage practices were applied. Thus, these patterns in ridge height are particularly important for calculation of the support practice factor P.

Results for the buffer strips are not included in the input parameter dataset. Results from RUSLE do not indicate the effect on soil loss where buffer strips *Maguet* or *Vetiver* occur. A P value of 1 is used for the buffer strips since they provide little protection to the majority of the field.

4.4.1. Support practice factor results

The support practice factor values of the main land cover types accounted for in the catchment are shown in Table 4.7. As with the C factor, Figure 4.6 clearly illustrates the distribution of the main land use types in the RDAC, with their associated average P factor values.

Table 4.7:   RUSLE support practice (P) values (dimensionless) for each defined land use
              type in the RDAC.

RUSLE Factor	Sugar-cane	Inter-crop	Veget-ables	Banana	Tea	Scrub	Forest	Urban	Pine-apple
P	0.7509	0.6250	0.9470	1.0000	1.0000	1.0000 [1]	1.0000 [1]	1.0000 [1]	0.3540 [2]

1. Value of 1 assigned to no support practice.

2. High support practice scenario estimated with RUSLE.

P values range from 0.3540 (a high support practice scenario) to 1 (no support practice).   As results show, pineapple has the lowest P value, as estimated by the RUSLE. The lowest P values are ascribed to the frequently disturbed land use types, whereas the highest value of 1 is ascribed to the infrequently disturbed land use types.
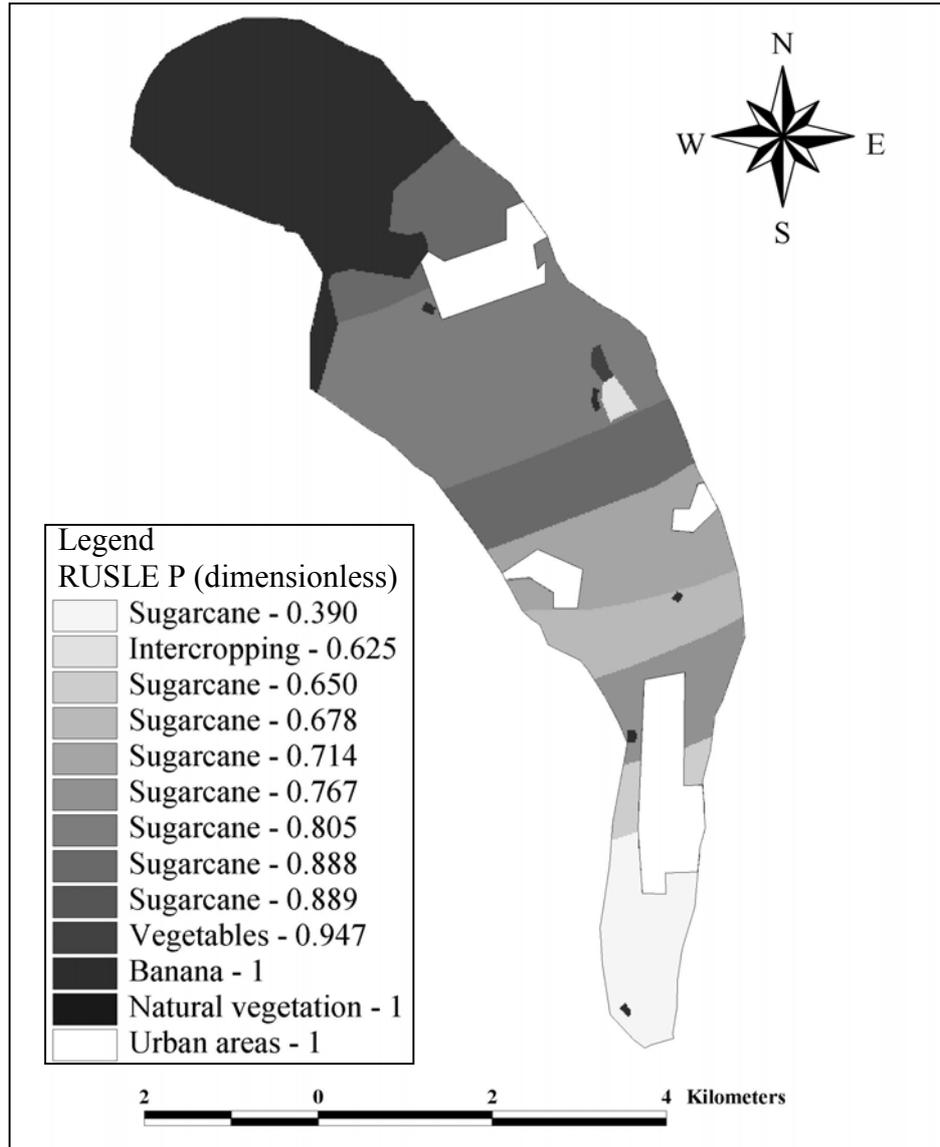
Figure 4.6:   RULSE support practice (P) map of the defined land use types in the RDAC.

4.5 Topography factors

A DEM of the RDAC is shown in Figure 4.7. The RDAC runs from sea level to an elevation of approximately 650 m a.s.l. Slope percentages for the catchment with classes adopted from Bergsma *et al*. (1996) is shown in Figure 4.8.
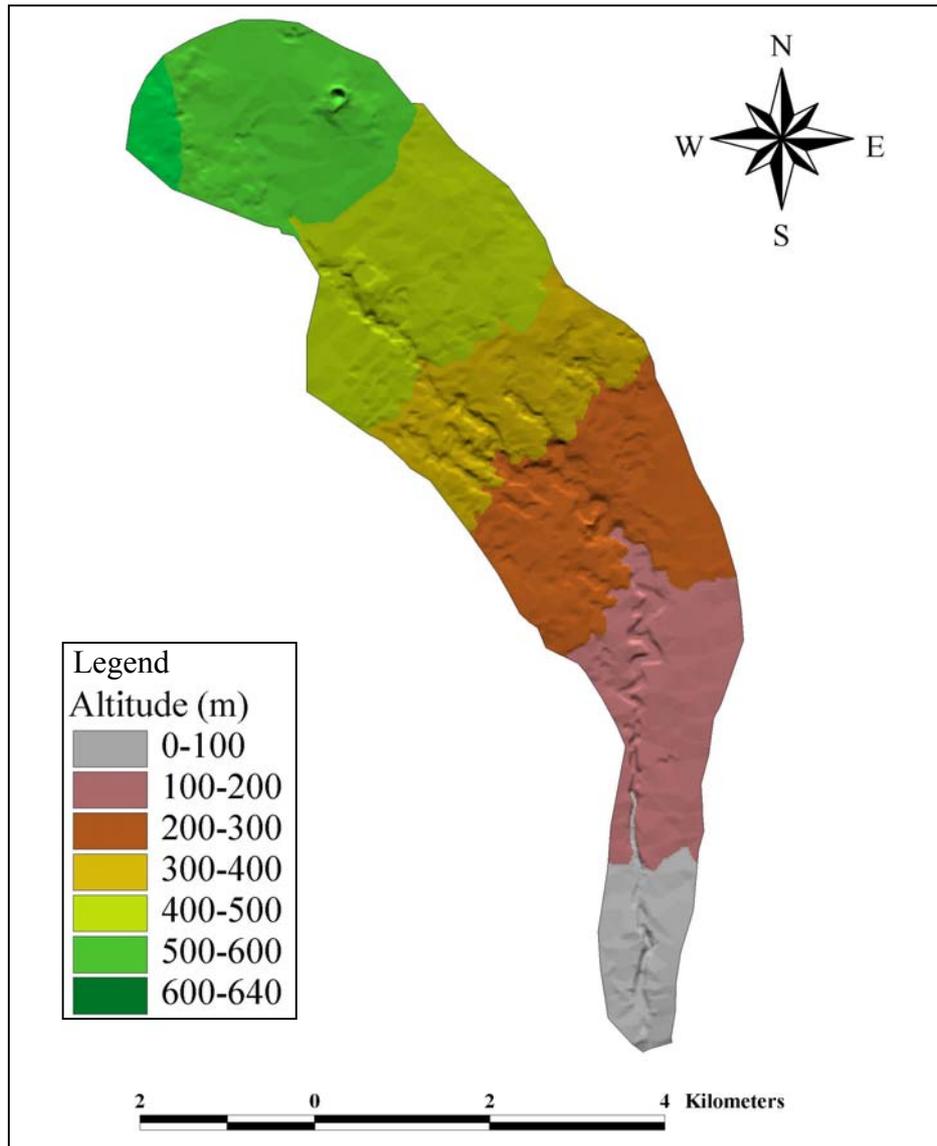
Figure 4.7:   Digital elevation model (DEM) of the RDAC.

Using SEAGIS, the DEM of the catchment shows a maximum slope of 39% and a minimum less than 2%. Most of the slopes in the catchment are gently - to strongly undulating ranging from 2 to 6%. Not clearly illustrated on these maps is the micro topography of the catchment. Field investigations confirmed that most of the sugarcane fields have uniform slopes that are dissected by dirt roads.   Scrub and forested areas have complex or nonuniform slopes, classified as strongly rolling (10-16%) and hilly (16-25%). Valley sides are steep to very steep, slopes ranging from 10 up to 40%. The slope factor map proves to be a valuable descriptor of local topography and is especially helpful for deriving the LS and X factors.
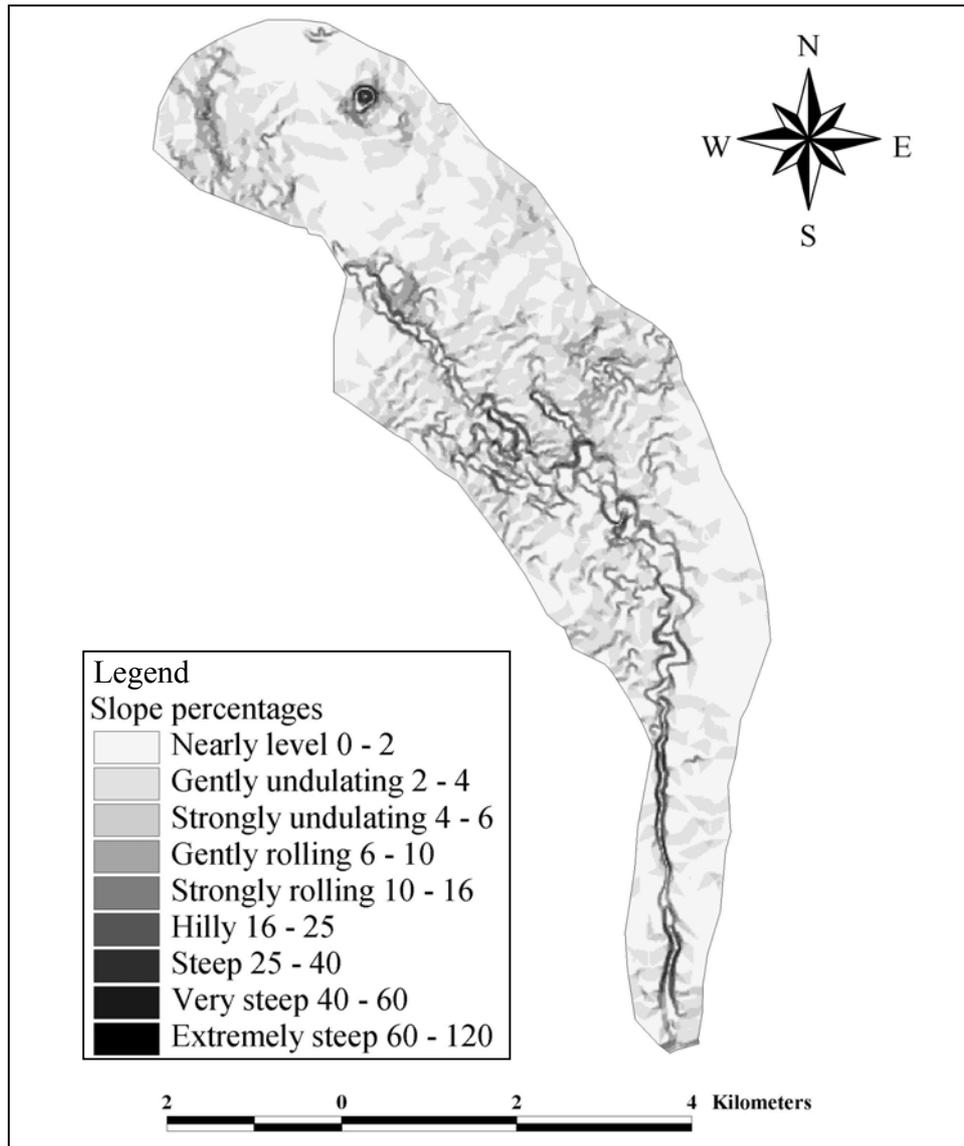
Figure 4.8:   Slope percentages map of the RDAC.

RUSLE LS factor values for the catchment are illustrated in Figure 4.9 and SLEMSA X factor values are illustrated in Figure 4.10. Both the LS and X factor values correspond with the percentage slope values given in the slope factor map. Therefore, high (4-6) and very high (above 6) LS factor values were computed for slopes of the RDA valley, as well as for a section of the forested upper slopes of the catchment. Likewise, the X factor values for SLEMSA are high for the slopes of the RDA valley, and also for the upper slopes of the catchment. Moderate and high slope factor values occur in the poorly covered vegetable plot. Most of the catchment, however, appears to have low LS (0-2) and X (0-4) factor values.
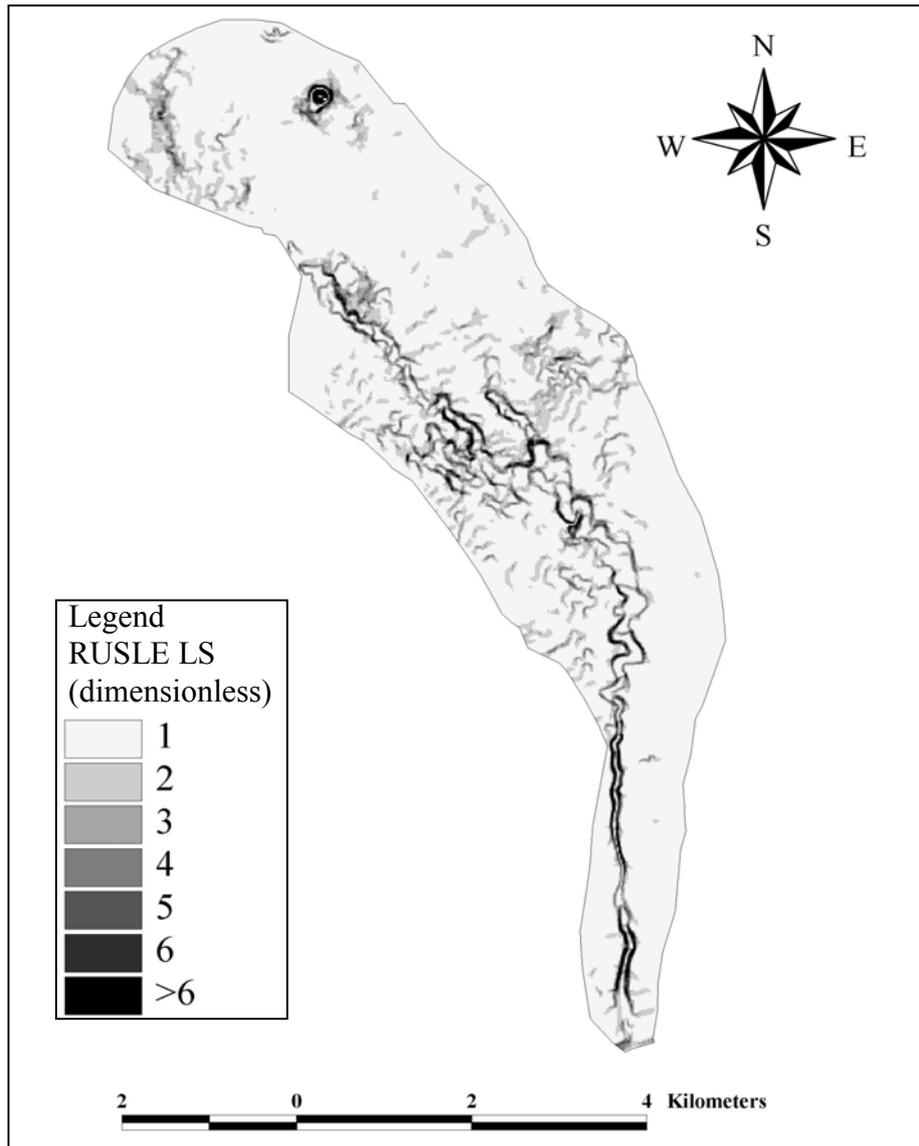
Figure 4.9:   RUSLE topographical factors (LS) map for the RDAC.

4.6 SLEMSA input data and factor values

The calculations and results for SLEMSA are discussed separately, since they are somewhat different compared to the computerized RUSLE. Input data required for each of the soil erosion factor values of SLEMSA (Z = K.C.X) are given below. SLEMSA input data and results are categorised according to the soil erosion factors including the soil factor K, the crop cover factor C, and the slope factor X. Calculations and results for the factors K and C of SLEMSA are shown in Appendix 4. Also included are the rainfall energy factor E and the soil erodibility factor F. Calculations and results for each land unit are presented in Table 4 of Appendix 4.
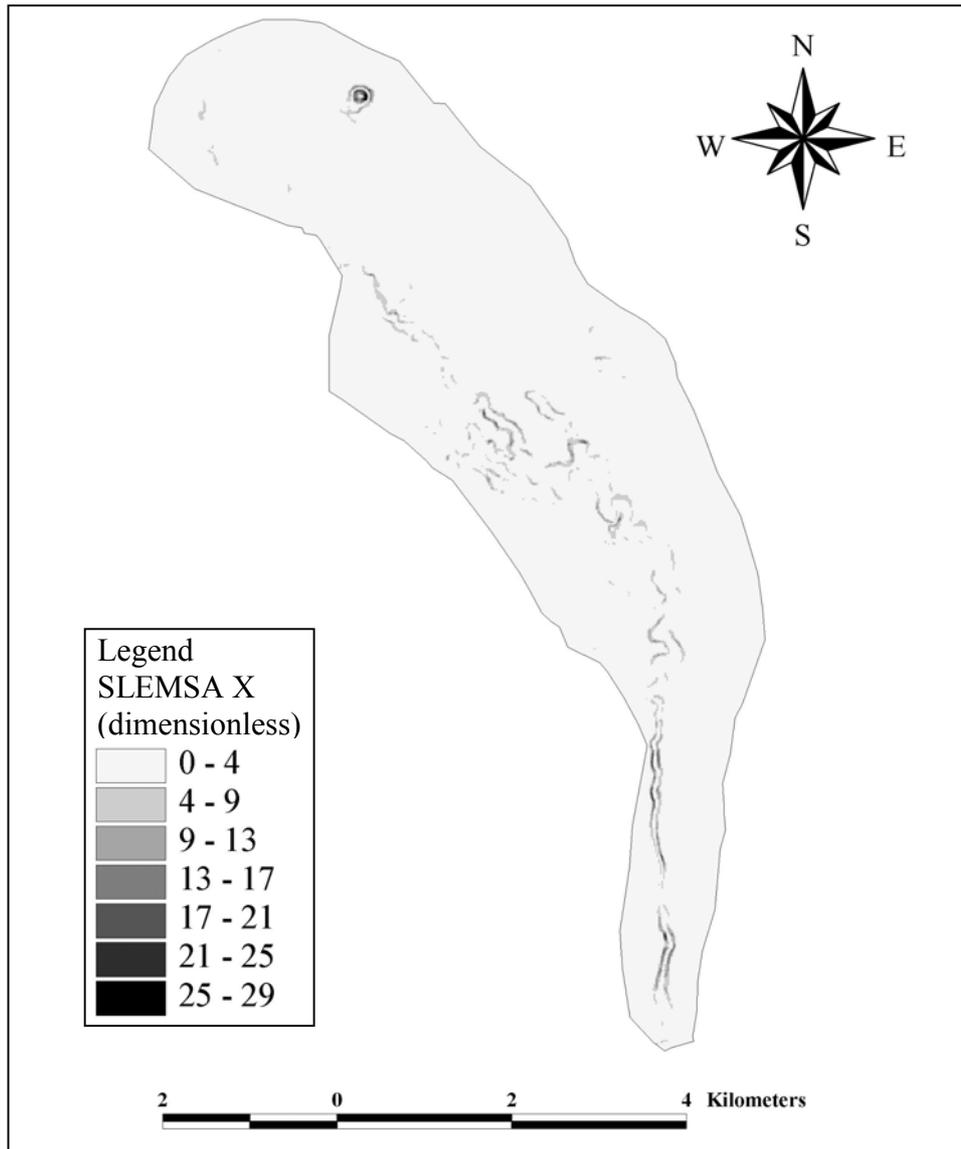
Figure 4.10:   SLEMSA slope factor (X) map for the RDAC.

4.6.1. SLEMSA rainfall energy factor E

Results for the SLEMSA E factor are illustrated in Figure 4.11. These results are in close correspondence with the annual rainfall amount for the catchment. As with the RUSLE erosivity factor R, the E value increases with altitude.
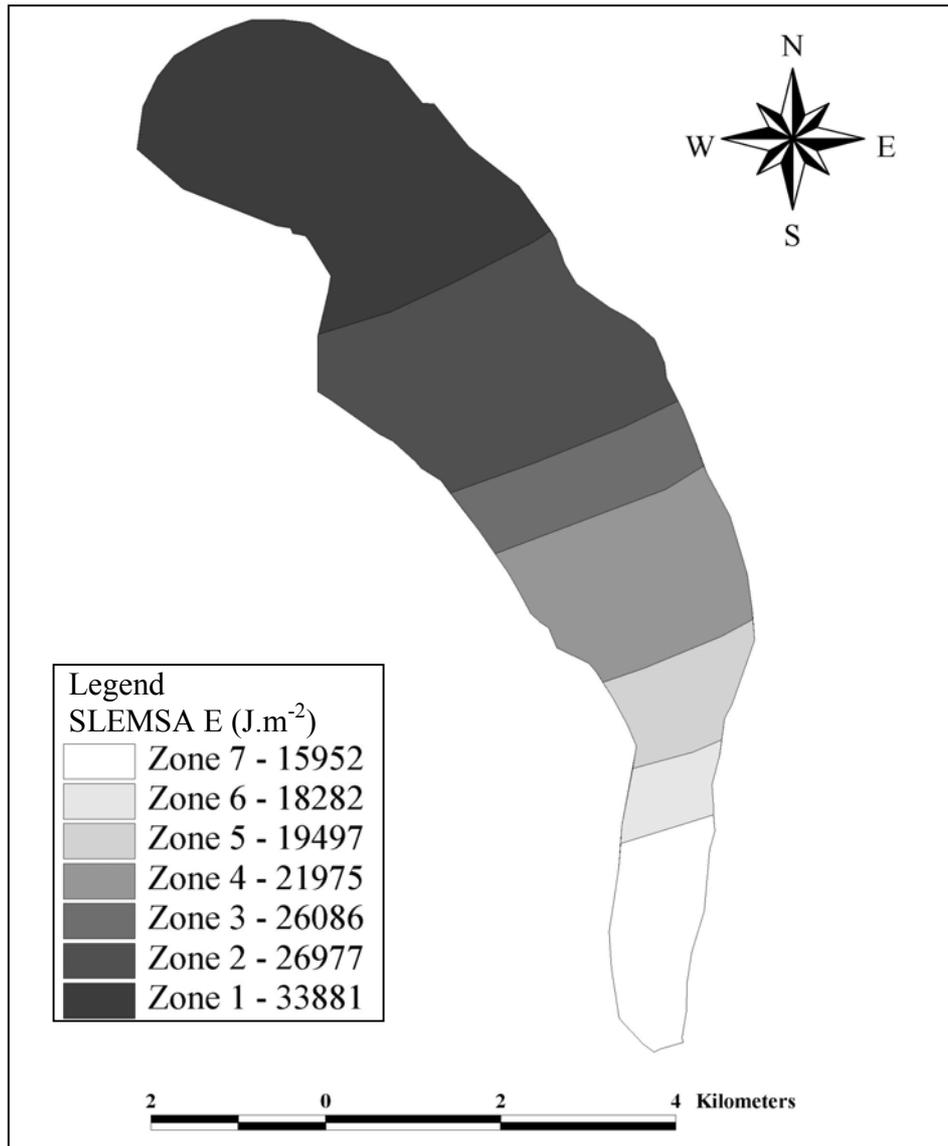
Figure 4.11:   SLEMSA rainfall energy factor (E) map for the rainfall zones of the RDAC.

4.6.2. SLEMSA soil erodibility factor F

Table 2 in Appendix 4 shows the soil indices affecting the soil erodibility factor F. The table indicates that only two soil indices affect the F value, including the soil texture and the permeability of the subsoil. The HFL *Midlands* family is the only soil that is classified as having a finer texture. All the other soils in the catchment have medium textures. The HFL soil families have slight restrictions in the permeability of the subsoil. The subsequent F values are illustrated in Figure 4.12. The map shows higher erodibility values in the south of the catchment (5) compared to the upper catchment area (4). These erodibility results therefore do not produce similar results given by the RUSLE. There are also management indices listed

in Table 3 in Appendix 4. The two management indices that affect the soil F values are contouring and no tillage.
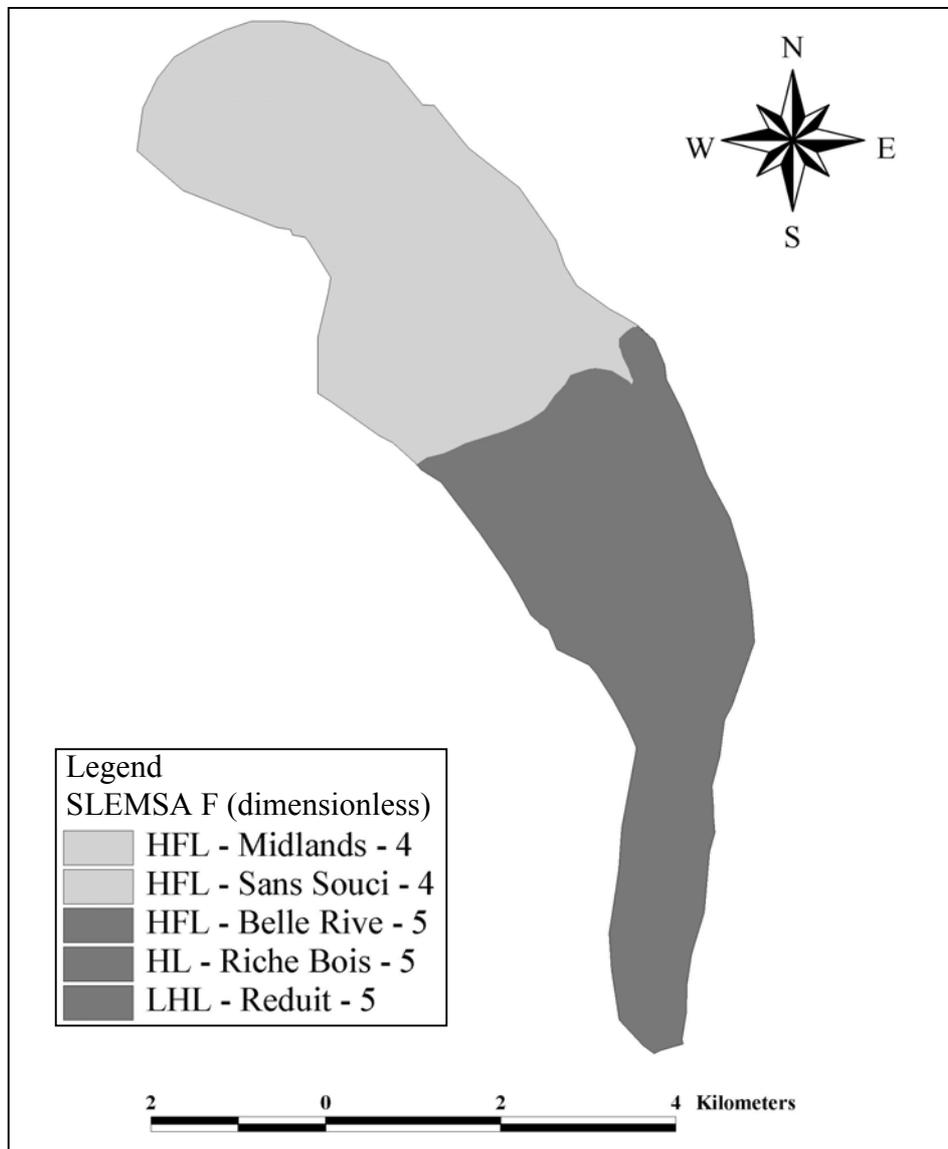
Figure 4.12:   SLEMSA soil erodibility factor (F) map for the soils of the RDAC.

4.6.3. SLEMSA soil factor K

The values of E and F are incorporated into the calculations shown in Table 4 in Appendix 4 to give the soil factor K (Figure 4.13). K values range from approximately 88 to 793 $t.ha^{-1}.yr^{-1}$ in a gradient from south to north. The K value therefore seems to be strongly affected by the rainfall energy factor.
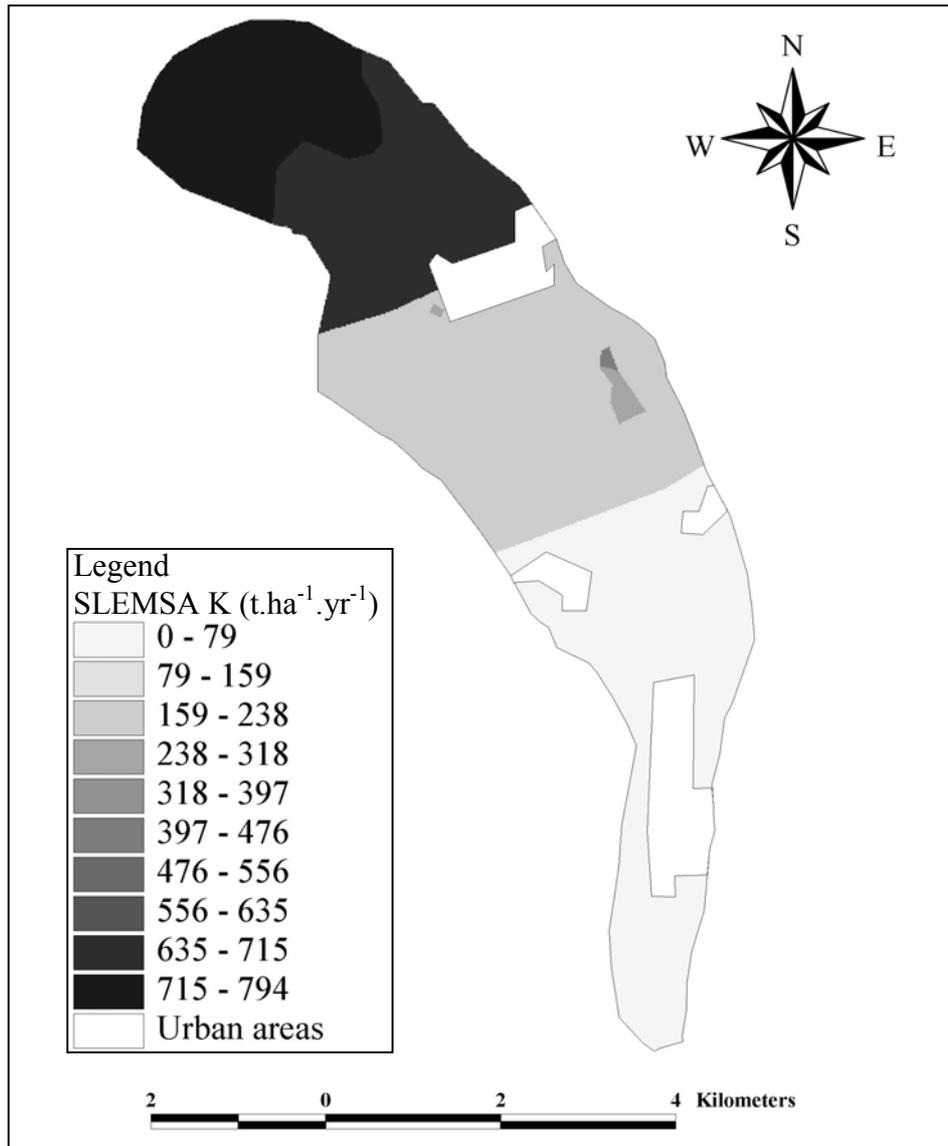
Figure 4.13:   SLEMSA soil factor (K) map of the RDAC.

4.6.4. SLEMSA crop cover factor C

Foremost, the characteristics for each crop and its growth stages requested by the SLEMSA model have been summarized in Table 5 in Appendix 4. The table shows the calculation and results of the C value. C is calculated in terms of the percentage rainfall intercepted by each crop stage. The crop cover factor is illustrated in Figure 4.14. The dimensionless C values range from 0.0433 for forest to 0.0665 for vegetables. It is noteworthy that the C value for vegetables is not as high as expected. Furthermore, there is not a marked difference in the C values between sugarcane, intercropped cane, tea - and banana plantations. The C value for urban areas is assigned 0.
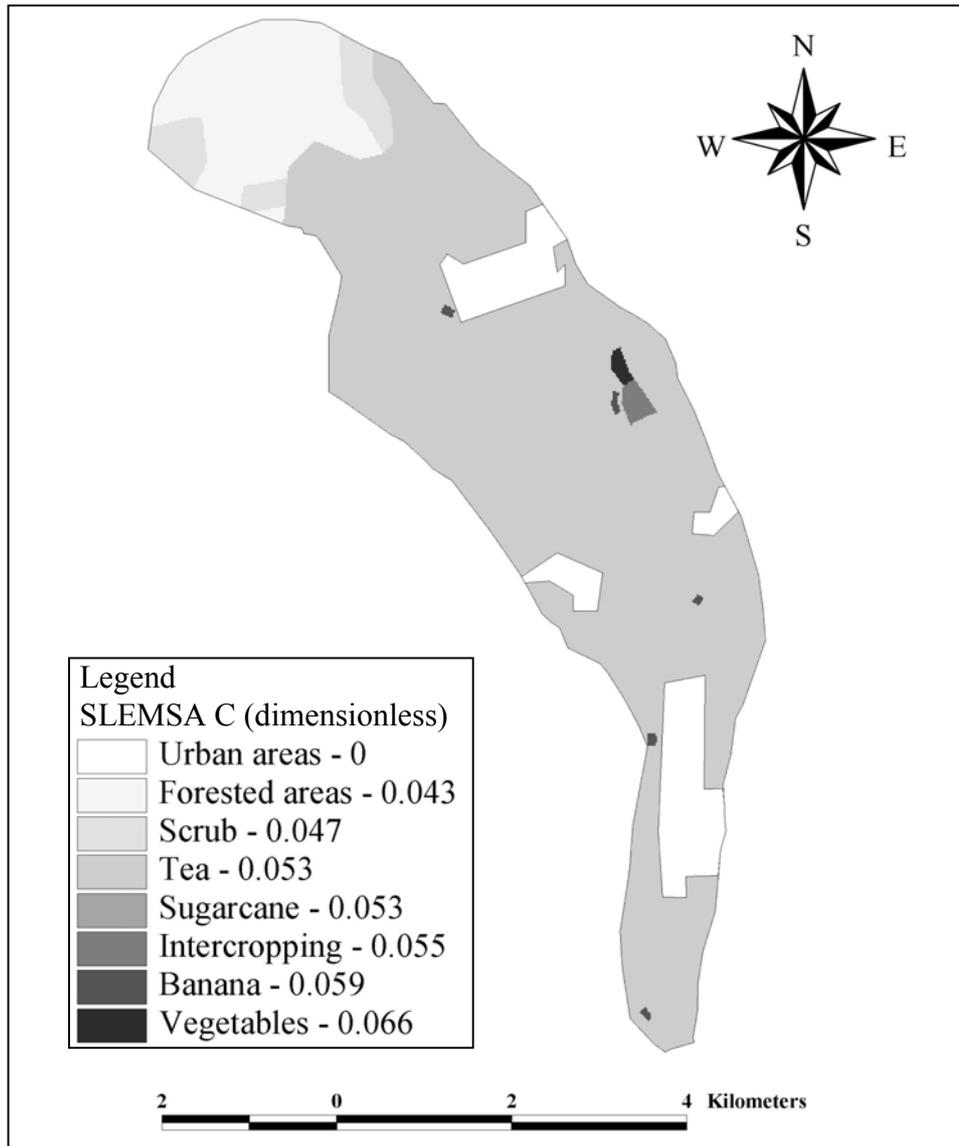
Figure 4.14:   SLEMSA crop cover factor (C) for the defined land use types of the RDAC.

4.7 Land units

Land units for the catchment are shown in Figure 4.15.   All these land units refer to subdivisions of land comprising different combinations (Table 4 of Appendix 4) of erosion factor values given above.   Thus, each land unit represents a unique value of the factors considered by the soil loss models RUSLE and SLEMSA.   Together, these land units represent the catchment.   Subsequently, the soil erosion factors of the RUSLE and SLEMSA were used to estimate the soil loss for 37 land units.   The sum of the erosion rates of these individual land units gives the soil loss for each land use.   Soil loss results are given below.
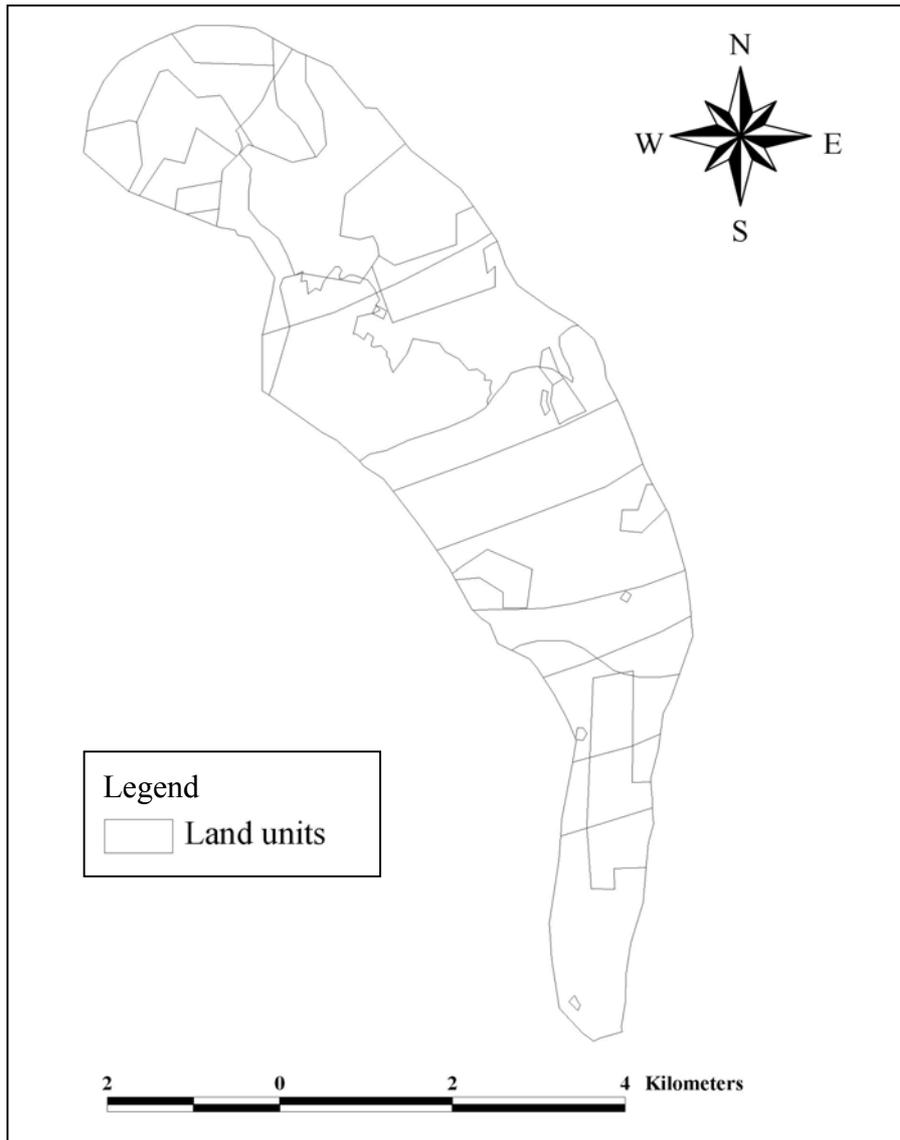
Figure 4.15:   Subdivisions of land (land units) in the RDAC comprising different combinations of soil erosion factors.

4.8 Soil loss results under current conditions

The end product of all the input data and erosion factors given above are presented below as a series of soil erosion prediction maps, tables and graphs. Erosion prediction maps show distribution of soil loss with low to very high soil loss classes adopted from (Bergsma *et al.*, 1996). Tables and graphs provide statistical descriptions of soil loss under different land use. An explanation of these results follows.

4.8.1. Soil erosion prediction maps for current conditions in the RDAC

The first set of maps illustrate soil erosion prediction under current conditions in the RDAC. Average annual soil losses (in $t.ha^{-1}$) as predicted by the RUSLE and SLEMSA are shown in Figure 4.16 and Figure 4.17, respectively. Figures 4.18 and 4.19 show the RUSLE and SLEMSA results of the SEAGIS application.   Statistics for these data are given in the following tables: Table 4.8 and 4.9 show the statistical results of soil loss values estimated by the RUSLE and SEAGIS-RUSLE application. Similarly, Tables 4.10 and 4.11 show the statistical data of the soil loss estimated by SLEMSA and the SEAGIS-SLEMSA application.

Soil loss results of both models for the current situation in the RDAC indicate a few crops with undesirable soil loss rates. Soil loss values of more than 80 $t.ha^{-1}.yr^{-1}$ are attained under the vegetable stand. Predictions indicate that intercropped sugarcane leads to values between 13 to 20 $t.ha^{-1}.yr^{-1}$. However, soil loss under sugarcane is minimal. The models predict soil loss under sugarcane below 2 $t.ha^{-1}.yr^{-1}$ to 10 $t.ha^{-1}.yr^{-1}$. Rates of less than 10 $t.ha^{-1}.yr^{-1}$ are found in natural vegetation, including scrub and forested areas. Although low rates under natural vegetation are not always the case for SLEMSA, predicting high erosion rates between 27 $t.ha^{-1}.yr^{-1}$ and 59 $t.ha^{-1}.yr^{-1}$. Erosion rates are in all cases lower under natural forest. Soil loss rates of 4 $t.ha^{-1}.yr^{-1}$ to 16 $t.ha^{-1}.yr^{-1}$ were predicted for land cultivated under banana plantations. Lastly, rates ranging from less than 1 $t.ha^{-1}.yr^{-1}$ to 41 $t.ha^{-1}.yr^{-1}$ were predicted for land cultivated under tea plantations.

Mean annual soil loss for the current situation in the RDAC is estimated at approximately 11 $t.ha^{-1}.yr^{-1}$ by RUSLE and the SEAGIS-RUSLE application. SLEMSA estimated 22 $t.ha^{-1}.yr^{-1}$ and SEAGIS-SLEMSA estimated 30 $t.ha^{-1}.yr^{-1}$. Total soil losses for each crop and for the catchment are also given in the above mentioned tables. The RUSLE predicts a total of 4229 tons of soil to be relocated by soil erosion under present land cover conditions in the RDAC. SLEMSA predicts the total to be 10 times higher at 46316 tons. These totals depend on the surface area covered by each land use. As stated in Chapter 2, sugarcane covers 2109 ha, approximately a third of the catchment area. Consequently, sugarcane contributes to most of the soil loss in the catchment (3158 tons predicted by the RUSLE). Mostly urban (347 ha) – tea (370 ha) - scrub (117 ha) – and forested (403 ha) areas cover the rest. Only small areas between 7 and 14 ha are cultivated under banana, intercropped cane and vegetables. Compared to sugarcane, the contribution to total soil loss under the vegetable stand is much less (610 tons predicted by the RUSLE), although the mean soil loss is significantly higher.
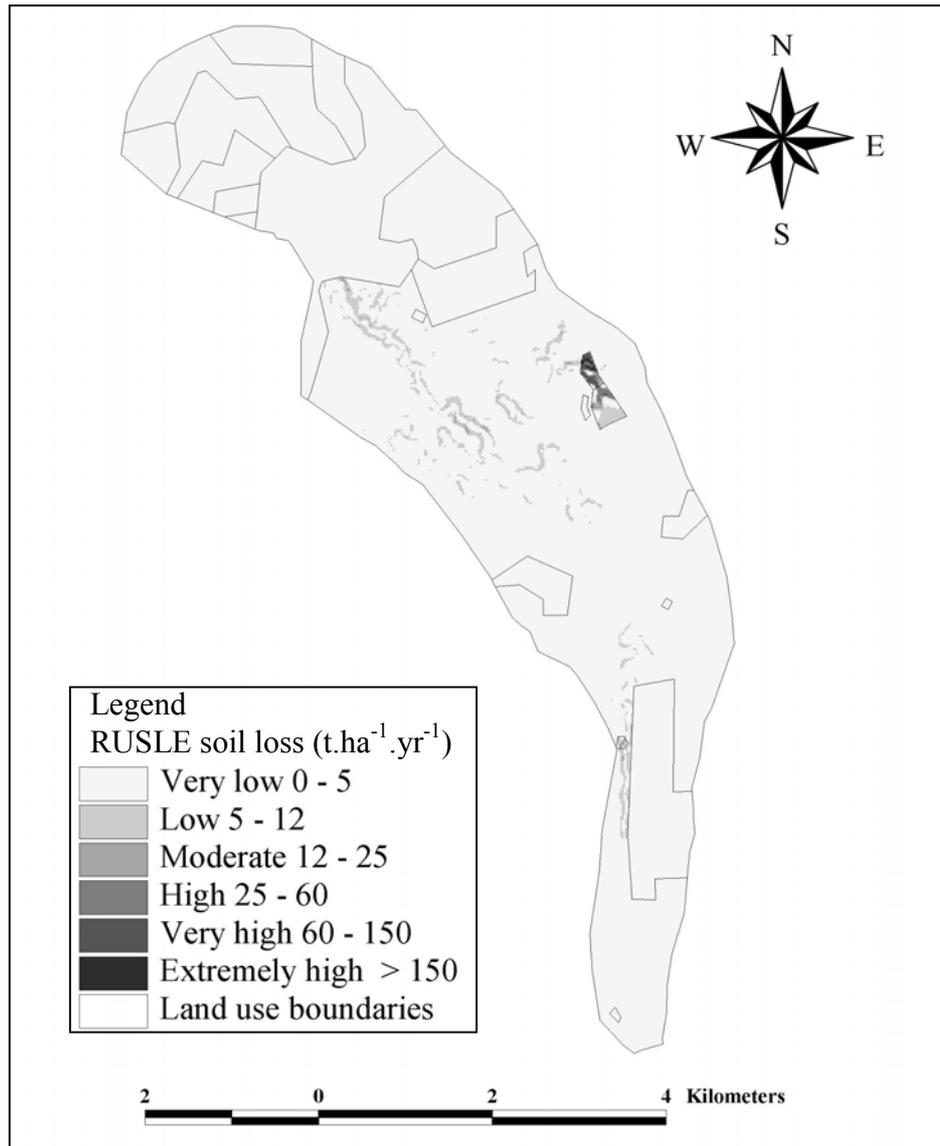
Figure 4.16:   RUSLE soil loss map for the RDAC under current conditions.

Table 4.8:   Statistical results of soil loss values estimated by the RUSLE.

Land use	Area (ha)	Min (t.ha^{-1}.yr^{-1})	Max (t.ha^{-1}.yr^{-1})	Range (t.ha^{-1}.yr^{-1})	Mean (t.ha^{-1}.yr^{-1})	STD (t.ha^{-1}.yr^{-1})	Total (t.yr^{-1})
Sugarcane	2109.16	0.01	17.55	17.54	1.46	1.77	3070.30
Intercropping	14.84	0.46	68.81	68.35	13.54	12.61	200.89
Vegetables	7.56	0.81	248.91	248.10	80.71	55.88	610.13
Banana	8.12	0.06	24.99	24.94	3.99	5.01	32.43
Tea	370.76	0.02	4.93	4.91	0.50	0.53	184.30
Scrub	117.64	0.01	4.34	4.33	0.41	0.56	47.97
Forestry	239.72	0.01	1.83	1.82	0.22	0.24	52.74
Natural forest	163.92	0.01	1.35	1.34	0.19	0.21	30.26
Urban	347.04	0.00	0.00	0.00	0.00	0.00	0.00
Catchment	3378.76	0.00	248.91	248.91	11.22	8.53	4229.04
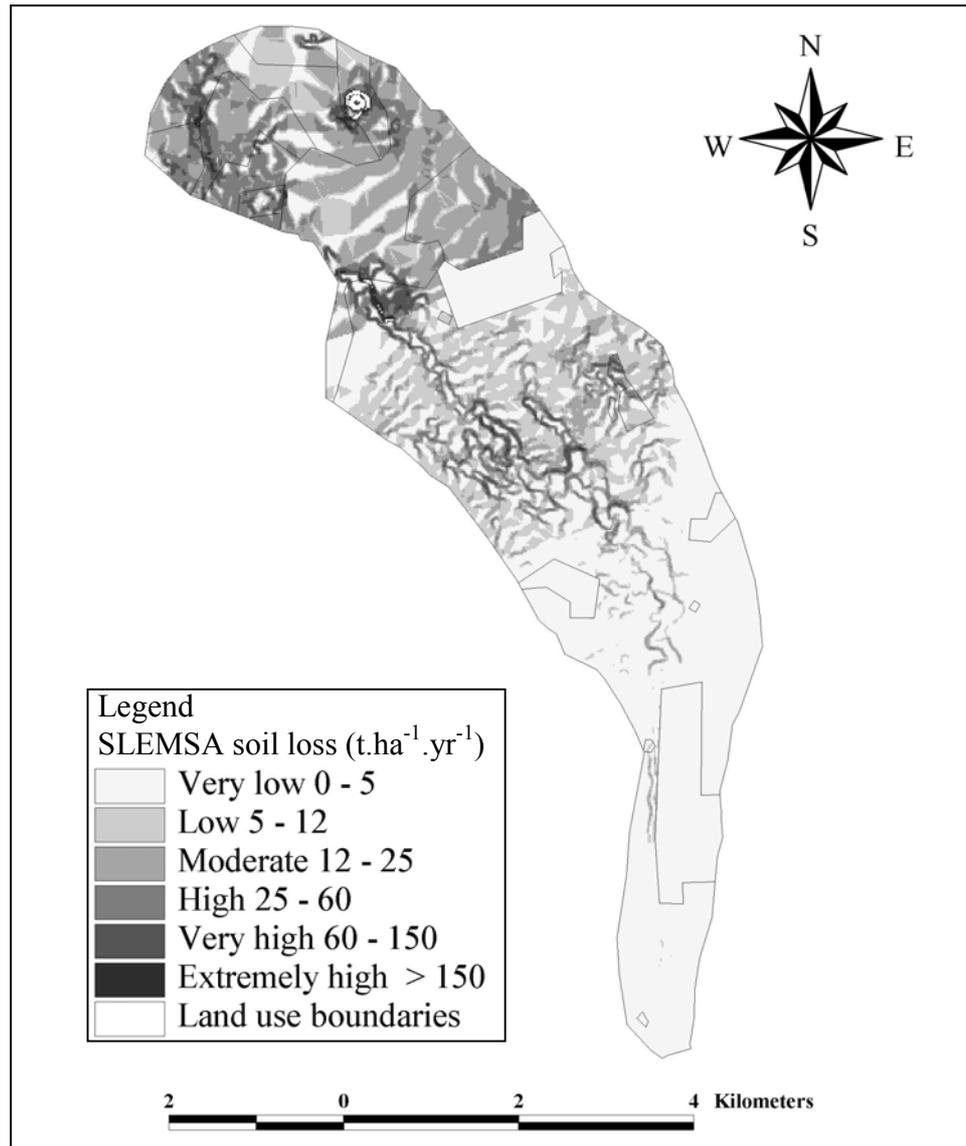
Figure 4.17:   SLEMSA soil loss map for the RDAC under current conditions.

Table 4.9:   Statistical results of soil loss values estimated by the SLEMSA.

Land use	Area (ha)	Min (t.ha^{-1}.yr^{-1})	Max (t.ha^{-1}.yr^{-1})	Range (t.ha^{-1}.yr^{-1})	Mean (t.ha^{-1}.yr^{-1})	STD (t.ha^{-1}.yr^{-1})	Total (t.yr^{-1})
Sugarcane	2109.16	0.05	468.06	468.02	10.13	19.11	21357.99
Intercropping	14.84	2.19	73.12	70.94	12.89	11.07	191.34
Vegetables	7.56	2.63	129.55	126.93	41.02	27.03	310.15
Banana	8.12	0.05	23.49	23.44	5.61	5.72	45.52
Tea	370.76	1.42	248.96	247.54	18.66	19.17	6918.23
Scrub	117.64	4.91	1091.19	1086.28	58.96	112.84	6950.67
Forestry	239.72	4.56	309.44	304.88	26.96	28.37	6462.99
Natural forest	163.92	4.56	219.98	215.42	24.54	26.53	4072.09
Urban	347.04	0.00	13.48	13.48	0.02	0.41	7.08
Catchment	3378.76	0.00	1091.19	1091.19	22.09	27.81	46316.07
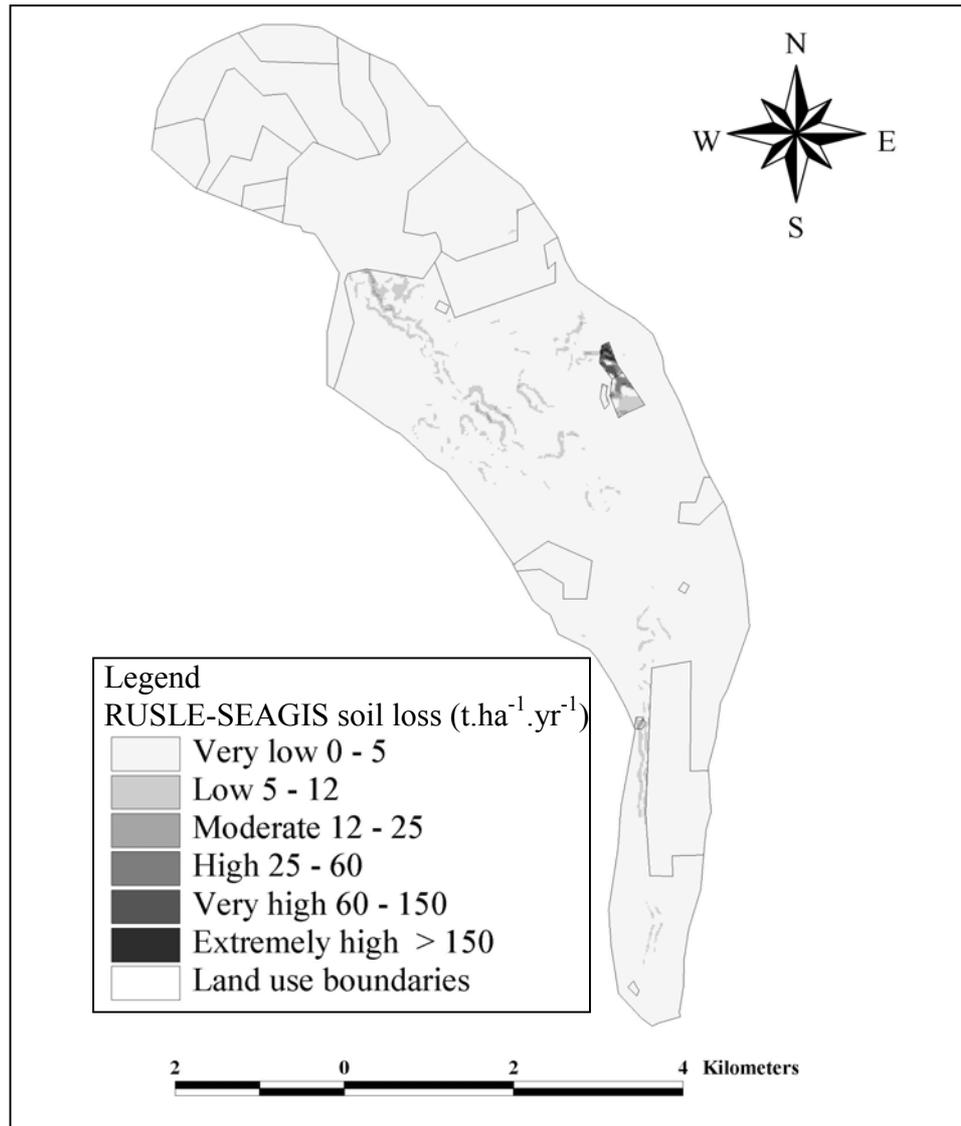
Figure 4.18:   RUSLE soil loss map for the RDAC computed by the SEAGIS application under current conditions.

Table 4.10:   Statistical results of soil loss values estimated by the SEAGIS-RUSLE application.

Land use	Area (ha)	Min (t.ha^{-1}.yr^{-1})	Max (t.ha^{-1}.yr^{-1})	Range (t.ha^{-1}.yr^{-1})	Mean (t.ha^{-1}.yr^{-1})	STD (t.ha^{-1}.yr^{-1})	Total (t.yr^{-1})
Sugarcane	2109.16	0.02	19.89	19.86	1.50	1.81	3158.05
Intercropping	14.84	0.49	72.75	72.26	14.31	13.32	212.37
Vegetables	7.56	0.86	248.91	248.05	82.07	55.80	620.47
Banana	8.12	0.06	26.24	26.18	4.17	5.27	33.87
Tea	370.76	0.02	4.93	4.91	0.50	0.53	185.38
Scrub	117.64	0.01	4.34	4.33	0.41	0.56	48.47
Forestry	239.72	0.01	1.83	1.82	0.22	0.25	53.79
Natural forest	163.92	0.01	1.38	1.38	0.19	0.22	31.10
Urban	347.04	0.00	0.12	0.12	0.01	0.01	3.58
Catchment	3378.76	0.00	248.91	248.91	11.49	8.64	4347.06
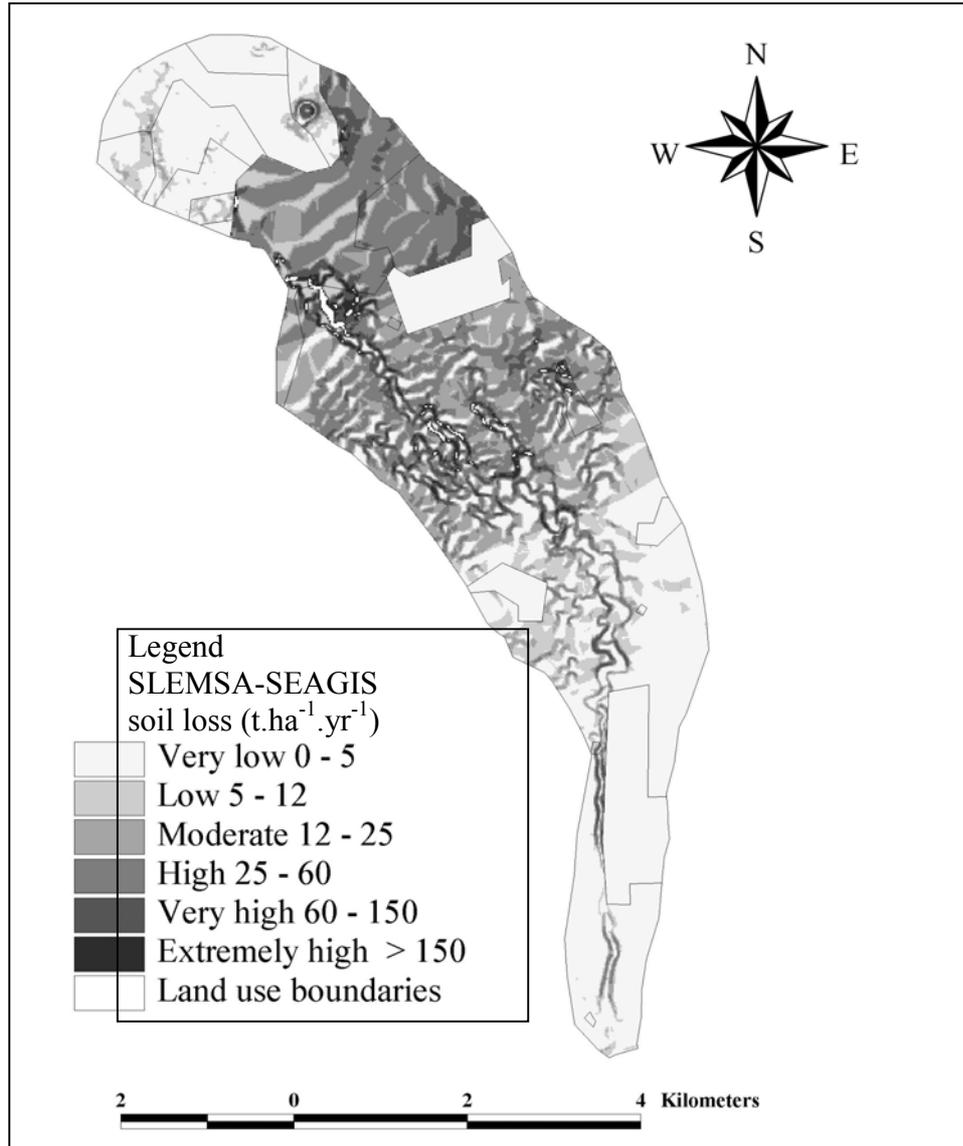
Figure 4.19:   SLEMSA soil loss map for the RDAC computed by the SEAGIS application under current conditions.

Table 4.11:   Statistical results of soil loss values estimated by the SEAGIS-SLEMSA application.

Land use	Area (ha)	Min (t.ha^{-1}.yr^{-1})	Max (t.ha^{-1}.yr^{-1})	Range (t.ha^{-1}.yr^{-1})	Mean (t.ha^{-1}.yr^{-1})	STD (t.ha^{-1}.yr^{-1})	Total (t.yr^{-1})
Sugarcane	2109.16	0.35	1041.15	1040.80	27.14	46.74	57238.81
Intercropping	14.84	3.51	117.42	113.91	20.71	17.77	307.26
Vegetables	7.56	10.24	461.89	451.66	151.39	98.46	1144.49
Banana	8.12	0.39	70.12	69.73	16.60	16.29	134.81
Tea	370.76	4.47	551.43	546.96	41.49	42.35	15383.81
Scrub	117.64	0.84	187.53	186.69	10.21	19.43	1200.49
Forestry	239.72	0.47	31.82	31.35	2.77	2.92	664.58
Natural forest	163.92	0.47	22.62	22.15	2.52	2.73	413.57
Vegetables	7.56	10.24	461.89	451.66	151.39	98.46	1144.49
Catchment	3378.76	0.00	1041.15	1041.15	30.32	27.56	76520.29

It is also noteworthy that within models, soil loss results for identical cropping systems deviate greatly. For example, occasionally the soil loss under vegetables is less than certain soil loss conditions under natural vegetation. This is, given the difference between the respective soil erosion factors involved, including the rainfall erosivity, the soil erodibility and the local topography. As expected, maximum soil loss values (249 - 461 $t.ha^{-1}.yr^{-1}$) are obtained where vegetables are cultivated on steep slopes with erodible soils in a region with high rainfall erosivity. These deviations can also be explained according to the data given in Tables 4.8, 4.9, 4.10 and 4.11. These tables show the minimum, maximum, range and standard deviation of the soil loss results. For example, in Table 4.8, the minimum soil loss under sugarcane is 0.01 $t.ha^{-1}.yr^{-1}$, the maximum is 17.55 $t.ha^{-1}.yr^{-1}$, and the therefore the range is 17.54 $t.ha^{-1}.yr^{-1}$. The standard deviation is 1.77 $t.ha^{-1}.yr^{-1}$. For better clarity, results are compared.

4.8.2. Comparison of results

For visual comparison of results, see the mean soil loss values for RUSLE (Figure 4.20), and SLEMSA (Figure 4.21), as well as comparison of mean soil loss values for both models (Figure 4.22). Also given are the total soil loss values for RULSE (Figure 4.23) and SLEMSA (Figure 4.24). All results indicate soil loss under vegetables to be the greatest. It is evident that the poorly conserved vegetable stand loses on average, about 2-3 times as much soil compared to other crops in the catchment. In contrast, results show that both models predict relatively low soil loss values under natural vegetation. However, SLEMSA results indicate that the range of soil loss values for each crop is more than three times higher compared to RUSLE predictions. Furthermore, results illustrate a notable difference between RUSLE and SLEMSA soil loss amounts under natural vegetation. Mean soil loss predicted by SLEMSA under scrub is most extensive (59 $t.ha^{-1}.yr^{-1}$). SLEMSA predicted excessive high soil losses on steep slopes and regions with high rainfall. It is evident that SLEMSA is highly sensitive to these soil erosion factors. It is apparent that SLEMSA gives rise to such anomalous readings, since it is not developed for use in natural conditions (see also Smith *et al.*, 2000).

Soil loss estimated by the RUSLE-SEAGIS application is equivalent to results obtained through the RUSLE. However, the SLEMSA-SEAGIS application estimates higher soil loss rates under cultivated land, whereas SLEMSA estimates higher soil loss rates under natural vegetation.
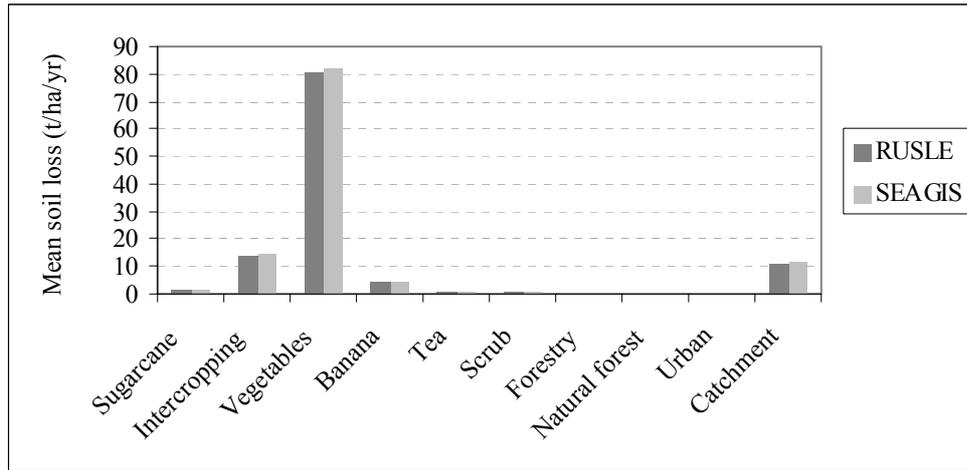
Figure 4.20:   RUSLE mean annual soil loss for the current situation in the RDAC.
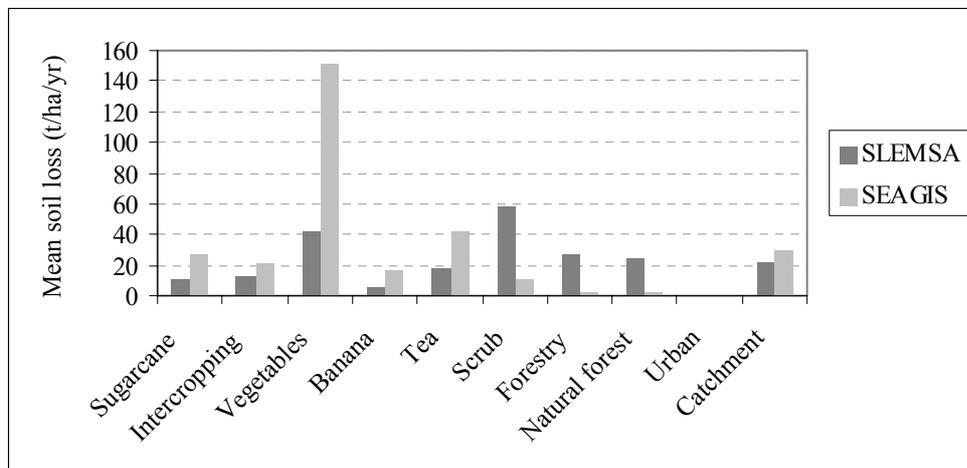
Figure 4.21:   SLEMSA mean annual soil loss for the current situation in the RDAC.
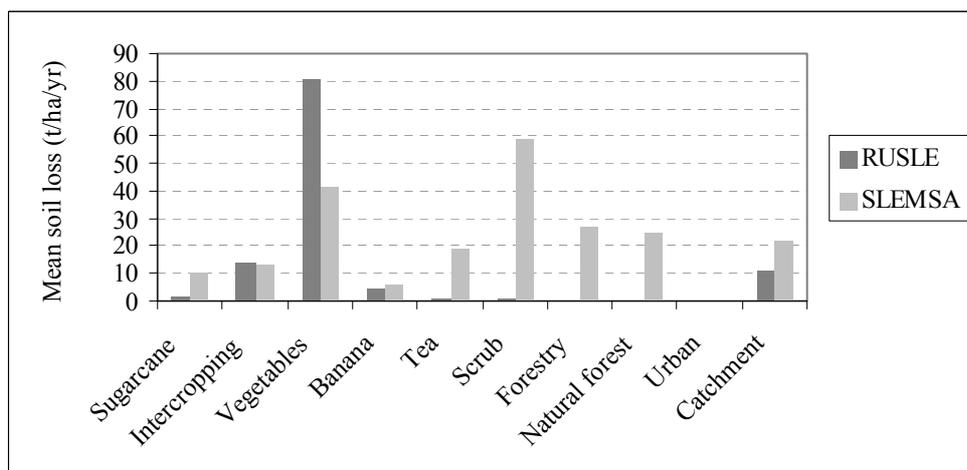
Figure 4.22:   RUSLE and SLEMSA mean annual soil loss for the current situation in the
                RDAC.
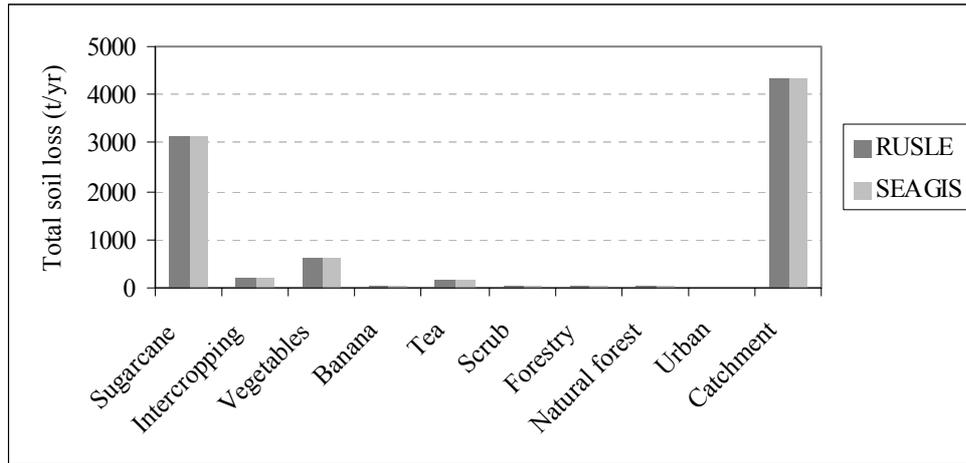
Figure 4.23:   RUSLE total annual soil loss for the current situation in the RDAC.
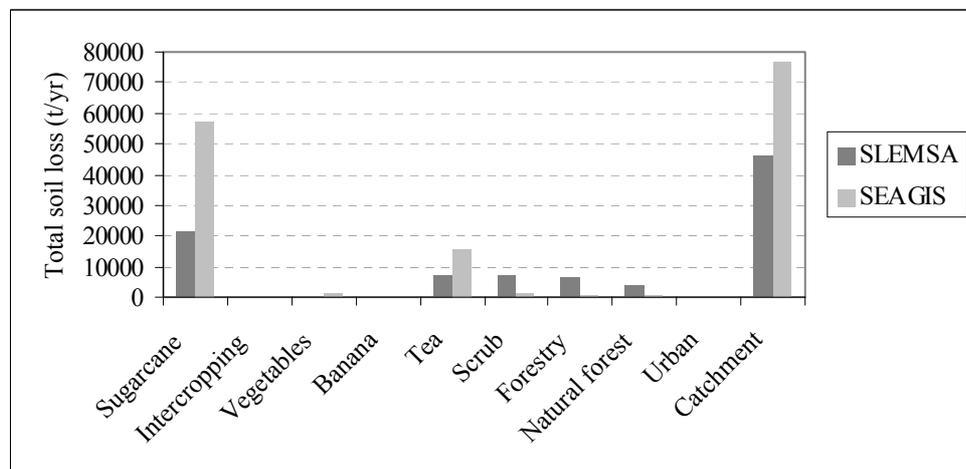
Figure 4.24:   SLEMSA total annual soil loss for the current situation in the RDAC.

Chapter 5 on page 121 gives a more detailed discussion of the reasons behind the differences between the predictions of the models. However, the deviations in these results are not as important as its comparison with possible future developments. Soil loss results are postulated to be very useful in terms of comparisons between current and possible future conditions.

4.9. Soil loss results under future land use change

Soil loss values computed for potential cropping systems are also displayed by means of soil erosion prediction maps. The following set of maps show the effects of alternative managements systems on soil erosion. Average annual soil loss (in $t.ha^{-1}$) under vegetables, pineapple and forest predicted by the RUSLE are shown in Figure 4.25, Figure 4.26 and Figure 4.27 respectively. Table 4.12 shows the statistical values of these results.
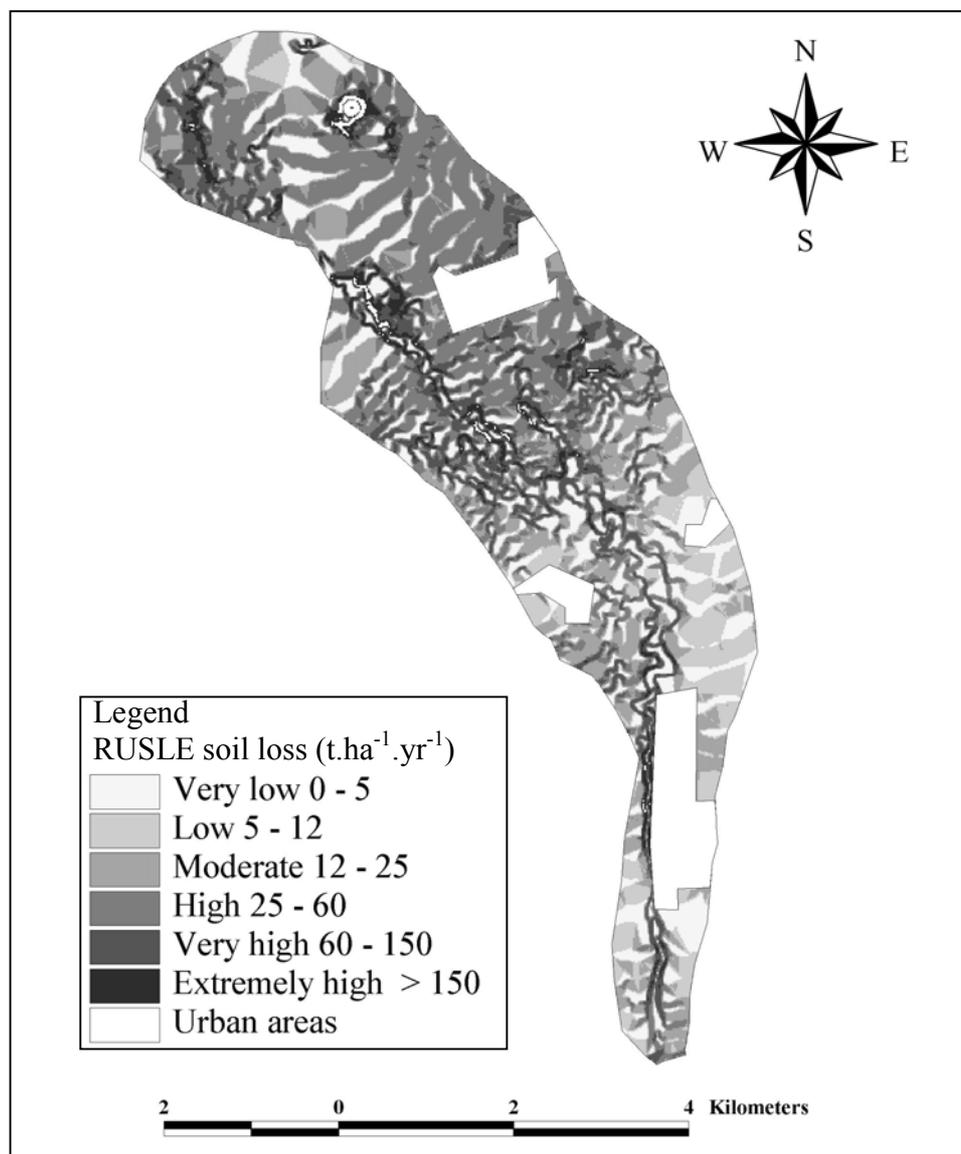
Figure 4.25:   RUSLE soil loss map for the RDAC under vegetables.
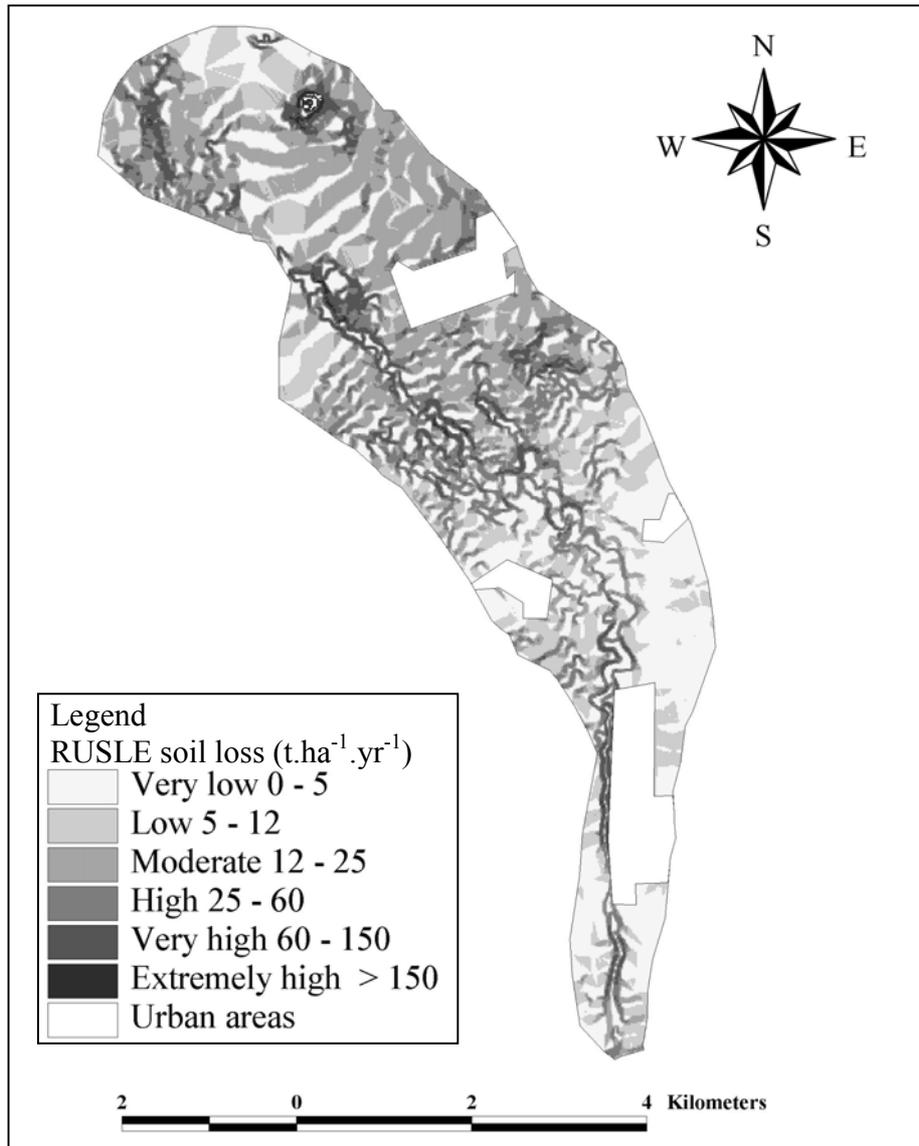
Figure 4.26:   RUSLE soil loss map for the RDAC under pineapple.

Since land of the RDAC is either suitable or at least conditionally suitable for other food crops (Arlidge and Wong You Cheong, 1975; Ramsamy and Govinden, 2001), the three potential crop systems were assumed to cover the whole catchment (3032 ha), except existing urban areas (349 ha).   Mean soil loss from the RUSLE model is 42 $t.ha^{-1}.yr^{-1}$, 20 $t.ha^{-1}.yr^{-1}$, and 0.2 $t.ha^{-1}.yr^{-1}$ under vegetables, pineapple, and forest, respectively. Results clearly illustrate that relatively moderate to high average annual soil losses are predicted for pineapple and vegetables. Results also indicate that soil loss in the catchment ranges significantly, with rates generally highest on steep slopes, increasing with rainfall erosivity. For all three alternative cropping systems, most of the erosion is predicted in the upper catchment area and valley sides of the catchment.   Predicted soil losses in the upper catchment area and valley sides are

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significantly higher (up to a 100 times or more), compared to the lower catchment area. However, all the forested land units are estimated to produce soil losses between 0 and 4 t.ha^{-1}.yr^{-1}. Hence, for the whole catchment, the soil loss values under forested areas fall in the very low soil loss class.
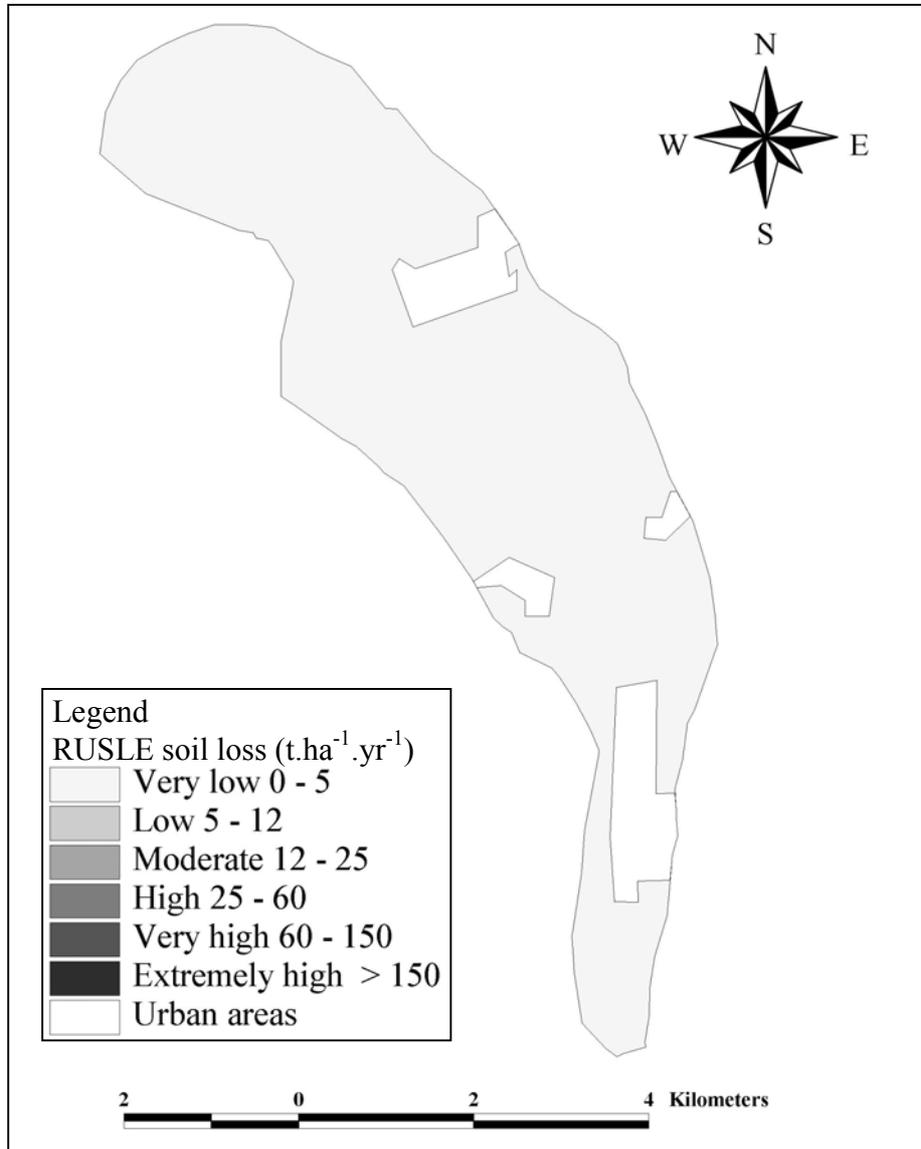

Figure 4.27:   RUSLE soil loss map for the RDAC under forest.

Table 4.12:   Statistical results of soil loss values estimated by the RUSLE under future land use change.

Land use	Area (ha)	Min (t.ha^{-1}.yr^{-1})	Max (t.ha^{-1}.yr^{-1})	Range (t.ha^{-1}.yr^{-1})	Mean (t.ha^{-1}.yr^{-1})	STD (t.ha^{-1}.yr^{-1})	Total (t.yr^{-1})
Urban	349.40	0.00	0.43	0.43	0.01	0.02	3.77
Forest	3031.84	0.00	4.34	4.34	0.19	0.24	568.47
Pineapple	3031.84	0.26	461.06	460.80	19.91	25.36	60369.69
Vegetables	3031.84	0.54	976.03	975.48	42.15	53.69	127798.40

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4.9.1. Comparison with current conditions

The following figures prove to be useful for comparison with soil loss results under current conditions. Mean annual soil loss under current and future cropping systems in the RDAC are shown in Figure 4.28. Total soil losses for the three alternative cropping systems against soil loss under current conditions are shown in Figure 4.29.
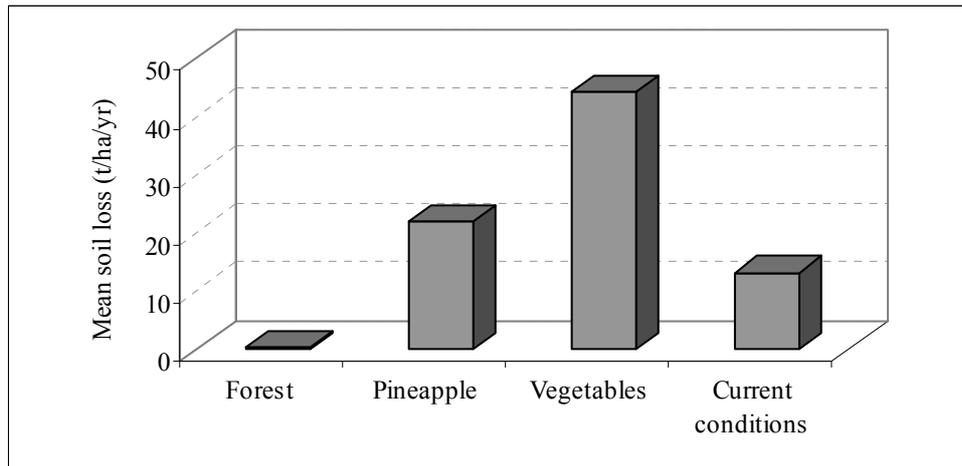
Figure 4.28:   RUSLE mean annual soil loss under current and future cropping systems in the RDAC.
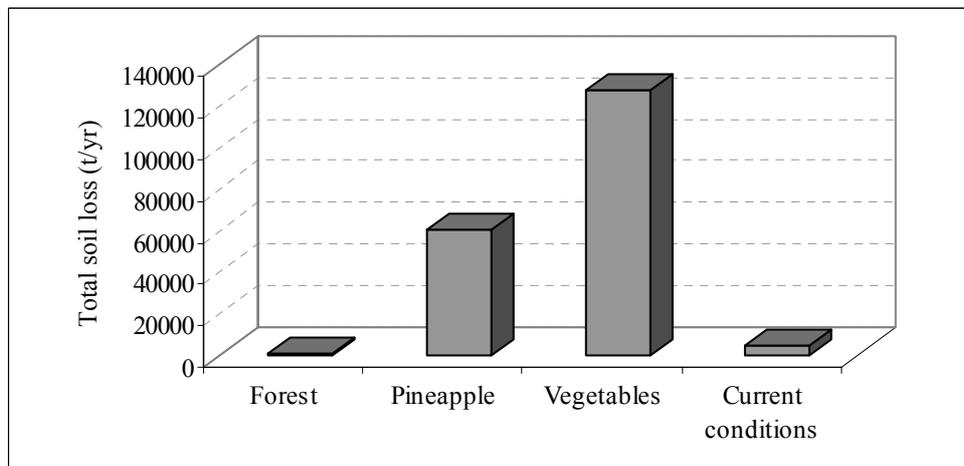
Figure 4.29:   RUSLE total annual soil loss under current and future cropping systems in the RDAC.

A total of 127798 tons of soil is predicted to be relocated by soil erosion under vegetable cover in the RDAC. The total soil loss under pineapple amount to 60370 tons. Forest give rise to very low soil loss values with a catchment total of 568 tons. When compared to current conditions, the mean soil loss for the catchment will double under pineapple (increase by

100%), and quadruple under vegetables (increase by 300%). In contrary, the mean soil loss will decrease by almost 100% under forest.

4.10 Geomorphological maps of gullies

In conclusion of the results, the measurement of three gullies in the catchment are illustrated in Figures 4.30, 4.31 and 4.32. Gullies in the catchment are limited to only three locations (Figure 2.13 on page 27) within sugarcane fields.
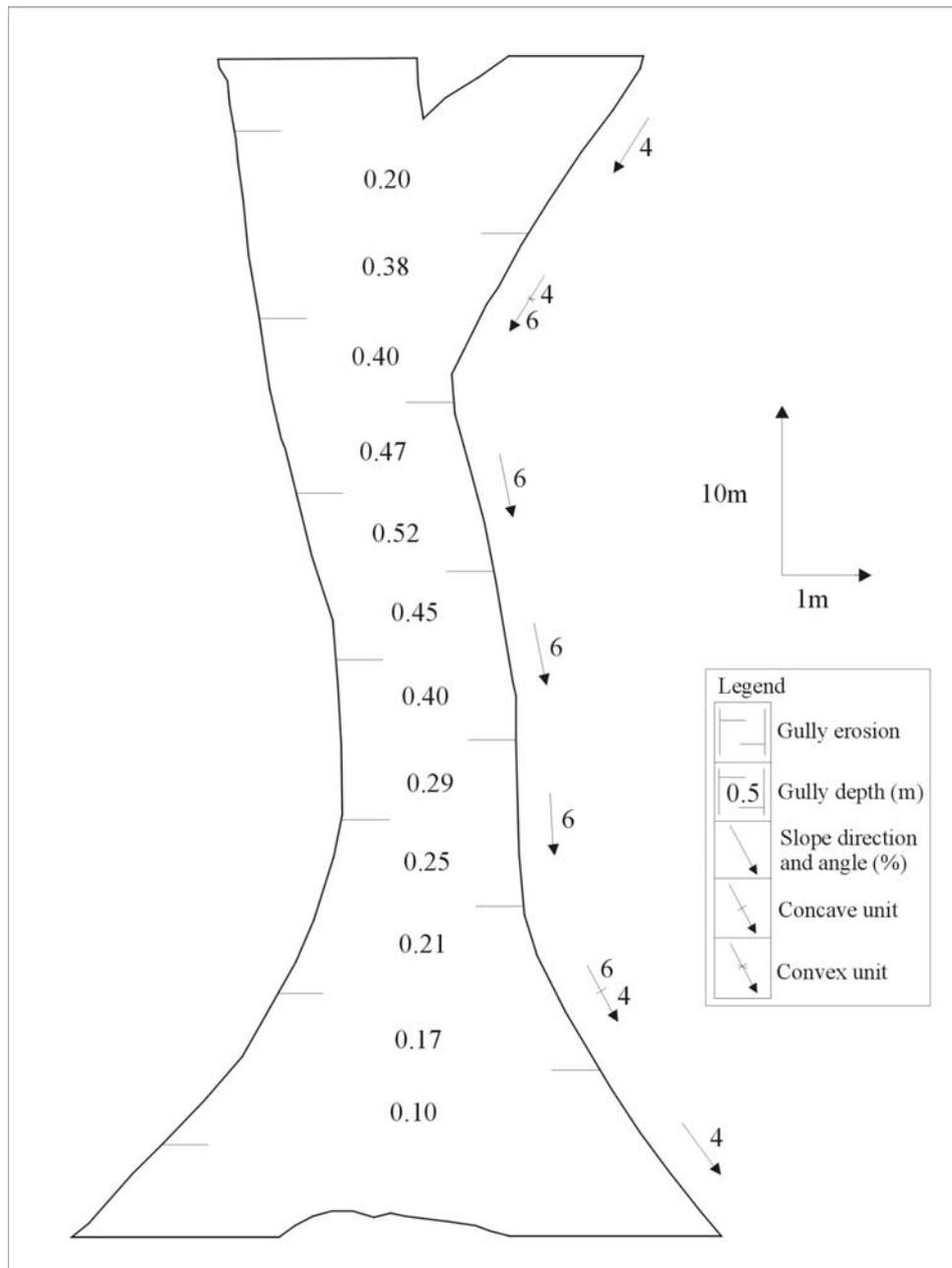
Figure 4.30:   Dimensions of first gully in sugarcane field.
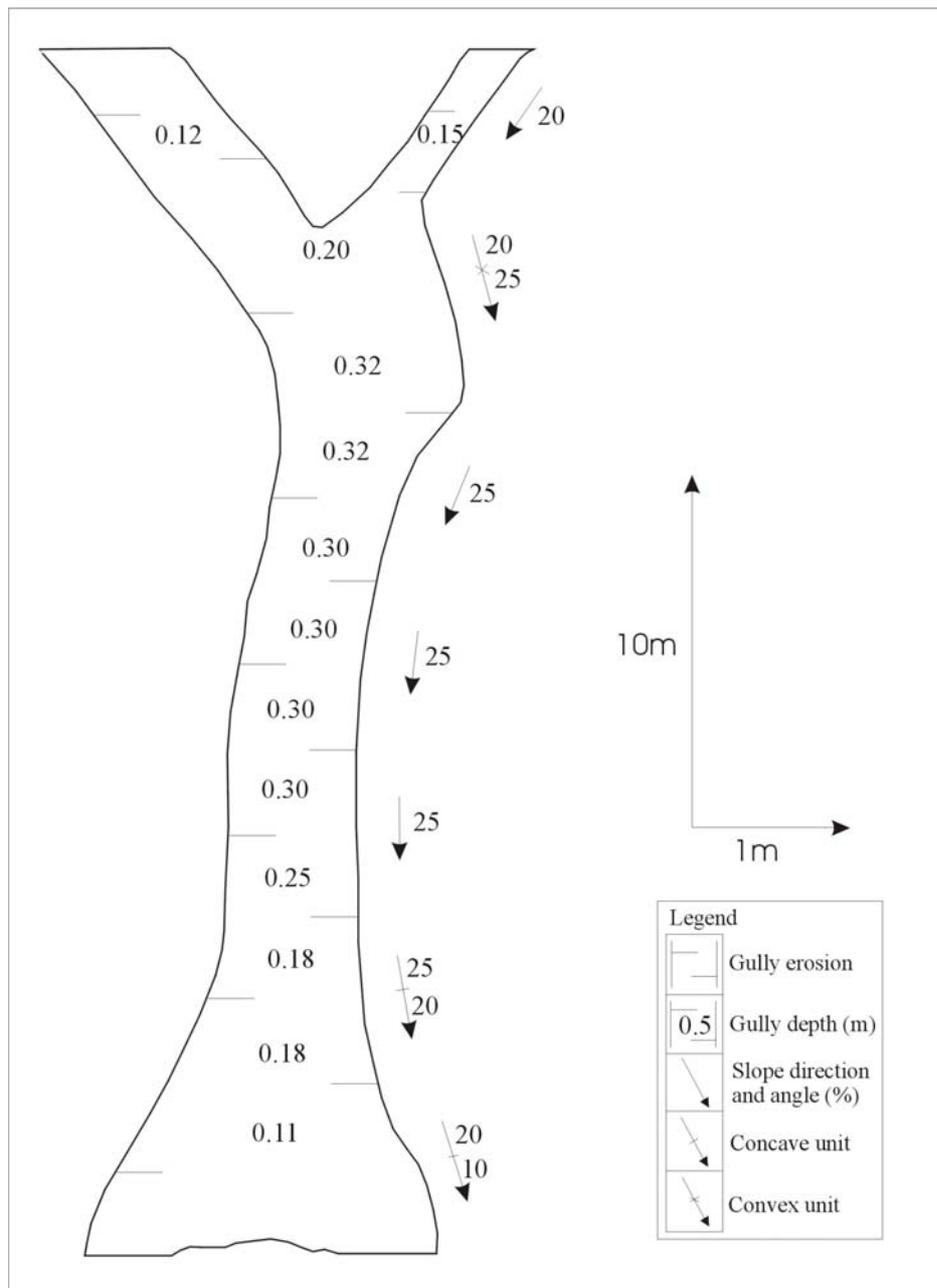
Figure 4.31:   Dimensions of second gully in sugarcane field.

Gully depths range between approximately 0.2 m and 1.5 m, lengths range between 35 and 80 m, and their widths between 0.5 and 9 m. Only one gully has a parallel pattern while the other two gullies are single, linear, long and narrow. All three gullies have a U-shape cross-section. In general, gullies are characterised by moderately to gently inclined floors. All three gullies seem to be situated in drainage lines on steep slopes. The two smallest gullies have gully fans stretching into the sugarcane fields consisting of deposits from the gully channel below its outlet.
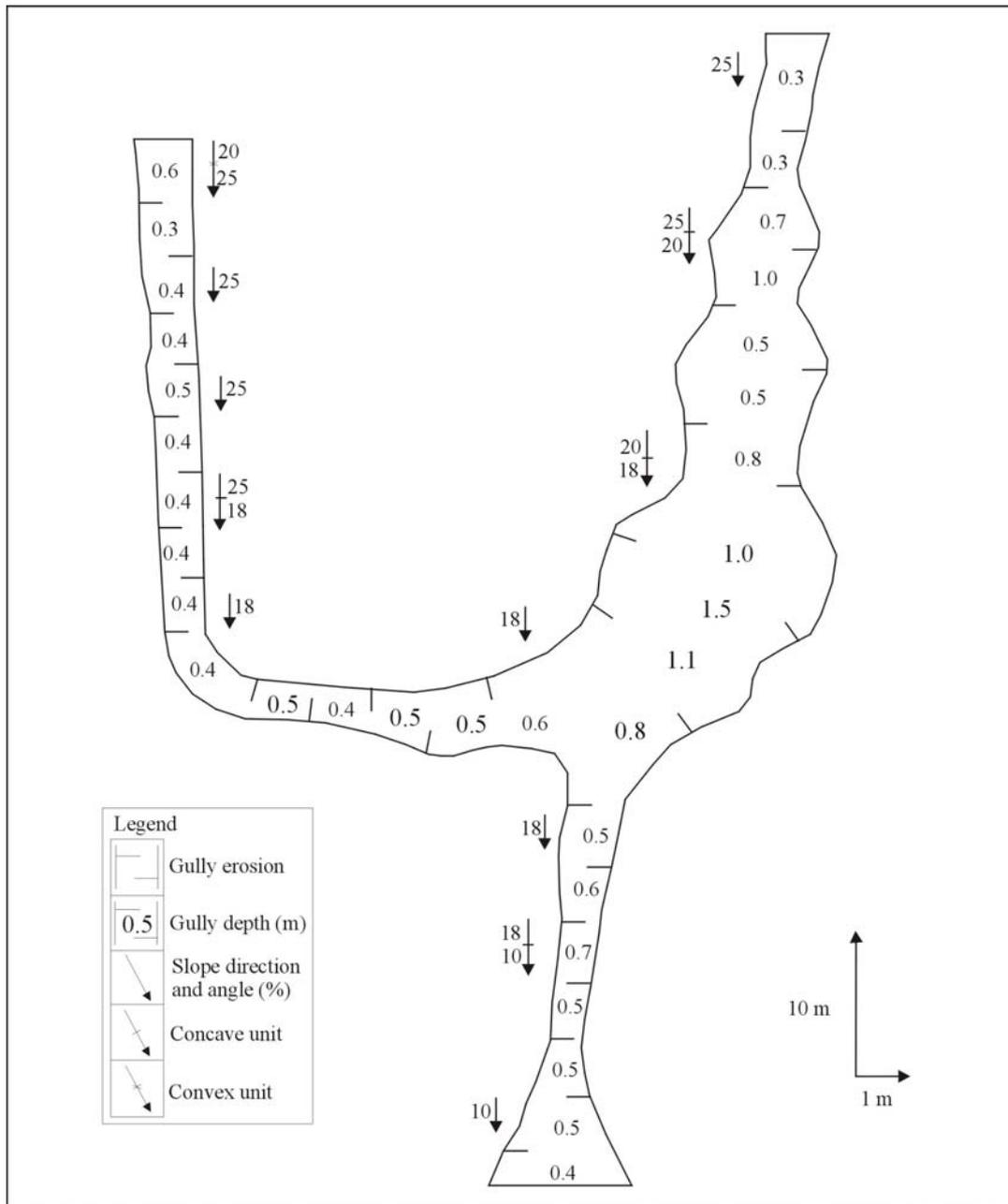
Figure 4.32:   Dimensions of third gully in sugarcane field.

Since field observations revealed only three gullies, their dimensions and processes are not key topics in the study. In contrary, RUSLE and SLEMSA soil loss results presented in this chapter are essential for depicting the nature of the factors governing erosion. Results provide information concerning how much soil loss is occurring under different management or crop systems, including soil loss under future land use.

Chapter 5 provides a detailed discussion of the results and justifies the outcomes of the parameters and their importance in terms of the environment and agriculture of Mauritius.

Chapter 5: <u>Discussion</u>

In this chapter soil erosion factors and their effect on soil loss in the *Rivierre des Anguilles* catchment (RDAC) are discussed. Soil erosion factors are discussed individually, despite the interdependency that exists between them. Discussions are categorised according to the five soil erosion factors of the Revised Universal Soil Loss Equation (RUSLE), and the Soil Loss Estimator of Southern Africa (SLEMSA) including rain erosivity, soil erodibility, land management, support practices and topography. Secondly, the discussion is followed by a detailed description of the distribution and extent of soil loss patterns in the RDAC. Different patterns in soil loss values between land units and land use types should be a direct outcome of the different influences of the factors on erosion. Discussion of soil loss under current conditions is followed by a comparative description of soil loss under future conditions. Discussions also include soil life and soil loss tolerance, erosion susceptibility, crop production and soil conservation. This chapter draws to a close with regard to model limitations and theoretical evaluation, followed by research needs and recommendations.

5.1 Erosivity

The RDAC has been divided into seven rainfall zones due to the large variability of the precipitation characteristics in the catchment. Erosivity values in the upper catchment area are four to five times higher than the coastal area. These high erosivity values not only have a strong influence on detachment of soil particles, but also have bearing on transport through runoff (Lal & Elliot, 1994). Therefore, the high erosivity values (2139 MJ.ha^{-1}.mm.hr^{-1}) in the upper catchment area are of major importance on any poorly vegetated, steep slopes. Fortunately, the actual erosive power of the rain depends largely on plant cover (Evans, 2000). For this reason, it is apparent that the well covered upper catchment area does not necessarily experience high erosion rates. Intensive cultivation of the upper catchment area, however, may lead to accelerated rates of erosion. Crop diversification will most definitely accentuate erosion problems. Therefore, the upper catchment area should be regarded as highly sensitive, which renders it unsuitable for cultivation without proper conservational measures. For this reason alone it is suggested that the natural vegetation in the upper catchment area and along the steep valley slopes should remain undisturbed.

Not illustrated in the average annual erosivity map on page 58 is that most of the erosive rains occur from December to April. Heavy showers during the summer months may cause most of the erosion, especially in areas with a pronounced dry season akin to the lower catchment area.

5.1.1. Rainfall intensity

Although erosivity is best estimated by direct measurements of a rainstorm's energy load (Renard *et al*., 1994), the EI_{30} database for the island is limited to a few regions only. Consequently, there is a pressing need for widespread rainfall intensity data measurement on Mauritius. Moreover, empirical equations need to be correlated to rainfall intensity data in tropical regions, which are occasionally characterized by high intensity rainstorms. In the study, calculated EI_{30} values from weather stations (*Plaicanse, Bel Ombre* and *Belle Rive*) situated close to the RDAC (Table 4.1 on page 58) tend to agree with estimated R values using the modified Fournier Index.

Additionally, Table 5.1 from Kremer (2000), shows the average number of days per annum experiencing rainfall above 50 mm, 100 mm and 200 mm. The table indicates that rainfall regions in the upper catchment area experience more rainfall events with high intensity than the lower catchment area. These numbers compare well with estimated R values using the modified Fournier Index. Bergsma, *et al*. (1996) reports that the modified Fournier Index proves to correlate well with EI values for rains in Belgium, Brazil and the Mediterranean area, although regional coefficients are necessary.

Table 5.1:   Number of days having rainfall above 50 mm, between 50 and 100 mm, between 100 and 200 mm, and above 200 mm for each rainfall zone (Kremer, 2000).

Rainfall Zone	Days >50 mm	Days 50-100 mm	Days 100-200 mm	Days >200 mm
1	13	8.5	3.5	1
2	8	5	2	0
3	10	6	2	0
4	3	4.3	0.3	0
5	7	5	2	0
6	6.75	4.75	2	0
7	5	3.5	1.5	0
8	4.25	3.25	1	0
9	2.5	1.75	0.75	0
10	1.75	1.5	0.25	0

(Rainfall zones of catchment shown on page 58).

5.1.2. Extreme events

A major research question facing geomorphologists is how extreme events contribute to total soil loss. It is also important to determine how many soil loss events, both large and small, actually occur. Knowledge of the frequency-magnitude distributions of erosion events is essential for an understanding of the role of small and large erosion events in terms of soil loss, and from the practical perspective of land management (Boardman and Favis-Mortlock, 1999). Although it is not the objective of the study to analyse frequency-magnitude distributions of rainfall in the RDAC, tropical cyclones are of considerable importance to agricultural production in Mauritius (Proag, 1995).

As stated in the results above, the R value (1367 $MJ.ha^{-1}.mm.hr^{-1}$) calculated from intensity data for Souillac in December 1996, does not compare well with the estimated R value (619 $MJ.ha^{-1}.mm.hr^{-1}$). The higher EI_{30} value may be explained by the occurrence of a tropical cyclone. Copious volumes of rainfall accompany tropical cyclones and consequently, cyclones are responsible for increasing R values substantially. Cyclones could lead to significant amounts of soil loss. During such an event, freshly tilled soil will be particularly prone to erosion. Fortunately, the tropical cyclone period (November to May) does not coincide with the sugarcane planting season (June to September). However, vegetables are harvested and planted during the cyclone period in February. Therefore timely tilling and maintenance of contours is particularly important.

Total soil loss over a one year period could be highly dependent on one or two large storm events. Rydgren (1996) predicted soil loss in a catchment in Lesotho, South Africa and very intensive storms were responsible for the bulk of seasonal soil loss. In the contrary, some authors (Boardman and Favis-Mortlock, 1999; Trustrum *et al*., 1999) report that in several areas around the globe, large storms appear to play a lesser role compared with the cumulative influence of more frequent, lower magnitude events. The issue is complicated further by differences in erosion processes. Estimated soil loss from any single event can vary greatly, depending on vegetation parameters and management such as the recency of tillage. Trustrum *et al*. (1999) argues that spatial and temporal variations in erosion thresholds, process dominance, and the effects of prior events make it particularly difficult to determine the role that events of a given magnitude play in the amount of soil erosion in large catchments. Although tropical cyclones are an important component of the rainfall regime of Mauritius, their effect on soil loss has yet to be adequately determined. As a result, the contribution of

tropical cyclones, though almost certainly significant, remains speculative. This information supports the need for long term records of soil loss during cyclones, and for use of emerging soil loss technologies, such as WEPP, that have capabilities for considering erosion from individual storms. The study by implication focuses attention on soil detachment.

5.2 Erodibility

The concept of erodibility has to do with soil detachment and overland flow production (Bergsma, *et al*., 1996). Therefore, erodibility is part of a series of processes including detachment, entrainment and transport followed by deposition. Soil erosion processes are complex and are influenced by several soil properties such as texture, structural stability, organic matter content, and permeability (Lal & Elliot, 1994). In general it appears that the basalt derived soils of the RDAC, although sometimes shallow, are relatively stable. As results indicate, erodibility values vary from low to medium between 0.074 and 0.147 $t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$. Following below is a discussion of how these soil properties influence the erodibility of the soils in the RDAC.

5.2.1. Drawing comparisons

Erodibility results from the RUSLE do not differ too widely from those of Hawaii where erodibility modelling was tested (El-Swaify and Dangler, 1976 cited in Bergsma *et al*., 1996). According to the RUSLE, erodibility (K) values vary mostly according to aggregation, base saturation, and particle size. A discussion of the results in Table 4.3 and Table 4.5 on page 61 and 63 follows.

A tendency to resistance is seen for the Humic Ferruginous Latosol (HFL) *Belle Rive* family. Erodibility results have shown that the HFL *Belle Rive* family is the least erodible (0.074 $t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$). Although this soil has a high modified silt content, its low erodibility value can mainly be explained by fairly strong and stable aggregation, a relatively high organic matter content, and a relatively low base saturation value. All the other soils in the RDAC have medium erodibility values (0.103-0.147 $t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$). With almost similar textures as above, the Humic Latosol (HL) *Riche Bois* and Low Humic Latosol (LHL) *Reduit* soils, although having slightly stronger aggregation, show a decrease in organic matter contents, and increase in base saturation. These soils also have slower infiltration rates. On the contrary, the *Sans Souci* and *Midlands* families of the HFL soil group have moderate to rapid infiltration rates. Furthermore, these soils have lower silt contents, the highest

percentages of unstable aggregates, the highest organic matter contents, and the lowest base saturation. A further issue is that soil erodibility also depends on land use. A discussion of each of the soil erodibility factors mentioned above, as well as a description of their interdependency follows below.

5.2.2. Soil texture

Soil texture is important in determining soil erodibility (Lal & Elliot, 1994). Usually, soil containing large amounts of coarse silt and fine sand are the most erodible (Briggs, 1977b; Manrique, 1988). These soils are easily detached and transported by runoff. In contrast, fine textured soils with high clay content are resistant to detachment, but have lower infiltration rates that may lead to greater runoff and increased erosion. Coarser textured sandy soils have lower runoff rates, but are easily detached. They are however, less easily transported than silty soils. In the catchment, however, soil losses are not so clearly related to soil type. It appears that soil type will be a prominent soil erosion factor only when vegetation cover is reduced. As stated above, soil erodibility in the catchment seems to depend heavily on land use together with structural stability, organic matter content, and base saturation. Further discussion is given on page 102.

5.2.3. Particle size distributions

The cumulative percentage frequency curves of every sample show the similarities and differences in particle sizes between, as well as within soil types. All the soil types in the catchment are positively skewed. Thus, in general, greater amounts of fine material occur. In addition, all the soils are poorly sorted and therefore have a mixture of different particles. Hence, sediments do not tend to segregate according to size through specific transport agents. Particle size distribution shows a gradient that relates to altitude. Soils at higher altitudes have coarser particles, and are more positively skewed than soils at lower altitudes. For example, the coastal LHL *Reduit* soil consist of very poorly sorted, fine clays together with a few concretions having the lowest mean phi size of –0.79, and skewness of 0.16. In contrary, the HFL *Midlands* soil is poorly sorted, with slightly coarser sandy loams and concretions with a mean phi size of –1.08, and skewness of 0.35.

Particle size distributions can be accounted for by the characteristics of the weathered volcanics, including varying amount of concretions. Soils of Mauritius developed almost exclusively on olivine basaltic lavas or highly vesiculated basaltic lavas (Parish and Feilafe,

1965). Latosolic soils in the catchment however, have minerals that are still in the process of weathering, characterized by the presence of angular stones and gravel of vesicular lava (Proag, 1995). In addition, boundaries between the soil families are diffuse, because rainfall is the dominant soil forming factor. High rainfall in the upper catchment area also explains why HFL soils are more weathered with poorer physical properties. The particle size distributions can also be accounted for by differences between cultivated or uncultivated soils. Thus, samples that are non-representative of its parent population could perhaps be described by land use. Therefore, the particle size distribution for soils on Mauritius is as yet poorly understood and needs further investigation.

5.2.4. Aggregation

Many types of structural peds occur in the RDAC soils. However, granular and crumb structures are common throughout the soils of the RDAC. The factors that govern the structural stability of a topsoil are generally the same as those that influence its erodibility (Evans, 2000). Soil structure affects the susceptibility to detachment, including infiltration. Soils with a strong structure render the soil very resistant to detachment and erosion. Furthermore, soils with silt and fine sand are usually very prone to structural breakdown and erosion. However, the natural stability of the structure of LHL and HL soils with high silt contents, tend to be higher than HFL soils. The HFL *Sans Souci* - and *Midlands* families have unstable aggregations. Fortunately, it appears that the high organic matter contents help to stabilise these soils against erosion. The HFL *Belle Rive* family tends to be more stable than the former two HFL families.

5.2.5. Base saturation

Another property of importance for the erodibility factor in the RUSLE is the percentage base saturation. It is a measure of the extent to which the exchange complex is saturated with basic cations (Fitzpatrick, 1980). The general trend is for the amount of exchangeable bases to increase with decreasing rainfall which explains why the LHL and HL soils have higher base saturation values (65% and 32% respectively) than HFL soils (10%), since the latter soil group is at higher elevation under superhumid conditions. Conversely, low figures for the percentage base saturation may be used as a criterion of leaching. Ultimately, low base saturation values contribute to higher erodibility values of HFL soils in the upper catchment area.

5.2.6. Organic matter content

Erodibility is not only a function of the RUSLE factors mentioned above, but also of the organic matter content. Fitzpatrick (1980) discussed the advantages of high organic matter content in the soil. It increases the water-holding capacity and infiltration, acts as a binding substance, and aids in structure formation, consequently lowering soil erodibility. Soil acidification and compaction are some of the more important factors that are coupled with loss of organic matter content. According to Evans (2000) soils with higher organic matter contents are often more porous and better structured. Haynes (1997) also stresses that soil organic matter has a profound effect on the structure of many soils. The high organic matter contents (6.9 – 10.4%) in the HFL soils contribute to lower erodibility values. By far the greatest amount of organic matter in these soils is derived from roots and litter just below the surface. For this reason the organic matter content is coupled with the local vegetation characteristics. A detailed discussion follows on page 102.

5.2.7. Infiltration capacity

According to Lal and Elliot (1994), one of the predominant processes that determine erosion is related to infiltration. When rainfall intensity exceeds the infiltration rates, overland flow occurs, leading to erosion. The driving forces behind the infiltration rate - capillary suction, osmotic suction, adsorption forces and gravity - are discussed by Bergsma *et al*. (1996). The main factors affecting infiltration are soil texture and structure, tillage conditions, crop cover and topography.

The coarser, sandy soil of the HFL soil group is more permeable than the fine textured LHL and HL soil groups. In addition, the coarser structures of the former soil group bring about a favourable infiltration rate (15.0 – 36.5 mm.hr^{-1}), which decreases erosion. Permeability is also favourably affected by its high soil organic matter contents. These characteristics indicate that water is draining at a faster rate in the HFL soils. However, although infiltration rates for the HFL soils appear to be excellent, the compact B horizon hinders drainage. During wet periods overland flow may occur due to topsoil saturation above a relatively impermeable subsoil (Bergsma *et al*., 1996). As a result, lateral drainage over the B horizon and on the steep slopes can lead to severe erosion when the land is cleared.

Although LHL and HL soils have low infiltration rates (7.5 – 20.0 mm.hr^{-1}), they have relatively high water-holding capacities (Proag, 1995). Bergsma *et al*. (1996) argues that soil

moisture is more important than the final infiltration rate in determining runoff. The spatial relationship between moisture storage, infiltration rates, runoff and soil characteristics is complex. There is a great need for more quantitative data about the variations in moisture regimes of soils in Mauritius. Due to limited observations, annual variations in the content of moisture in soil remains unknown.

The response of a soil to erosion processes is complex and is influenced by soil properties such as texture, aggregate stability, organic matter content *etc*. mentioned above. In addition, erodibility also depends on land use characteristics.

5.2.8. *The influence of land use on erodibility*

Soil properties determine plant growth by affecting water and nutrient availability, including temperature (Bergsma *et al*., 1996). Plant growth, in turn, influence soil properties such as organic matter production, which is important to soil stability. Therefore, information is needed of the crop systems covering each of the soils in the catchment. More than 80% of LHL *Reduit*, HL *Riche Bois*, and HFL *Belle Rive* soils are covered by sugarcane. HFL *Midlands* family is predominantly covered by tea (±30%) and sugarcane (±35%) plantations. Lastly, the HFL *Sans Souci* family is covered by natural vegetation (±40%), as well as sugarcane (30%). Soil under natural vegetation experiences no human disturbance. Likewise, soil under tea plantations also experiences little disturbance because of no till operations. Soil under ratoon cane is tilled on average every seven years, when new cane is planted. In between those seven years, the cane stubbles are left intact during harvest. On the contrary, soil under the vegetable plot is tilled and disturbed twice a year. Newly tilled soil will be easily detached compared to a consolidated soil (Bergsma *et al*., 1996).

Activities such as tillage and mechanical harvesting affect soils largely through their effect on soil structure. Excess tillage usually contributes to lower aggregate stability thereby increasing the soil erodibility. The individual soil particles that break down are susceptible to erosion and may accentuate the erosion problem. In contrast, harvesting often involves the use of heavy machinery that may compact the soil (Morgan, 1995). Compaction of the soil, takes place during harvest, particularly when the soil is wet (Cheong *et al*., 1999). The soil compaction problem is accentuated by traffic in ratoon cane fields, which are not cultivated for up to seven consecutive years. Compaction of the soil by agricultural activity leads to high bulk densities.

The two main factors affecting bulk density are composition and packing of soil (Briggs, 1977b). Therefore, soils in the catchment show a wide range from 0.74 g.cm^{-3} to 1.94 g.cm^{-3} as a result of differences in the volume of voids and/or porosity. Low values are generally associated with recently cultivated or well structured topsoils. The average bulk densities (0.98 – 1.13 g.cm^{-3}) of the RDAC soils compare well with typical bulk density values of most cultivated horizons (Fitzpatrick, 1980). High values, however, are characteristic of compacted soils where pore spaces have been reduced. Effects associated with soil compaction are lowering of infiltration rates and increasing runoff. Moreover, an increase in bulk density due to increased use of heavy machinery leads to decrease in ratoon yield (Soopramanien, 1995).

Cheong *et al*. (1999) established that soils of Mauritius have relatively low bulk densities (averaging between 1.1 and 1.2 g cm^{-3}), which renders them more susceptible to compaction, especially at shallow depths. The relatively low bulk density of the topsoil in the RDAC can be explained by the porous nature and fine granular structure of the topsoil, with a relatively high organic matter content. Organic matter and mineral soils have low densities. Consequently, as the organic matter content of the soil increases, its bulk density decreases. This explains the lower bulk densities of the HFL *Midlands* soil. The high amount of organic matter in these soils lowers the intrinsic density.

Results in Table 4.5 on page 63 indicate that bulk density may also be an indication of soil strength. Under natural vegetation, detachment and transport of particles is mainly determined by its shear strength. The major factors affecting shear strength are soil water content and texture (Bergsma *et al*., 1996). Soils with the highest clay content show more resistance to the blades of the shear vane test. However, the effect of tillage is to reduce the soil's resistance, which explains low strength values. As stated above, the shear strength also decrease with increasing soil moisture. It is therefore important when measuring penetrometer resistance, that soil water content is also known. Van Antwerpen and Meyer (1996) demonstrated the potential of trash to reduce soil penetrometer resistance and bulk density. Soil penetrometer results obtained were lower for the trashed soil surface due to higher soil water content. Increased soil strength, however, may restrict water infiltration, potentially leading to increased runoff.

It is also known that soil compaction affects infiltration. The variation in rates of infiltration in the catchment can mainly be accounted for by the effect of tillage. Infiltration is usually

increased by tillage due to the increase in macroporosity (Bergsma *et al*., 1996). After tillage this effect wears off with time. However, the breakdown of aggregates can impede infiltration and result in runoff and surface erosion (Haynes, 1997). Infiltration rates variations within the same soil types may be explained by soil compaction induced by heavy machinery. Cheong *et al*. (1999) specified that infiltration rates are reduced by traffic, indicating soil compaction. Infiltration rates decreased from 306 mm.h^{-1} to 40 mm.h^{-1}.

Soil surface roughness also affects erosion processes primarily as it affects runoff processes (Nearing *et al*., 1990). According to Evans (2000) the major factor controlling surface roughness is how the farmer works the soil. The effects of roughness on surface runoff processes are discussed in Renard *et al*. (1994). Although more research for Mauritius is needed, it is alleged that the heavy surface roughness on the forest floor and scrubland in the RDAC limits soil losses to some extend.

Through cultivation, the soil's structure is degraded not only physically by ploughing but also by lowering its organic matter content (Evans, 2000). Under arable cropping, the amount of organic material is considerably less than under forest land. In addition, interactions with the cover management factor C are primarily due to the effect of organic matter on soil loss. The organic matter content again depends on the amount of crop residue. According to Renard *et al*. (1994), no sharp delineation can be made where the effects of residue cease to be part of the C factor and become part of the K factor. Discussion of these processes is considered beyond the scope of the study.

From the discussion above it is apparent that soil erosion processes are complex and are influenced by several soil properties. Most of these properties can alter over time due to land use, management practices and farming systems. Therefore, the extent and frequency of erosion related to the soil factors above, is implicitly related to the crop factor C.

5.3 Land management

Land use is important and can dominate over all other influences (Wischmeier and Smith, 1978; Hallsworth, 1987; Higgit, 1993; Garland, 1995; Evans, 2000). The C value is mainly a function of the canopy cover and residual effect (Appendix 2). The importance of an optimum plant cover cannot be over emphasised. Soils under natural vegetation in the upper catchment area erode up to 80 times slower than under pure stand vegetables. High R value of the upper

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catchment area appear to be compensated for by the C factor. Soil loss under sugarcane also appears to be minor compared to vegetables and intercropped cane. There are two main reasons for this. First, the soil under ratoon cane is not disturbed during harvest; the root system is left in tact; only during replanting of new cane every seven years is the soil tilled. Second, sugarcane provides a dense cover within less than two months after regrowth or planting.

The canopy, however, is not always protective against erosion. The effect of the canopy cover on soil loss depends not only on its density but also on its height (Wischmeier & Smith, 1978). If the canopy height is too high (>3 m), the fall velocity of the drip is higher than unintercepted rain. Surface cover, such as the rocks and residue composition, is considered as one of the most sensitive factors controlling erosion (Renard *et al*., 1991; Renard *et al*., 1994; Evans, 2000). According to (McPhee, 1980), surface cover including mulch and gravel are more effective than equivalent percentages of canopy cover. Although the canopy height of the forested areas exceeds 3 m, the surface cover on the forest floor inhibits erosion. A forest typically has good basal cover, including a complex network of roots immediately below the soil surface. A high percentage of rock on the surface is also very effective against erosion. Rocky soils, especially the HFL *Midlands* soil family, act as surface mulch by protecting the soil surface from raindrop impact. Raindrops falling on the surface cover regain no fall velocity and rocks or residue that are firmly attached to the surface also reduces the velocity of runoff.

In general, C values for this study are low compared to C values from other sources of literature (Appendix 5). Sugarcane also has low C values (±0.110) due to crop residues being left on the ground. Trash mulching avoids direct impact of raindrops on soil and renders overland flow. In a study conducted by Yang (1995) in Fiji, contour planting with trash mulch has proved to be the most effective practice to conserve soil and water on sloping land. A reduction of 10% in soil erosion was obtained from trashed contour plot under normal rainfall in comparison to the treatment with no trash. The MSIRI (1998a) found in sugarcane similar results between a plot with no cover, a plot with trash cover every interrow, and a plot with trash on alternate interrows. Plots with trash cover every interrow, reduced soil erosion by 50% or more. Growers in the drier regions in particular, adopted green cane trash blanketing to conserve soil moisture (Newell *et al*., 2001). In most cases trash blanketing also improves weed control, maintains organic matter content, and improves productivity. Cane trash can be

added to the soil surface of other crops, but the effects will need further investigation. Green trash blanketing also has disadvantages. Heavy trash blanketing may lead to an increase in pests (*e.g.* Army worms) that have a negative effect on cane production. Furthermore, trash blanketing is inadvisable in the superhumid areas since an excess of water in the soil appears to be detrimental to the crop. Therefore, green cane trash blanketing is only advised for the lower catchment area.

5.3.1. Soil loss ratio (SLR)

Land that is cultivated results in seasonal changes in vegetation parameters (Smith *et al*. 1995). Furthermore, disturbed soil is by far more erodible than consolidated soil under natural conditions. According to Evans (2000) soils are considered at risk of erosion between the time of cultivating out the last crop to when the crop covers roughly more than 30% of the ground surface. In addition, land is highly susceptible to erosion when crop cover is at its lowest and rainfall erosivity at its highest (Haarhof *et al*. 1994). Therefore the soil loss potential is distributed in time and follows a seasonal pattern. This is best illustrated by the soil loss ratio (SLR) computed in the RUSLE. The model combines the effects of all the C subfactors to compute a SLR for the crops that are frequently disturbed (sugarcane, intercropped cane, and vegetables). The SLR allows identification of periods when the land surface is most vulnerable to erosion processes.

SLR results illustrate that the most vulnerable time for erosion is during the early part of the wet season when the rainfall increases but the vegetation has not grown sufficiently to protect the soil. On the evidence of these results it appears that soil erosion is most likely to occur during the stage of harvesting, soil preparation and replanting. In contrast, SLR values are low for the final crop stages, the period from good canopy cover to harvest. Individual crop SLR values do not correlate with each other due to the differences in harvesting and planting dates. In addition, the SLR values for all crops tend to increase with increasing erosivity. Unless conservation tillage techniques are used, the soils are dominantly bare leading to erosion. Therefore farmers should ensure that crops have an effective canopy cover during high rainfall periods. Residues have to compensate for the harvesting - planting - and first crop growth stages.

Kremer's (2000) quantitative study on soil loss for Mauritius strongly indicates the seasonal variation in soil loss under sugarcane. Minimum cover during periods of maximum

precipitation may lead to serious soil losses. These tendencies are also experienced in catchments under sugarcane in KwaZulu Natal, South Africa (Meyer *et al*., 1996). Up to 90% of soil loss takes place during replanting when soil loss of 30 t.ha^{-1} for a single storm is common. However, in the catchment, ratoon cane has a higher surface cover value during the early part of the rainy season, resulting in appreciably lower soil losses predicted. According to Renard *et al*. (1994), surface cover is the subfactor having the greatest effect on the soil loss ratio. In the case of ratoon cane, the root system is left intact during harvest. In addition, conservation tillage leaves plant debris on the ground between the harvest of one crop and the planting of the next. Therefore, harvested cane lands are not left bare and unprotected. For these reasons sugarcane has very low SLR values.

5.4 Support practice

P values for sugarcane (0.7059) and intercropped cane (0.6250) for this study compare well with P values for contour farming by McPhee & Smithen, (1984), and Singh *et al*. (1985) (Table 2 in Appendix 5). According to Renard *et al*., (1994) high ridges reduce overland flow's detachment and transport capacity. RUSLE calculations show that contour farming at the vegetable plot are inadequate. Other crops (banana and tea) in the catchment have very little or no support practices. During extreme rainfall events, high soil loss values can be expected without higher contour ridges.

The destruction of old cane stubble is a problem in plant cane and intercropping (MSIRI, 1997). Deep working implements such as the heavy disc harrow have to be used to remove stubble in the soil. The soil is consequently loosened and more susceptible to erosion.

RUSLE results indicate that buffer strips are ineffective on the boundaries of cane fields. The reason is that buffer strips are typically located at the base of the slope. Therefore, this practice does not trap eroded sediment on the hillslope and has minimal benefit as a P factor. The benefit of deposition depends on the amount and the location of deposition (Renard *et al*., 1994). Thus, several strips grown on the upper parts of the slope along the contour will be more effective.

5.5 Topography

Although the influence of slope on soil loss is subordinate to that of cover, as basal cover declines its influence increases (Snyman, 1999). According to Smith *et al*. (2000), the effect of

other erosion factors such as raindrop impact are aggravated by slope steepness. In addition, infiltration decreases with increasing slope, causing more overland flow and erosion. Long steep slopes, a common feature in the upper catchment, render the land extremely susceptible to erosion once the vegetation cover is degraded. A few land units in the RDAC, including units in the upper catchment area and the river valley, have very high LS values (above 4). As a result, the steep slopes in these areas are the main soil loss factor. The fact that topography is the dominating factor affecting the amount of soil loss in these areas is further substantiated from soil loss data from SLEMSA. Fortunately, most of these areas are covered by natural vegetation including forest and scrub. However, despite the dense canopy and surface cover of the natural vegetation in these areas, soil erosion is still prevalent due to the steep slopes.

In South Africa, according to Haarhof *et al*. (1994) the effect of slope steepness is significant on steep slopes of 20% or more. However, the amount of soil loss cannot simply be explained by variation in slope length and slope angle. Complex interrelationships exist between the microtopography, rainfall energy, plant cover and soil properties. At these localities poor soil conditions and excessive rainfall additionally contribute to soil loss. Moreover, results show that slope steepness plays an important role in the susceptibility of erosion of cultivated lands. Some of these land units with steep slopes contain banana plantations that are particularly prone to erosion. It is therefore suggested that no crop diversification or cultivation be carried out in the upper catchment area and along the steep slopes (>20%) of the *Rivierre des Anguilles* valley.

From the above discussion it is apparent that certain variables are more influential than others in affecting the outcome of the RUSLE and SLEMSA. The main factor affecting soil erosion in the catchment appears to be land use. However, an understanding of the connections between cause and response remains far from complete. This intimates that the interactions between the input variables are quite complex.

5.6 Soil loss results under current conditions

Calhoun and Fletcher (1999) estimated with the USLE, that the 55.5 km^2 Hanalei watershed in tropical Kauai Island in the south Pacific, lose a total of 4800 tons of sediment per year (1.4 ± 0.5 $t.ha^{-1}.yr^{-1}$). McMurtry *et al*. (1995) calculated lower sediment yields (2630 $t.yr^{-1}$ or 0.6 $t.ha^{-1}.yr^{-1}$) in a 42.9 km^2 canal of Oahu Island. Despite its smaller size (32.6 km^2), the RDAC show similar soil loss totals (4229 $t.yr^{-1}$ predicted by RUSLE) compared to the Hawaiian catchments

mentioned above. The RDAC has a much higher soil loss rate (11 t.ha^{-1}.yr^{-1} predicted by RUSLE and 22 t.ha^{-1}.yr^{-1} predicted by SLEMSA) compared to the Hawaiian catchments, since most of the catchment is under extensive cultivation. A total of 74% of the catchment is currently covered by sugarcane, including small patches of intercropped cane, pure stand vegetables, and banana – and tea plantations. Soil loss is minimal under the remainder areas covered by dense forest and scrub as well as urban areas.

5.6.1. Interactive effect of the input variables

An important feature of the derived soil loss maps, is the interactive effect of input variables. Different patterns in soil loss values between land units and/or land use types are a direct outcome of the different influences of the soil erosion factors on erosion. For example, although the R values (2139 MJ.ha^{-1}.mm.hr^{-1}) of the upper catchment are the highest, the effects of high plant cover results in very low soil loss values (0 – 5 t.ha^{-1}.yr^{-1}). Results also indicate different patterns in soil loss values within land use types. The variation in soil loss values under the same land use can be ascribed to differences in rainfall erosivity, soil erodibility, and slope gradient. These latter soil erosion factors also explain why soil loss under vegetables is sporadically lower than the soil loss under natural vegetation on steep slopes. Nonetheless, potential soil loss results seem to indicate a strong inverse relationship with vegetation cover. The crop management factor is most important in preventing these high soil loss values. This tendency has been proven by several other studies (*i.e.* McPhee, 1980; Smith *et al.*, 1995; Van Antwerpen and Meyer, 1996; Smithers, *et al.*, 1997; Smith *et al.*, 2000). Using the USLE and SLEMSA, Rydgren (1996) determined soil and nutrient losses under different management options in catchments of Lesotho, South Africa. Poorly conserved cropland loses on average (6-7 t.ha^{-1}) up to six times as much soil as does the well conserved cropland (1-2 t.ha^{-1}). Results from the rangeland plots show lower soil losses than those from the cropland plots. Therefore, crops or land use types with dense cover, such as forestry, usually give rise to very low predicted soil loss.

5.6.2. Comparison between current land use types: frequently disturbed versus infrequently disturbed crops

Sugarcane provides a dense cover within less than two months after regrowth or planting. In addition, soil under ratoon sugarcane is tilled on average every seven years, when new cane is planted. In between those seven years, the cane stubbles are left intact during harvest. As a result the mean soil loss values computed by the RUSLE for sugarcane are very low (1.5 t.ha^{-}

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[1].yr^{-1}).   These values correspond well with the soil loss values (0.2 – 5 t.ha^{-1}.yr^{-1}) under sugarcane obtained by the MSIRI (2000), using a rainfall simulator. The fact that little erosion takes place from sugarcane was further substantiated by the qualitative data from Kremer (2000). However, Kremer's qualitative hazard maps show that the erosion hazard increases greatly when the canopy cover of sugarcane decreases. These results remain speculative since ratoon cane, when harvested, does not leave the soil bare. As noted, the trash and cane stubbles protect the soil and reduce erosion by 10-50% (Yang, 1995; MSIRI, 1998a).

RUSLE predicts low mean soil loss values under natural vegetation (less than 1 t.ha^{-1}.yr^{-1}), as well as tea (0.5 t.ha^{-1}.yr^{-1}) - and banana (4 t.ha^{-1}.yr^{-1}) plantations.   Land management, especially the infrequency of disturbance, can mainly account for these low soil loss values. Soils under these land use systems are infrequently disturbed. Consequently, those soils have long since been consolidated and are relatively resistant to erosion (Hillel, 1982). Soils such as the LHL *Reduit* and HFL *Midlands* families are naturally more erodible than neighbouring soil families. The main reasons for higher erodibility values of these soils are higher silt contents and the unfavorable structure of the soils. Because of this and slope steepness, the infiltration capacity is restricted which can lead to high runoff (Smith *et al*. 1995). Fortunately, these scenarios are restricted to only a few small land units with moderately to steeply sloping areas of deeply weathered soils in the upper catchment area and valley.

Cropping systems such as intercropped cane, with less cover and frequently disturbing the soil, give rise to moderate predicted soil loss (13 t.ha^{-1}.yr^{-1}). Worst case scenarios occur on land units with steep slopes (>20%), high rainfall (>2400 mm) and poor cover (<30%). Those are the main reasons why the vegetable plot is affected by serious erosion (>80 t.ha^{-1}.yr^{-1}). The most important factors include poor management and ineffective conservation practices. Vegetables have a short 3-5 months crop cycle. Consequently, at least two crop cycles are run per annum and soil under vegetables is disturbed twice as much compared to annual crops. Newly tilled soil will be easily detached compared to a consolidated soil (Bergsma *et al*., 1996). Furthermore, the high erosion hazard under vegetables is attributed to the interaction of high rainfall erosivity with erodible soils. This is evident especially on the land unit in rainfall zone 2 (R = 1712 MJ.ha^{-1}.mm.hr^{-1}) with a HFL *Midlands* soil (K = 0.14 t.ha.h.ha^{-1}.MJ[-1].mm^{-1}), on relatively steep slopes (>20%). The finding for vegetables is supported by SLEMSA.

5.6.3. Comparison between RUSLE and SLEMSA results

RUSLE soil loss results are much lower compared to SLEMSA results. SLEMSA results are three to ten times higher compared to RUSLE predictions. SLEMSA predicted anomalous high soil losses on steep slopes and regions with high rainfall. Likewise, soil loss results predicted by SLEMSA are excessively high for scrub (58 t.ha^{-1}.yr^{-1}) growing in the upper area of the catchment. This is due to the model being very sensitive to changes in rainfall energy, while lacking sensitivity to changes in the vegetation cover (Smith *et al*., 2000). Differences in the results of the RUSLE and SLEMSA can be explained by mainly three reasons: their differences in structure, the different conditions in which each model was developed; and the different techniques in obtaining input values (Morgan, 1995). A theoretical model evaluation is considered further on page 121.

Generally, models signify a similar trend in soil loss rates between the cropping systems. Soil loss values display a strong distinct relationship between land use patterns and soil loss. A detailed study of the results indicates that decreasing rates of soil loss for each defined land use type correlate well with increase in canopy and/or surface cover. The majority of data have very low (0 - 5 t.ha^{-1}.yr^{-1}) to moderate (5 – 12 t.ha^{-1}.yr^{-1}) soil loss values, with only the vegetable stand leading to very high soil erosion rates (>80 t.ha^{-1}.yr^{-1}). Rates are generally highest on land units with steep slopes, high rainfall and poor vegetation cover. Steep slopes and high rainfall are most prevalent in the upper catchment area.

5.6.4. Comparison with SEAGIS

Soil loss estimated by SEAGIS is equivalent to results obtained through the RUSLE. The reason for the almost identical results is because both the RUSLE and SEAGIS received identical input values. However, this is not the case for SLEMSA. SLEMSA estimates higher soil loss rates under natural vegetation, whereas SEAGIS estimates higher soil loss rates under cultivated land. As mentioned above, it is presumed that SEAGIS and SLEMSA results vary significantly due to the fact that SLEMSA is not intended for use under natural conditions; and due to slight differences in calculating the factor values. Further discussion can be found in DHI (1999).

The RUSLE proved to be, in this study, a reliable estimate of soil loss under current conditions in the RDAC. However, confirmation of these findings is required. Although some of the estimated soil loss values of the models differed significantly, models signify a similar trend in

soil loss rates between the cropping systems. The average annual soil loss value under current conditions might not be a cause for great concern. However, quantitative soil loss results are important in their relation to soil loss under potential crop diversification. Due to the probability of crop diversification in Mauritius, its outcome had to be assessed. The following section discusses the effect of potential land use changes in the catchment on future soil erosion.

5.7 Soil loss under future land use change

An important component of the research was to estimate soil loss under possible diversification of agricultural systems. Mean and total soil loss values demonstrate the differences in soil loss between the current situation in the RDAC, and potential future crop diversification. Results reveal that predicted total values and the average annual soil loss per hectare increases significantly under vegetables and pineapple. The differences can be ascribed to the level of protection provided by the opposing crop systems. Under a similar set of environmental conditions, the average soil loss predicted for sugarcane and natural vegetation are significantly lower than the soil loss values predicted for pineapple and vegetables. Predictions of the RUSLE indicate that mean soil loss for the catchment will double under pineapple (increase by 100%), and quadruple under vegetables (increase by 300%). Under forest mean soil loss will decrease to almost zero.

Predictions clearly show that excessively high soil loss values (>150 t.ha^{-1}.yr^{-1}) with a mean of 42 t.ha^{-1}.yr^{-1} are estimated under pure stand vegetables. Mean and maximum soil loss values differ significantly due to the interactive effects of soil erosion factors. Excessively high soil loss values are predicted in the upper catchment area and valley sides with steep slopes ($>20\%$) and high rainfall (>2400 mm.yr^{-1}). The most important factors include poor vegetation cover, ineffective conservation practices and high rainfall. Results imply that significant erosion may occur during development of the crop. Steep slopes become the dominant factor when vegetation cover is poor. Therefore, the highest rates of soil loss are predicted on steep slopes with erodible soils. Steep slopes and erodible soils are limited to land units in the upper catchment area and along the river valley. Predicted soil loss in these areas is much higher (up to a 100 times or more) compared to the lower catchments area.

Proposed pineapple plantations appear to be associated with moderate ($12 - 25$ t.ha^{-1}.yr^{-1}) to extremely high (>150 t.ha^{-1}.yr^{-1}) erosion hazard with a mean of 20 t.ha^{-1}.yr^{-1}. Mean and

maximum soil loss values also differ significantly due to the interactive effects of soil erosion factors. It is postulated that soil loss will be very high during the introductory and early stages of pineapple development. Other sources of literature (Roose, 1975 cited in Bergsma *et al.*, 1996: 87; Elwell, 1976; McPhee & Smithen, 1984; Cooley and Williams, 1985) indicate that cover management together with heavy support practices may provide protection against erosion. Soil loss will decrease after crop establishment. Yet, appropriate erosion control measures will definitely be needed in order to minimise long term erosion problems. Long term erosion control would involve intensive measures. Such an erosion hazard infers that planning will need to carefully consider the balance between the probability of long term erosion damage and the maintenance needed to ensure the viability of pineapple plantations. Therefore, pineapple will not be viable in the upper catchment area and steep slopes of the valley. Pineapple should be confined to nearly level (0-2%) to gently undulating (2-4%) slopes of the lower catchment area.

Results indicate that no appreciable erosion damage (<4 t.ha^{-1}.yr^{-1}) will occur in the RDAC under commercial forestry. In Mauritius, selective logging provides near continuous cover. The dense cover of ground vegetation and tree litter on the surface leads to very low rates of erosion. In addition, the presence of a rootmat provides protection against drip from the canopy. According to Bergsma, *et al.* (1996), protection and sustaining of soil fertility are two of the most distinctive features of forestry. Trees maintain organic matter, nitrogen fixation and other processes. Furthermore, after the establishment of all the inputs necessary for agroforestry, the system can be highly cost effective. However, periodic damage from cyclonic winds is a limiting factor to the accrued benefits of forestry. In addition, the planting of trees for timber is not always very profitable in Mauritius (Ministry of Agriculture and Natural Resources, 1999). Nevertheless, it still remains a vital land use on account of the protection it affords to the catchment. As noted above, dense forest cover compensates for high rainfall erosivity and steep slopes in the upper catchment area. Natural forest also regulates ground water. Therefore, natural as well as commercial forests in the upper catchment area and along the steep valley slopes should not be diversified into other agricultural systems.

In conclusion, results indicate that crop diversification should lead to accelerated erosion. Soil will become more at risk of erosion under vegetables and pineapple. Pineapples will provide more cover after establishment and cause less erosion (50%) than vegetables. However, results

indicate that the interactive effect of the topography and rainfall, combined with inefficient support practices, would result in extensive soil loss. Most of the erosion under alternative cropping systems is predicted in the upper catchment area and valley sides of the catchment. Due to high rainfall and steep slopes, the predicted soil losses in the upper catchment area and valley sides are significantly higher (up to a 100 times or more), compared to the lower catchment area. These alarmingly high values should give planners an indication of the risk involved with crop diversification. Soil erosion will become the most pervasive form of soil degradation and is a subject of increasing concern because of its implications for food production for an increasing Mauritian population.   Although food crop production is expensive, diversification of cropping systems has already taken place in certain areas. Due to economic constraints, further diversification seems very likely. Other agricultural systems that are scattered on Mauritius, which may also contribute to further diversification or replacement of sugarcane, include Litchi, Mango and various Citrus species such as Orange, Lemon and Grapefruit. There has been increasing interest in Litchi due to lucrative prices on the local market and an attractive export market (Ramburn, 1997).   The continuing process of diversification can only be viable with intense planning and assessment or prediction of long term changes outside the scope of this text. For agricultural intensification and diversification to be successful, efforts of several different sectors should be coordinated. Information on the severity of erosion can be linked with data from land suitability surveys (Arlidge and Wong You Cheong, 1975; Jhoty *et al.*, 2001), and used for delineating areas of land suitable for crop diversification.   Considerably more research is required before more profitable cropping systems are installed. It is therefore recommended that research in crop diversification should be intensified.

5.8 Soil life and soil loss tolerance

Tolerable soil loss and the soil life concept are recommended as a good tool for communication with agronomical planners. Soil life can be defined as the period a soil can be used for production under present conditions of erosion (Bergsma *et al.*, 1996). Having the soil formation rate coupled with the bulk density, one can calculate the depth of soil loss over a certain time period. In the Maphutseng area in Lesotho, Rydgren (1996) estimated that the top 10 cm would be lost in 37 years with an average soil loss of 36.4 $t.ha^{-1}.yr^{-1}$ and a bulk density of 1.35 $g.cm^{-3}$. On the contrary, the soil life span for rangeland is between 2700 and 6800 years before net soil losses reach 10 cm. For the purpose of this exercise the average bulk density of (0.98 – 1.13 $g.cm^{-3}$) for the RDAC is considered.   Under current conditions for the

RDAC, the average loss of 11 t.ha^{-1}.y^{-1} would amount to an average reduction of ±1 mm.yr^{-1} soil depth.   Further refinement is necessary for Mauritian conditions.   Furthermore, the permitted soil loss calculated in such a way does not take into account the loss of valuable nutrients and good structure in the topsoil, the off-site effects of soil loss, and the exponential character of soil loss (Bergsma *et al*., 1996).   Soil formation in general, or reestablishment of the soil after being eroded, is usually very slow (Elwell, 1976).   Correspondingly, even low rates of soil loss cannot be interpreted as realistic permissible losses.

According to Renard *et al*. (1994) soil loss tolerance defines the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically. If computed soil loss is greater than the soil loss tolerance value assigned to the particular soil, erosion is considered excessive. Tolerable soil loss can be determined with bulk density, the rate of soil loss, and the soil formation rate. McPhee and Smithen (1984) proposed a range of soil loss tolerances between 3 t.ha^{-1}.yr^{-1} for shallow soils and 10 t.ha^{-1}.yr^{-1} for deep alluvial soils. Smith *et al*. (2000) also proposed the soil loss tolerance for the basalt-derived soils in Lesotho to vary between 3 and 10 t.ha^{-1}.yr^{-1}. In the absence of research data, the MSIRI (2000) accepts the general tolerable limit for soil loss of 11 t.ha^{-1}.yr^{-1} or 0.7 mm of topsoil for Mauritius. However, according to Bergsma *et al*. (1996), these upper limits are considered far too high for tropical soils. In addition, soils in the study area have great variations in soil depths. The soil loss tolerance for shallow soils is thus not accounted for.   The medium textured Humic Ferruginous Latosol soils with unfavorable subsoil characteristics should have much smaller tolerable soil loss rates than do deep Low Humic Latosol soils. Although average annual soil loss values for some crops does not exceed the soil loss tolerances significantly, erosion may increase substantially under crop diversification. The study indicates that some of the average annual soil loss rates predicted within the RDAC exceed the proposed soil loss tolerances. Predicted mean soil loss results for vegetables (42 t.ha^{-1}.yr^{-1}) and pineapple (20 t.ha^{-1}.yr^{-1}) do exceed the soil loss tolerance of 11 t.ha^{-1}.yr^{-1} on slopes steeper than 5%.   Therefore, in respect to soil loss tolerance, full stand pineapple and vegetables, should only be allowed on level to gently undulating slopes (0-4%) within the RDAC.

Due to the lack of data on soil formation rates for the soils of Mauritius, estimation of tolerable soil loss needs further investigation. Tolerable soil loss and the related term soil life could be the next step for illustrative purposes.   When the predicted losses are compared with site specific soil loss tolerances, the RUSLE can provide guidelines for affecting erosion control by

specified practices (Morgan, 1995). Such results can be used so that if an acceptable value of soil loss is chosen, the crop management value C required to limit soil loss accordingly can be calculated. Consequently, any combination of cropping for which the predicted erosion rate is less than the rate for soil loss tolerance may be expected to provide satisfactory control for erosion. The alternative cropping system best suited to a particular area may then be selected.

5.9 Gullies

Gullies are formed through a complex series of processes dominated by concentrated surface water flow. Concentrated runoff periodically removes the soil and can result in deep incised channels. Garland (1995) and Bull and Kirkby (1997) provide detailed discussions of the processes (such as scour, headward erosion and widening) and stages (initial - incision - maturing - and stabilizing stage) of gully erosion. Two gullies (Figures 4.30 and 4.31 on page 92 and 93) in the RDAC developed mainly due to runon from a road. A third gully (Figure 4.32 on page 94) is well developed. Gully walls and gully heads are still in the process of down-wearing while the gully floors are incised. The gullies also have a negative effect below its mouth termed a gully fan, consisting of deposits from the gully channel. Without control the gullies will probably develop extensively. Possibilities for control include, stone mattresses, grassed waterways, various drop structures and gully checkdams (Bergsma, *et al*., 1996). These measures might prevent the lateral or headward extension of the gullies. Questions still remain concerning the rate of development of these gullies. Although the RUSLE and SLEMSA do not account for gully erosion, these processes are not considered significant methods of sediment movement in the catchment since field observations revealed only three gullies in the RDAC. However, a few other catchments of Mauritius are extensively gullied and may need to be considered differently. Parameters to predict gully growth and sediment yield contribution should be given consideration in future research.

5.10 Model limitations

As noted above, the study applied the RUSLE and SLEMSA to predict soil loss. In meeting this objective, the models displayed severe limitations. The RUSLE and SLEMSA do not:

- Yield exact or definite outcomes;
- Accurately estimate erosion for a specific storm event, season or a single year;
- Estimate soil erosion on a catchment scale, but are designed for soil loss prediction on single slopes;
- Account for erosion by concentrated flow, stream channels;

- Account for gully erosion, and mass movement;

- Estimate onsite deposition;

- Accurately estimate sediment yield from fields using delivery ratios;

- Provide information on sedimentation characteristics required to estimate potential deposition and transport of chemicals by sediment.

A detailed discussion of these limitations follows below.

5.10.1. Data variability

In soil erosion models, every factor value has its associated uncertainty caused by different sources of variance (Higgit, 1993; Lark and Bolam, 1997). This variability is due both to natural and measurement variability. Furthermore, there is considerable interdependence between the soil erosion factor values. Although some of these interactions are considered, other sources and their errors are unavoidable (*e.g.* the variability of micro climate or chemical properties of the soil). Spatial variability within the RDAC can be attributed mainly to weather, but also to topography, soil properties, and land use. As a result, considerable variation in erosion rates can be expected within any particular land unit. All of these variations consequently result in significant differences in soil erosion rates at various parts of the catchment as well as on individual hillslopes. Due to environmental variability models have to concentrate on those processes having the greatest influence over the output, and ignoring those having very little effect (Morgan, 1995). Thus, empirical models are based on statistical analysis of only the important factors in the soil erosion process and, consequently, yield only approximate outcomes. More research is required to develop procedures for analysing uncertainty in model predictions.

5.10.2. Non-reliable input data

Wishmeier and Smith (1978) cautioned the user of the USLE that the greatest potential source of error is in the selection of inappropriate factor values. The conditions to be evaluated must be clearly defined. The P factor is the least reliable due to field variabilities (Toy *et al*., 1999). In SLEMSA, F values needed for the calculation of the erodibility factor K, have to be derived subjectively. This may lead to invalid soil loss results, since the accuracy of the soil factor K has a profound effect on the accuracy of the soil loss estimate (Elwell, 1976).

5.10.3. Unsuitable conditions for models

The greater concern about the sugarcane industry and the consequences of agricultural diversification, necessitates the application of these models to conditions beyond its database. However, the level of uncertainty and error increase when soil erosion prediction models are used in an environment significantly different from that for which it was developed. Although the RUSLE is described as "universal", its database is restricted to the USA. Both (R)USLE and SLEMSA were developed from data derived from small plot studies. Therefore, the validity of extending it to larger areas may be questionable. Measurements at this scale cannot be "scaled up" to evaluate erosion for a whole catchment (Dickonson and Collins, 1998). Although the GIS-approach entails dividing the catchment into many cells, making the application of field scale models a practical option (Wallace, 1997), use of the proposed models outside of conditions for which it was developed for, may lead to large errors. For these reasons it is advised that soil erosion models and their results need to be tested by comparison with field data. Unfortunately, given the limited temporal period of measurement, the model predictions could not be tested and validated according to field plot data. It would have been exceptionally difficult to obtain field plot results that are applicable under larger and more varied field conditions of the RDAC. In addition, results from field plot data would have been obtained from a restricted data set under limited conditions that may not have been representative of the whole catchment.

5.10.4. Lack of data: rainfall intensity

A major limitation to a wider use of the RUSLE in the tropics is the lack of data to estimate R. Long term intensity data are not available for Mauritius and were thus calculated using equations such as the Modified Fournier Index. In addition, the rainfall factor R of the (R)USLE is based on average values that work well for the Great Plains in the USA (Hallsworth, 1987). However, modelling of weather parameters on Mauritius has shown substantial variations in its climatic characteristics (Rughooputh, 1997). In addition, results from the subtropics (Edwards, 1985) have shown that the quantity of soil removed is determined by the occasional erosive storm. Therefore, estimations of EI_{30} using equations cannot always give reliable erosivity results.

5.10.5. Runoff

Runoff is a major constituent to which soil loss is closely related. An important scientific limitation of the RUSLE is that it does not represent fundamental hydrologic and erosion

processes explicitly (Renard *et al*., 1991).   Runoff is incorporated in the erosivity factor. RUSLE accounts for runoff by classifying the soil into a permeability class and a ratio of rills to interills. The reason is that soil erosion by water results from both rainfall and runoff. Rain intensity is not only significant for detachment, but also for generating overland flow. The amount and intensity of runoff affects the formation of rills as distinct from interrill erosion, which is of great influence on the amount of soil loss. However, because of the way in which the land's surface modifies the responses of erosional systems to a given runoff event, distributions of runoff and erosion cannot be linked in any simple way to distributions of rainfall (Boardman and Favis-Mortlock, 1997).   These responses are also due to temporal changes in vegetation cover and soil properties. Therefore, a major weakness of the RUSLE (and SLEMSA) is the failure of the R factor to adequately express hydrology. The effect of runoff, as might be reflected in a hydrological model such as the Modified USLE (MUSLE), is not represented directly.

5.10.6. Single events

As stated above, soil loss results are strongly affected by low frequency, high magnitude events. Soil loss from any single event will differ appreciably. Due to unpredictable short time fluctuations in the levels of influential variables such as rainfall, soil loss equations are substantially less accurate for the prediction of specific events (Renard *et al*., 1994). Both the RUSLE and SLEMSA equations were designed to long term average annual values (Risse *et al*., 1993). Irregular cyclone activity in Mauritius, limits the application of the RUSLE and SLEMSA.

5.10.7. Other processes of erosion: gullies and mass movement

The biggest limitation of SLEMSA, is that it only takes interrill erosion into account. RUSLE accounts for both rill and interrill erosion. However, rill and interrill erosion are usually not the only source of soil loss from a catchment, since mass movement also contributes to overall soil loss (Calhoun and Fletcher, 1999). Furthermore, in regions where gully - and subsurface erosion is prominent, the RUSLE will underestimate soil losses (Biesemans *et al*., 2000). Field observations revealed that mass movement, as well as gully - and subsurface erosion, in the RDAC is minimal. Therefore, these erosion processes are not considered significant methods of sediment movement in the RDAC.

5.10.8. Problems with the topographical factor

The soil erosion factor value that poses the most problems and is most complex, is the LS factor (Renard *et al*., 1994; Dickinson and Collins, 1998; Biesemans *et al*., 2000). One of the reasons is that the slope length involves subjective judgments and different users may choose different slope lengths for identical situations. Although digital terrain modelling improves limitations of the LS factor on catchment scale, the resolution of a DEM is usually too low to describe the micro-topography (Engel, 1999). Convex, concave and straight slope forms must be distinguished, instead of assuming a mean slope steepness (Liu *et al*. 2000). For instance, the average soil loss from a convex slope is usually more than that for a uniform slope with the same average steepness. Renard *et al*. (1994) stresses the importance of critical slope lengths, which also is believed to limit the accuracy of LS values determined by SEAGIS. Critical slopes are long slopes more than 300 feet (90 m). Moreover, the accuracy of LS estimates for very steep gradients (>35%) will possibly be lower. Therefore, the slope gradient and slope length parameters of SEAGIS remain questionable. However, here it is noteworthy that SEAGIS cancels subjective measurements, as well as sampling and measurement errors. As stated above in the Methodology, digital terrain modelling is an essential method of determining the topographic factor for use in soil loss studies at catchment scale (Flacke *et al*., 1990).

5.10.9. Sediment transport and deposition

Foremost, the term soil erosion should be restricted to detachment or entrainment of soil particles, thus distinguishing it from deposition or sedimentation and sediment transport. The RUSLE can be used with a sediment delivery ratio (SDR) to describe the effects of sedimentation between the area of erosion and downstream. The SDR can be described as the reduction of the total eroded volume by deposition within the catchment (Wischmeier & Smith, 1978). However, delivery ratios can be extremely variable and site specific. Measurement of sediment yield from plots or subcatchments cannot be directly extrapolated to large catchments since the effect of the sediment delivery ratio is not easily quantifiable (Dickinson and Collins, 1998). The results from both models do not refer to the sediment yield, which is the amount of eroded material that leaves the catchment at a designated point. Moreover, soil material eroded from a slope may be deposited along various areas within or outside the catchment. Thus, the RUSLE and SLEMSA do not account for deposition and only estimate the sediment leaving a field within the catchment. The RUSLE and SLEMSA should, therefore, not be used to estimate sediment yield from catchments (Morgan, 1995). Efforts have been made to develop

physical-or process-based models, which predict the spatial distribution of both runoff and sediment over the land surface during individual storms. Morgan (1995) and Bergsma *et al*. (1996) discuss the following models: Chemicals Runoff and Erosion from Agricultural Management Systems (CREAMS); Water Erosion Prediction Project (WEPP); Griffith University Erosion Sedimentation System (GUESS); and the European Soil Erosion Model (EUROSEM). These models, however, require extensive and detailed data that are seldom available in the tropics. Requirements for on-site calibration and field testing may further preclude their use in areas with limited history of field experimentation. Because these models are so massively data intensive, their usefulness in Mauritius is very limited.

Estimation of sediment deposition was not part of the study and has to be given consideration in future research. This may include the following: The identification of the principle sediment-generating mechanisms; construction of a sediment budget; sediment sources will have to be mapped, including sediment storage areas; to obtain long term records of sediment transport and deposition on Mauritius; the establishment of the Sediment Delivery Ratio (SDR); the measurement of sediment transport and sediment accumulation off-site, which must be a measure of the transport capacity of the overland flow (Biesemans *et al*., 2000); to evaluate the downstream impact of land use changes; and suspended sediment concentrations need to be related to flow records[3].

5.11 Theoretical model evaluation

The success of any model must be judged by how well it meets its objectives. Failure, however, does not make them ineffective models, but may result from poor conceptualization of the problem or inaccurate representation of a particular element in the model. The accuracy of model predictions is usually tested by comparing predicted with measured values. Unfortunately, as stated above it was not possible to validate the models according to field plot data. Since very little research on soil erosion for Mauritius has been conducted, the predicted quantitative soil loss results could not be evaluated against other studies. It was not in the scope of the study to develop a set of data that will measure the performance and accuracy of the models. Instead, following below is a brief discussion of theoretical evaluations of empirical models done by several authors under different conditions. The discussion is based

[3]. Information from email with Dr. E. Dollar, Centre for Water in the Environment, School of Civil and Environmental Engineering, University of the Witwatersrand, 22 November 2001.

on the application and performance of the two models under different conditions. Unfortunately, the published literature provides only a limited number of direct measurements for tropical conditions. On this subject, Risse *et al*. (1993) and Smith (1999) discuss literature that serves as a basis for theoretical evaluations.

5.11.1. The SLEMSA

SLEMSA is a widely used soil loss model in Africa (Elwell & Stocking, 1982), including study sites outside the country of its development, Zimbabwe. For example, Smith *et al*. (1999) investigated the application of SLEMSA in southern Africa; and Rydgren (1996) validated soil loss estimates obtained by SLEMSA to actual field measurements in Lesotho. Other examples include soil erosion assessment in Malawi by Paris (1990), and in Richards Bay in South Africa by Schulze (1979). According to Hudson (1987), SLEMSA proved to be a good index of the erosion hazard within the South African Drakensberg catchment areas. The studies mentioned above indicate that SLEMSA is considered to fairly accurately predict soil loss from a variety of land uses, despite being applied to conditions beyond its database. In the RDAC, these conditions include mountainous terrain and non-agricultural conditions of the upper catchment area.

SLEMSA, however, was not intended for use on steep terrain (Smith *et al*., 2000). The evaluation done by Hudson (1987) also concludes that the slope gradient parameter of SLEMSA is questionable.   Any small increase in slope steepness above 20% has a disproportionately large influence on the calculated erosion hazard due to an over-estimation of soil loss values from colinearity between the S and L factors. An equation developed by Hudson (1987) should be applied for steep slopes between 20 to 60%. The modification includes the L factor, combined with the rainfall energy E factor, and the inclusion of a complex slope profile factor. This modification, however, is not incorporated into SEAGIS that has been used to compute the SLEMSA topographical factor X. Nonetheless, for catchment analyses, the productive accuracy of the modification plus the time consuming calculations required does not warrant its inclusion into SLEMSA.

The studies mentioned above also stress that SLEMSA soil loss estimations are very sensitive to slight variations in rainfall energy. Slight increases in the annual rainfall amount result in huge increases in the predicted soil losses. This also contributes to the excessively high soil erosion rates in the RDAC on steep slopes where the rainfall is high. In addition, SLEMSA

shows little sensitivity to changes in vegetation cover. Dense cover of scrub and forest produces only marginal changes in total soil loss. This explains the high soil erosion rates predicted under scrub and forested areas on the steep upper slopes of the catchment. As a result, soil loss values obtained by SLEMSA should be viewed as relative values. Any predictions should be regarded as ratings of the soil erosion hazard. Yet, SELMSA is judged useful as an index of the spatial distribution of soil loss and SLEMSA is especially useful in regions with limited input data.

5.11.2. The RUSLE

The RUSLE has been widely tested all over the globe (*e.g*. Busacca *et al*., 1993; Biesemans *et al*., 2000; Smith *et al*., 2000; Wang *et al*., 2000). The study of Biesemans *et al*. (2000) indicates the possible power of the RUSLE model when applied in agricultural watersheds in Belgium. In combination with methods presented in that paper, the RUSLE is capable of predicting on-site soil losses and even off-site sediment accumulation with acceptable accuracy. Smith *et al*. (2000) applied the RUSLE in an initial soil loss study in the Lesotho Highlands. The study proved RUSLE to be a promising tool for conservation planning on catchment scale under different conditions.   The most significant characteristic of RUSLE is that the model allows for detailed and accurate description of input variables, especially for vegetation characteristics. Several subfactors are taken into account, which are applicable to a wide range of conditions. RUSLE proves to be dynamic (Smith *et al*., 2000), and its flexibility is believed to make it advantageous for application in the RDAC. However, a lack of input data, especially for the tropics, may restrict the application of RUSLE. According to Montgomery *et al*. (1997) the reliability of RUSLE estimates depends in part on how complete the user's knowledge is of operator's tillage and management practices. A need is once again recognized for improved verification of the results against long term measured data from field plots.

Based on the work of Risse *et al*. (1993), Rapp (1994), and the judgment of the RUSLE development team referenced by Toy *et al*. (1999), the RUSLE is the least accurate (50%) where soil loss is less than 0.25 t.ha^{-1}.yr^{-1} or where soil loss is greater than 123.80 t.ha^{-1}.yr^{-1}. At these levels, soil loss is simply regarded as low or high respectively. Furthermore, the (R)USLE has been found to be less accurate at extreme slopes and climatic conditions (Manrique, 1993). In general, studies have shown that the RUSLE overpredicts soil loss for

large values, and underpredicts for lower values. Similar outcomes have been found for SLEMSA in extreme conditions (Hudson, 1987).

The studies mentioned below performed sensitivity analyses of the RUSLE to different environmental conditions, in order to place more confidence on the interpretation of results. Smith *et al*. (2000) performed a sensitivity analysis of the RUSLE when applied in the Lesotho Highlands in South Africa. Results reflected sensitivity of the model for the selection of realistic local input values for even minor changes in management practices. Similarly, Wang *et al*. (2000) established that soil loss is quite sensitive to canopy cover, crop residue and surface roughness. The responses of the RUSLE to changes in these input parameters and the output of the model appeared rational and showed acceptable trends and magnitudes in soil loss patterns. Risse *et al*. (1993) argues that the cover management and topographic factors had the most significant effect on the overall USLE efficiency. Former sensitivity analysis by Wang *et*. *al*. (2000) of the RUSLE also indicates that soil loss is most sensitive to the LS factor. This indicates that most of the research emphasis should continue to be placed on the C and LS parameters. However, lack of accurate historical records of these conditions necessitates that C and LS be estimated which leads to uncertainty in the management input files used in the RUSLE.

5.11.3. RUSLE and SLEMSA by comparison

The soil loss studies mentioned above were all executed under different conditions and show the potential of prediction models outside its country of origin. The theoretical evaluations and sensitivity analysis performed on the two models clearly show the advantage of the more flexible and dynamic structure of the RUSLE against the strict empirical structure of the SLEMSA. Based on the results above and of the theoretical evaluations discussed, the RUSLE proves to be the most suitable model of application in the RDAC. The RUSLE provides a dynamic approach to predicting soil loss and proved to be a promising tool for conservation planning. However, in order to effectively evaluate the accuracy of the RUSLE and SELMSA for the Mauritian conditions, a well defined data set will be needed. Therefore, more research is needed to assess the confidence limits for the erosion estimates generated by the RUSLE and SLEMSA.

5.12 Research needs and recommendations

5.12.1. Future research on soil erosion for Mauritius

Foremost, estimations of the RUSLE and SLEMSA need to be validated by measuring actual erosion using field plots. It is also recommended that more generalized investigations be instigated to determine soil loss for the whole island. In addition, the measurement of rainfall intensity is highly recommended. Rainfall intensity data can be used to compile isoerodent maps that will greatly improve and assist future research on soil erosion for Mauritius.

5.12.2. Research on potential crop diversification

In designing and evaluating soil conservation alternatives for a site, the planner should know the impact of a proposed crop system on soil loss. It is therefore recommended that an extensive effort have to be made to determine erosion factor values for a wider range of crops and conditions in Mauritius. Moreover, questions should be addressed concerning the probability of meeting specified soil loss tolerance levels with a given crop system. The RUSLE can be rearranged to estimate the requirements necessary to reduce the amount of soil loss under a certain chosen scenario. For example, if an acceptable soil loss value is chosen, the land use (crop management factor C) required to reduce soil loss to that value can be calculated. Changes in tillage dates, different tillage implements, new crop rotations, strip cropping, terraces and reduced tillage can all be evaluated for their potential in controlling erosion. This information will provide the user a more realistic means of making management decisions and performing cost benefit analysis. In this way appropriate cropping systems can be recommended.

5.12.3. Crop suitability

Additional fruits of economic importance to Mauritius include litchi, mango, papaya and citrus trees (Jawaheer, 2001). It is noteworthy that the potential profitability of these fruits is considerably higher compared to that of sugarcane. Although best yields and profit are sought, it is important to ensure that adequate protection of the limited natural resources is maintained. Some forms of land use appear to be highly profitable in the short run, but in the long run these may lead to serious land degradation. Such consequences would outweigh short term profitability. Therefore the emphasis should shift from profit to long term productivity. According to Proag (1995), any soil within a land unit can be made productive with adequate capital investment. Arlidge and Wong You Cheong (1975) recognised three types of improvements necessary for making unsuitable land completely suitable for other food crops:

implementation of intensive irrigation systems; derocking; and bench terracing. Such activities, however, require substantial capital investments and will have a major effect, permanently changing the characteristics of the land, including irreversible negative impacts. For example, in the case of Humic Ferruginous Latosol *Midlands* soil of the superhumid zone, the potential returns are so low that they should be left under their natural vegetation of forest or scrub. Forested areas also play an important role in ground water control and groundcover. Therefore in the upper catchment area, a change in crop type does not appear to be suitable. Further crop diversification desire a complete land suitability evaluation. Such an approach has to include a basic inventory of the following (Meyer *et al*., 1996; Toory and Tonta, 1997; Govinden, 1990): land resource data; ecological requirements; economics of land use; new technologies; transport; marketing; and the attitudes and goals of people affected by the proposed changes.

5.12.4. Small-scale planters

At present, small-scale planters produce on average 25 tonnes cane less per hectare than miller planters (Toory and Tonta, 1997). The majority of small-scale planters have fields that are less than 0.5 ha. In a broader perspective, the modernization and the long term viability of the small-scale planters will only be possible through the grouping of planters into larger land area management units (LAMUS). The small-scale planters will have to group themselves on a co-operative basis in order to cope with labour and transport constraints during harvest. The project, however, has not progressed as initially expected. Some small-scale planters have already made a shift to more profitable crops such as vegetables. Therefore, physical and socio-economical research will have to be extended to promote a better understanding of small farming systems in terms of crop diversification. Areas belonging to small-scale planters, especially diversified crop systems can be targeted with detailed investigations, including erosion control works. Furthermore, it is important to appreciate the perceptions and skills of small-scale planters, and to formulate locally appropriate site-specific conservation and development strategies. This could be achieved through the process of participatory rural appraisal (APR), described by Beckedahl *et al*. (2001).

5.12.5. Sustaining the sugar industry

A possibility exists that sugarcane cultivation might be diversified into other agricultural systems, since the sugarcane industry is currently facing tremendous economic constraints (Mauritius Sugar Syndicate, 2001). The problem is compounded by factors such as rockiness,

lack of irrigation, gaps in cane fields, the cultivation of non-recommended varieties and maintenance of old ratoons that have a lowering effect on productivity (MSIRI 1997; MSIRI,1998a; MSIRI, 2000). As a result, crop diversification is promoted to attain a certain degree of self-sufficiency in food production. In terms of soil loss, however, it is important to sustain the sugar industry since sugarcane is a soil conserving crop. The sugarcane crop is a good conservation agent and together with appropriate farming techniques, ensures that soil losses are kept to a minimum. Sugarcane provides good cover and ratoon cane requires minimum tillage operations. Sugarcane is also very versatile because it can tolerate a wide range of soil and climate conditions. Profitable yields have been obtained on steep slopes with shallow and stony soils. Moreover, sugarcane has developed as a monocrop over the centuries because of its high degree of resistance to cyclones.

5.12.6. Intercropping

Another possible method of sustaining the sugarcane industry is by intercropping. Through intercropping, agricultural lands can be diversified without replacing sugarcane fields entirely. Much research has been carried out on the principle and practices of intercropping (Govinden, 1990; MSIRI, 1997; MSIRI, 1999; MSIRI, 2000). There are a few important disadvantages with intercropping. Intercrops including the sugarcane (plant cane), having a one year crop cycle, have to be harvested annually. Consequently, the soil is disturbed more frequently than ratoon cane, making the soil more susceptible to erosion. Another disadvantage is that the width of cane rows has to be altered (widened). Furthermore, sugarcane facilitates energy production, whereas vegetables or intercrops do not. Future research on intercropping will have to focus on higher production by adopting high-yielding varieties and appropriate sustainable production techniques.

5.12.7. Application of results

The study shows the potential of two empirical models in soil conservation and research planning. Results may be interpreted as a pilot study to develop soil loss research for the whole island, and to identify research priorities. Furthermore, results can ideally be used to link erosion susceptibility, land capability and conservation treatment, aiding land use planners in decision making in terms of areas suitable for land use under diversified conditions. However, conclusions reached in the RDAC will not necessarily apply equally well in another catchment. Different areas have to be considered independently. Accurate soil erosion factor values for all land units would make it possible to generate erosion hazard maps for the whole

island. Erosion prediction maps compiled for the RDAC, should be extended for the rest of the island, and also updated after changes in land use have occurred. It is therefore suggested that empirical soil loss models still have to be applied to their full potential in Mauritius.

Chapter 6: __Conclusion__

Two models, the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1994) and the Soil Loss Estimator of Southern Africa (SLEMSA) (Elwell, 1976), were used in conjunction with a GIS to compile soil erosion prediction maps of the *Rivierre Des Anguilles* catchment (RDAC) in Mauritius. These models, as well as the GIS application termed Soil Erosion Assessment using GIS (SEAGIS) (DHI, 1999), were used to investigate average annual soil loss from the RDAC under key management practices. Moreover, the study was an attempt to predict the consequences in terms of soil erosion under potential future conditions in the RDAC. Using the RUSLE in a GIS, it was possible to estimate the soil loss for different future scenarios, given information on the mean and variability in vegetation parameters. The study also provides guidelines and methods for using empirical equations and GIS technology as tools for soil loss prediction in Mauritius.

As stated, prediction models are interfaced with a GIS in previous studies (*e.g.* Flacke *et al*., 1990; Busacca *et al*., 1993; Desmet and Govers, 1996; Mitasova *et al*., 1996; Pretorius and Smith, 1998; Breetzke, 2004). ArcView 3.2 was used as a tool for capturing, manipulating, integrating, storing, analyzing and displaying data from a variety of sources. The catchment was subdivided into 8 distinct land use types including: Frequently disturbed land use types (sugarcane, intercropped sugarcane, and a vegetable stand); and Infrequently disturbed land use types (banana plantations, tea plantations, scrub, forested land and urban areas). Due to spatial variation, the catchment was further subdivided into 37 land units. This was done for modelling purposes and in order to collect representative values for factors governing soil loss. Based on digitized maps of soils, precipitation, topography and land use, soil erosion factor maps could be derived. The following conclusions can be drawn from the study:

(1) Erosivity values in the upper catchment area (1712 - 2139 MJ.ha^{-1}.mm.hr^{-1}) are four to five times higher than the lower coastal area (619 MJ.ha^{-1}.mm.hr^{-1}). The high erosivity values in the upper catchment area are of major importance on any poorly vegetated, steep slope (Lal & Elliot, 1994; Evans, 2000). Fortunately, it is apparent that the well vegetated upper catchment area does not experience excessive erosion rates. Intensive cultivation of the upper catchment area, however, may lead to accelerated rates of erosion. Crop diversification will most definitely accentuate erosion problems. Therefore, the upper catchment area should be regarded as highly erosive, which renders it unsuitable for cultivation without proper

conservational measures. For this reason alone it is suggested that the natural vegetation in the upper catchment area, and along the steep valley slopes, should be left undisturbed.

(2) <u>As results from the RULSE indicate, erodibility values vary from low to medium between 0.074 and 0.147 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}.</u> Erodibility values vary mostly according to aggregation, base saturation, and particle size (El-Swaify and Dangler, 1976 cited in Renard *et al.*, 1994: 78). For these reasons the Humic Ferruginous Latosol (HFL) *Belle Rive* family is the least erodible. Although this soil has a relatively high modified silt content, its low erodibility value can mainly be explained by fairly strong and stable aggregation and a relatively low base saturation value (Parish and Feilafe, 1965). Low erodibility values are also attributed to relatively high organic matter contents and infiltration rates (Bergsma *et al.*, 1996). In the catchment, however, the amounts eroded are not so clearly related to soil type. It appears that soil type will only be a prominent soil erosion factor when vegetation cover is reduced. Soil erodibility in the catchment seems to depend heavily on land use. Therefore, the extent and frequency of erosion is implicitly related to the crop factor C.

(3) <u>In general, the crop management factor is mainly a function of the frequency of disturbance, canopy cover and residual effect.</u> This tendency has been proven by several other studies (Wischmeier and Smith, 1978; Hallsworth, 1987; Higgit, 1993; Garland, 1995). For this reason, soil loss under sugarcane is considered to be minor when compared to vegetables and intercropped cane. Sugarcane has low C values (±0.0110) because: sugarcane provides a dense cover within less than two months after regrowth or planting; harvested cane lands are not left bare and unprotected; and crop residues are left on the ground. Likewise, forested land also has a low C value (0.0010) due to a great basal cover, including a complex network of roots immediately below the soil surface. A high percentage of rock on the surface is also very effective against erosion. Similarly, land management, especially the infrequency of disturbance, can mainly account for the relatively low C values for tea – and banana plantations. Soils under these land use systems are infrequently, or by no means, disturbed. In contrary, vegetables have a short 3-5 months crop cycle and two crop cycles are run per annum. The soil under vegetables is therefore disturbed twice as much compared to annual crops.

(4) <u>Soil Loss Ratio (SLR) results illustrate that the most vulnerable time for erosion is during the early part of the wet season when rainfall increases but vegetation has not grown</u>

sufficiently to protect the soil. The RUSLE combines the effects of all the C subfactors to compute a SLR for the crops that are frequently disturbed (sugarcane, intercropped cane, and vegetables) (Renard *et al*., 1994). On the evidence of these results it appears that soil erosion is most likely to occur during the stage of harvesting, soil preparation and replanting. Therefore farmers have to ensure that crops have an effective canopy cover during high rainfall periods. Support practices such as adding residues have to compensate for the harvesting - planting - and first crop growth stages.

(5) RUSLE calculations show that current support practices, such as contour farming at the vegetable plot, are inadequate. Banana and tea plantations have very little or no support practices. During extreme rainfall events, high soil loss values can be expected without higher contour ridges. In addition, the destruction of old cane stubble in plant cane and intercropping consequently loosen the soil, making it more susceptible to erosion (MSIRI, 1997). RUSLE results also indicate that buffer strips are ineffective on the boundaries of cane fields. The reason is that buffer strips are located at the base of the slope. Therefore, this practice does not trap eroded sediment on the steep slopes of the upper catchment area and has minimal benefit as a P factor (Renard *et al*., 1994). Thus, several strips grown on the upper parts of the slope along the contour will be more effective.

(6) Long steep slopes, a common feature in the upper catchment, render the land extremely susceptible to erosion once the vegetation cover is degraded. Although the influence of slope on soil loss is subordinate to that of land use, as basal cover declines, the influence of slope seems to increase (Snyman, 1999; Smith *et al*. (2000). Consequently, a few land units in the RDAC, including units in the upper catchment area and the river valley, have very high LS values (4-6). The fact that topography is the dominating factor affecting the amount of soil loss in these areas is further substantiated from soil loss data from SLEMSA. Results show that slope steepness plays an important role in the susceptibility of erosion of cultivated lands. Some of these land units with steep slopes contain banana plantations that are particularly prone to erosion. Fortunately, most of these areas are covered by natural vegetation including forest and scrub. It is therefore suggested that no crop diversification or cultivation be carried out in these areas.

From the above discussion it is apparent that the interactions between the soil erosion factors are quite complex. The foregoing analysis signifies that the natural factors of soil, rainfall and

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slope determine the potential for erosion in any given area in the RDAC. Furthermore, certain variables are more influential than others in affecting the outcome of the RUSLE and SLEMSA. However, the study indicates that the effects of different farming practices will have the largest impact on soil erosion.

(7) <u>Soil loss results of both the RUSLE and SLEMSA for the current situation in the RDAC indicate some crops with undesirable soil loss rates.</u> Very high soil loss values of more than 80 $t.ha^{-1}.yr^{-1}$ are attained under the vegetable stand. Predictions indicate that intercropped cane leads to moderate values (between 13 to 20 $t.ha^{-1}.yr^{-1}$). However, soil loss under sugarcane is minimal. The models predict soil loss under sugarcane to be low (10 $t.ha^{-1}.yr^{-1}$) or very low (less than 2 $t.ha^{-1}.yr^{-1}$). Low rates (less than 10 $t.ha^{-1}.yr^{-1}$) are found in natural vegetation, including scrub and forested areas. Low rates under natural vegetation are not always the case for SLEMSA, predicting high erosion rates between 27 $t.ha^{-1}.yr^{-1}$ and 59 $t.ha^{-1}.yr^{-1}$. Banana plantations obtained very low (4 $t.ha^{-1}.yr^{-1}$) to moderate (16 $t.ha^{-1}.yr^{-1}$) ratings. Tea plantations obtained very low to high rates ranging from less than 1 $t.ha^{-1}.yr^{-1}$ to 41 $t.ha^{-1}.yr^{-1}$.

(8) <u>Mean annual soil loss for the current situation in the RDAC is estimated at approximately 11 $t.ha^{-1}.yr^{-1}$ by RUSLE and the SEAGIS-RUSLE application.</u> SLEMSA estimated 22 $t.ha^{-1}.yr^{-1}$ and SEAGIS-SLEMSA estimated 30 $t.ha^{-1}.yr^{-1}$. The RUSLE predicts a total of 4347 tons, and SLEMSA predicts a much higher 46316 tons of soil to be relocated by soil erosion under present land cover conditions in the RDAC.

(9) <u>In general, RUSLE soil loss results are much lower compared to SLEMSA results.</u> SLEMSA results are three to ten times higher compared to RUSLE predictions. SLEMSA predicted anomalous high soil losses on steep slopes (>20%) and regions with high rainfall (>2400 mm). Soil loss results predicted by SLEMSA are excessively high for scrub growing on the upper area of the catchment. A theoretical evaluation show that this is due to the model being very sensitive to changes in rainfall energy, while lacking sensitivity to changes in the vegetation cover (Elwell & Stocking, 1982; Hudson, 1987; Smith *et al*., 2000).

(10) <u>Although some of the estimated soil loss values of the models differed significantly, models signify a similar trend in soil loss rates between the cropping systems.</u> For example, it is evident that the poorly conserved vegetable stand loses on average, about 2-3 times as much soil compared to other crops in the catchment. A detailed study of the results indicates that

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decreasing rates of soil loss for each defined land use type correlate well with increase in canopy and/or surface cover, as well as frequency of disturbance. Generally, infrequently disturbed land use types such as natural vegetation, tea – and banana plantations generally have low soil loss values $(1 - 4$ t.ha^{-1}.yr^{-1}), whereas frequently disturbed land use types such as intercropped cane and vegetables have moderate $(13$ t.ha^{-1}.yr^{-1}) to very high $(80$ t.ha^{-1}.yr^{-1}) soil loss rates, respectively. Furthermore, rates are generally highest on land units with steep slopes $(>20\%)$, high rainfall $(>2400$ mm.yr^{-1}) and poor vegetation cover $(<30\%)$. Although the average annual soil loss value under current conditions might not be a cause of great concern, quantitative soil loss results are important in their relation to soil loss under potential crop diversification.

(11) <u>It is apparent that crop diversification would have a considerable influence on soil erosion.</u> Off the three potential cropping systems, the most soil loss was estimated for vegetables and the least for forested land. The mean soil loss from the RUSLE model is 42 t.ha^{-1}.yr^{-1}, 20 t.ha^{-1}.yr^{-1}, and 0.2 t.ha^{-1}.yr^{-1} under vegetables, pineapple, and forest, respectively.

(12) <u>The RUSLE predicted severe and sustained erosion under vegetables.</u> Results imply that significant erosion may occur during development of the crop. Although the highest rates of soil loss are predicted on steep slopes with erodible soils, the most important factors include poor vegetation cover, ineffective conservation practices and high rainfall.

(13) <u>Future pineapple plantations seem to be associated with moderate to extremely high erosion hazard.</u> It is postulated that soil loss will be very high during the introductory and early stages of pineapple development (Roose, 1975 cited in Bergsma *et al*., 1996: 87; McPhee & Smithen, 1984; Cooley and Williams, 1985). After establishment, soil loss will decrease as support practices have effect. Therefore, appropriate erosion control measures will be needed in order to minimise long term erosion problems. Long term erosion control, however, would involve intensive measures. Such an erosion hazard infers that planning will need to carefully consider the balance between the probability of long term erosion damage and the maintenance needed to ensure the viability of pineapple plantations. Therefore pineapple will not be viable on the steep slopes of the valley and upper catchment area.

(14) <u>Predicted soil loss values for the RDAC decrease greatly under a forest scenario.</u> Results indicate that no appreciable erosion damage will occur in the RDAC under forested land. The

dense cover of tree litter on the ground surface leads to very low rates of erosion. In addition, the presence of a rootmat contributes to the low rates of erosion. Although the system can be highly cost effective, periodic damage from cyclonic winds is a limiting factor to the accrued benefits of forestry (Ministry of Agriculture and Natural Resources, 1999). Nevertheless, it still remains a vital land use on account of the protection it affords to the catchment and the consequent regulation of ground water (Proag, 1995).

(15) <u>Results illustrate that it is the combination of extreme gradients and intense rainfall events which makes the RDAC sensitive to soil erosion under vegetable and pineapple scenarios.</u> Results indicate that soil loss in the catchment range significantly, with rates generally highest on steep slopes, increasing with rainfall erosivity. Steep slopes and erodible soils are limited to land units in the upper catchment area and along the valley. As a result, most of the erosion for alternative cropping systems is predicted in the upper catchment area and valley sides of the catchment. The predicted soil losses in the upper catchment area are significantly higher (up to a 100 times or more), compared to the lower catchment area. Therefore vegetables and pineapple will not be viable in the upper catchment area and steep slopes of the valley.

(16) <u>Estimated soil loss values were further compared to values or rates with what is considered acceptable (soil loss tolerance).</u> Although average annual soil loss values for some crops do not exceed the soil loss tolerances significantly, erosion may increase substantially under crop diversification. The study indicates that the average annual soil loss rates predicted for vegetables and pineapple will exceed the proposed soil loss tolerances (11 $t.ha^{-1}.yr^{-1}$) MSIRI (2000) on slopes steeper than 5%. Therefore, in respect to soil loss tolerance, full stand pineapple and vegetables, should only be allowed on level to gently undulating slopes (0-4%) within the RDAC. Results need to be confirmed.

(17) <u>Due to the scope of the study, no attempt at the calibration of the factor values of models was made.</u> Furthermore, since no measured soil loss data from runoff plots exists in the catchment areas of southern Mauritius, results on potential soil loss are best used in a qualitative way. The RUSLE and SLEMSA can be used to qualitatively evaluate different types of land use in terms of their potential towards erosion, delineating areas suitable for specific conditions/land use practices (Morgan, 1995). The importance of the results is shown in the comparison between the current situation and potential crop diversification scenarios.

(18) <u>Results reveal that the predicted total values and the average annual soil loss per hectare increases significantly under vegetables and pineapple.</u> A total of 127798 tons of soil is predicted to be relocated by soil erosion under vegetable cover in the RDAC. The total soil loss under pineapple amount to 60370 tons. When compared to current conditions, the mean soil loss will double under pineapple (increase by 100%), and quadruple under vegetables (increase by 300%). Forest give rise to very low soil loss values with a catchment total of 568 tons.

(19) <u>It is recommended that more generalized investigations be instigated to determine soil loss for the whole island.</u> Erosion prediction maps compiled for the RDAC, should be extended for the rest of the island, and also updated after changes in land use have occurred. Furthermore, estimations of the RUSLE and SLEMSA need to be refined for Mauritian conditions by measuring actual erosion using field plots. Measurement of rainfall intensity is also highly recommended. Rainfall intensity data can be used to compile isoerodent maps that will greatly improve and assist future research on soil erosion for Mauritius. Future research should also include investigations regarding intercropping, crop diversification and crop suitability.

Prior to this investigation, little information was available concerning the rates and patterns of erosion on a catchment scale in Mauritius. The study improved the understanding of factors governing erosion in Mauritius, which is important in targeting of research and soil conservation efforts. The RUSLE and SLEMSA enable planners to predict the average rate of soil loss for each of various alternative combinations of crop systems, provided input data for local conditions can be developed. More importantly, the results provide considerable information over the potential land use change. It also provides a point of departure for future modeling efforts, insight on data collection and, for certain situations, provides measured values for some model input data. Landowners and the government can use results to promote farming systems that do not degrade land resources. In doing so, the planner have the opportunity to prevent irreversible impacts and to plan remedial actions or land use change scenarios.

7. <u>References</u>

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Appendix 1: <u>Soil classifications</u>

Table 1:   Tentative correlation with U.S.D.A. & F.A.O./U.N.E.S.C.O. soil classifications
(Source: Arlidge and Wong You Cheong, 1975).

Mauritius Great soil Groups	Family	U.S.D.A.	F.A.O./U.N.E.S.C.O.
Latosolic Reddish Prairie	*Medine*	*Ustic Eutropept*	*Chromic Cambisol*
	Labourdonnais	*Ustic Eutropept*	*Eutric Cambisol*
	Mon Choisy	*Lithic Ustic Eutropept*	*Eutric Cambisol*
Latosolic Brown Forest	*Rose Belle*	*Lithic Humitopept*	*Dystric Cambisol*
	Bois Cheri	*Gibbsioxic Humitopept*	*Ferralic Cambisol*
Low Humic Latosol	*Richelieu*	*Tropeptic Haplustox*	*Chromic Cambisol*
	Reduit	*Tropeptic Haplustox*	*Humic Nitosol*
	Ebene	*Tropeptic Haplustox*	*Humic Nitosol*
	Bonne Mere	*Tropeptic Haplustox*	*Humic Nitosol*
Humic Latosol	*Rosalie*	*Oxic Humitropept*	*Humic Nitosol*
	Riche Bois	*Oxic Humitropept*	*Humic Nitosol*
Humic Ferruginous Latosol	*Belle Rive*	*Dystropeptic Gibbsiorthox*	*Humic Acrisol*
	Sans Souci	*Dystropeptic Gibbsiorthox*	*Humic Acrisol*
	Midlands	*Dystropetic Gibbsiaquox*	*Plinthic Acrisol*
	Chamarel	*Humoxic Dysandrept & Gibbsihumoxic Dysandrept*	*Humic & Ferralic Acrisol*
Dark Magnesium Clay	*Lauzun*	*Tropeptic Torrert*	*Pellic Vertisol*
	Magenta	*Tropeptic Torrert*	*Pellic Vertisol*
Grey Hydromorphic	*Balaclava*	*Typic Tropaquept*	*Gleyic Cambisol*
	St. Andre	*Typic Tropaquept*	*Gleyic Cambisol*
Groundwater Laterite	*W*	*Plinthic Gibbsiorthox*	*Plinthic Ferralsol*
Low Humic Gley	*Petrin*	*Typic Tropaquept*	*Dystric Gleysol*
	Valetta	*Typic Tropaquept*	*Dystric Gleysol*
Lithosol	*T1, T2, T3, T4*	*Lithic Ustropept*	*Lithosols*
Regosol	*C*	*Typic Ustipsamment*	*Calcaric regosol*

Appendix 2: <u>RULSE input data for land use</u>

Table 1:   RUSLE cover management factor (C) input data for infrequently disturbed land use types.

Land use type	Banana		Tea		Scrub		Forest	
Range (R) & Average (A)	R	A	R	A	R	A	R	A
Root mass (lb.ac[-1]) [1]	-	3 000	-	5 000	-	10000	-	10000
Canopy cover (%)	30-40	35	65-90	70	-	90	-	100
Fall height (ft)	6.5-10.0	8.0	2.3-3.0	2.6	6.5-33.0	8.0	>33.0	33.0
RUSLE field roughness [2]	0.6-1.0	0.8	-	0.5	1.0-1.8	1.5	0.6-1.5	0.8
Years for soil consolidation [3]	-	7	-	7	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Years since last disturbance	2-6	4	-	50	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Total ground cover (%)	15-25	20	0-25	10	20-100	100	20-100	85
Rock (%)	5-10	5	10-25	10	20-40	30	20-40	30
Residue (%)	10-15	15	0-5	0	60-80	70	50-60	55
RUSLE surface cover function (b-value) [4]	-	0.035	-	0.045	-	0.045	-	0.045

Table 2:   RUSLE support practice factor (P) input data for infrequently disturbed land use types.

Land use type	Banana		Tea		Scrub		Forest	
Range (R) & Average (A)	R	A	R	A	R	A	R	A
Ridge Height (in)	2.0-3.0	3.0	0-2.0	1.5	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Furrow grade (%)	-	0	-	0	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Equivalent slope (%) [5]	10-16	15	-	5	*n.a.*	*n.a.*	*n.a.*	*n.a.*
RUSLE soil hydrologic class [6]	B-C	C	-	C	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Cover at disturbance (%) [7]	-	15	-	15	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Cover at consolidation (%) [8]	-	55	-	80	*n.a.*	*n.a.*	*n.a.*	*n.a.*
RUSLE roughness at disturbance [2, 8]	-	1.0	-	1.0	*n.a.*	*n.a.*	*n.a.*	*n.a.*
RUSLE roughness at consolidation [2, 8]	-	0.4	-	0.4	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Years for soil consolidation [3]	-	7	-	7	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Years since last disturbance	2-6	4	>50	50	*n.a.*	*n.a.*	*n.a.*	*n.a.*

Table 3:   RUSLE cover management factor (C) input data for frequently disturbed land use types.

Land use type	Sugarcane		Intercrop		Vegetables	
Range (R) & Average (R)	**R**	**A**	**R**	**A**	**R**	**A**
Rock (%)	0-20	10	0-10	5	0-10	10
Surface cover function (b-value) [4]	-	0.035	-	0.035	-	0.030
Years in rotation	-	7	-	7	-	7

Table 4:   Date and type of field operations.

Sugarcane [9]		Intercrop [10]		Vegetables [11]	
Date	**Field operation**	**Date**	**Field operation**	**Date**	**Field operation**
2001-05-15	Burning or no burning	2001-06-01	Remove mulch	2001-09-01	Furrowing
2001-06-01	Harvest	2001-06-07	Disk harrow, plow	2001-09-15	Planting
2001-06-01	Add current crop residue	2001-06-15	Subsoiler	2001-09-30	Add other crop residues
2001-08-01	Begin growth	2001-06-30	Furrowing	2001-10-01	Begin growth
2001-09-01	No operation	2001-07-01	Planting	2001-12-01	Harvest
2002-05-01	No operation	2001-07-15	Begin growth	2001-12-15	No operation
		2001-07-15	Add other crop residue	2002-02-01	Furrowing
		2001-08-01	No operation	2002-02-15	Planting
		2001-09-01	Harvest vegetables	2002-02-15	Add other crop residues
		2001-10-01	Add current crop residue	2002-03-01	Begin growth
		2002-06-01	Harvest	2002-05-01	Harvest
				2002-05-15	No operation

Table 5:   RUSLE cover management factor (C) input data for growth stages of sugarcane.

Sugarcane crop	Harvest, soil preparation, planting Jun - Aug		First growth stage Sep - Oct		Second growth stage Nov - Jan		Mature growth stage Feb - May	
Range (R) & Average (A)	R	A	R	A	R	A	R	A
Plant population (#.ac^{-1}) [12]	-	25 000	-	25 000	-	25 000	-	25 000
Row spacing (in)	-	60	-	60	-	60	-	60
Root mass (lb.ac^{-1}) [1]	-	3 000	-	3 000	-	3 000	-	3 000
Canopy cover (%)	0-10	5	10-50	30	50-100	75	-	100
Fall height (ft)	-	0.0	0.0-2.3	1.2	2.3-9.8	6.1	9.8-11.5	10.6
Residue amount: (lb.ac^{-1}) [13]	-	4 456	-	2 228	-	6 685	-	3 342

Table 6:   RUSLE support practice factor (P) input data for growth stages of sugarcane.

Sugarcane crop	Harvest, soil preparation, planting Jun - Aug		First growth stage Sep - Oct		Second growth stage Nov - Jan		Mature growth stage Feb - May	
Range (R) & Average (A)	R	A	R	A	R	A	R	A
Ridge height (in)	>6.0	6.0	5.0-6.0	6.0	4.0-6.0	5.0	2.0-3.0	2.0
Furrow grade (%)	-	0	-	0	-	0	-	0
Equivalent slope (%) [5]	-	5	-	5	-	5	-	5
RUSLE soil hydrologic class [6]	B-C	C	B-C	C	B-C	C	B-C	C
RUSLE cover code [14]	C3-C5	C4	C3-C5	C4	C3-C5	C4	C3-C5	C4

Table 7:   RUSLE cover management factor (C) input data for growth stages of sugarcane intercropped with vegetables.

Sugarcane intercropped with vegetables	Harvest, soil preparation, planting Jun - Aug		First growth stage Sep - Oct		Second growth stage Nov - Jan		Mature growth stage Feb - May	
Range (R) & Average (A)	R	A	R	A	R	A	R	A
Plant population (#.ac^{-1}) [12]	-	20 000	-	20 000	-	20 000	-	20 000
Row spacing (in)	-	30	-	30	-	30	-	30
Root mass (lb.ac^{-1}) [1]	-	0	1000-2000	1570	1000-2000	1500	1000-2000	1500
Canopy cover (%)	0-10	5	10-60	40	60-100	70	80-100	90
Fall height (ft)	-	0.0	0.0-2.3	1.2	2.3-9.8	6.1	9.8-11.5	10.6
Residue amount: (lb.ac^{-1}) [13]	-	3 207	-	1 647	-	4 680	-	2 367

Table 8:   RUSLE support practice factor (P) input data for growth stages of sugarcane intercropped with vegetables.

Sugarcane intercropped with vegetables	Harvest, soil preparation, planting Jun - Aug		First growth stage Sep - Oct		Second growth stage Nov - Jan		Mature growth stage Feb - May	
Range (R) & Average (A)	R	A	R	A	R	A	R	A
Ridge height (in)	>6.0	6.0	5.0-6.0	6.0	4.0-6.0	5.0	3.0-4.0	3.5
Furrow grade (%)	-	0	-	0	-	0	-	0
Equivalent slope (%) [5]	-	5	-	5	-	5	-	5
RUSLE soil hydrologic class [6]	-	C	-	C	-	C	-	C
RUSLE cover code [14]	-	C4	-	C4	-	C4	-	C4

Table 9:   RUSLE cover management factor (C) input data for growth stages of vegetables.

Vegetable crop	Harvest, soil preparation, planting Jun - Aug		First growth stage Sep - Oct		Second growth stage Nov - Jan		Mature growth stage Feb - May	
Range (R) & Average (A)	**R**	**A**	**R**	**A**	**R**	**A**	**R**	**A**
Plant population (#.ac^{-1}) [12]	-	14 692	-	14 692	-	14 692	-	14 692
Row spacing (in)	-	40	-	40	-	40	-	40
Root mass (lb.ac^{-1}) [1]	-	0	0-107	60	107-275	230	-	275
Canopy cover (%)	-	0	0-20	15	20-75	60	-	75
Fall height (ft)	-	0	0.6-1.0	0.8	1.0-1.6	1.3	1.6-2.0	1.8
Residue amount: (lb.ac^{-1}) [13]	-	1 959	-	1067	-	2 675	-	1 392

Table 10:   RUSLE support practice factor (P) input data for growth stages of vegetables.

Vegetable crop	Harvest, soil preparation, planting Jun - Aug		First growth stage Sep - Oct		Second growth stage Nov - Jan		Mature growth stage Feb - May	
Range (R) & Average (A)	**R**	**A**	**R**	**A**	**R**	**A**	**R**	**A**
Ridge height (in)	>6.0	6.0	5.0-6.0	6.0	4.0-6.0	5.0	3.0-4.0	3.5
Furrow grade (%)	-	0	-	0	-	0	-	0
Equivalent slope (%) [5]	-	5	-	5	-	5	-	5
RUSLE soil hydrologic class [6]	-	C	-	C	-	C	-	C
RUSLE cover code [14]	-	C5	-	C5	-	C5	-	C5

Table 11:   Source table.

Refrence number	Source
1	An approximation from RUSLE vegetation database (Renard *et al*., 1994).
2	Obtained roughness code from RUSLE illustrative database (Renard *et al*., 1994).
3	RUSLE average, default setting (Renard *et al*., 1994).
4	Obtained from RUSLE surface cover function: b-value code (Table 5 in Appendix 3) (Renard *et al*., 1994).
5	Constant value used for calculation of C and P.
6	RUSLE soil hydrological classification (Table 4 in Appendix 3) (Renard *et al*., 1994).
7	Value obtained in field from disturbed soil.
8	Value obtained in field from non-disturbed soil.
9	Sugarcane agronomy data obtained in field and from Societe de Technologie Argricde et Sucriere de Maurice (1990); McIntyre *et al*. (1995); Jacquin, *et al*. 1995); Claite *et al*. (1997); MSIRI (1997, 2000).
10	Intercrop agronomy data obtained in field and from Govinden (1990).
11	Vegetable agronomy data obtained in field and from RUSLE database (Renard, *et al*., 1994); and Govinden (1990).
12	Societe de Technologie Argricde et Sucriere de Maurice (1990); MSIRI (1998).
13	McIntyre *et al*. (1995).
14	RUSLE cover management code (Table 3 in Appendix 3) (Renard *et al*., 1994).

Appendix 3: <u>RUSLE classification codes</u>

Table 1: RUSLE field operation data (after Renard *et al*., 1994).

Field operation	Operation effect (1-9)	Surface disturbed (%)	Initial random roughness (in)	Final random roughness (in)	Residue left on surface (%)	Depth of residue incorporation (in)
Disk harrow plough	2, 8, 1, 1, 1	100	1.9	0.24	15	6
Subsoiler	2, 1, 1, 1, 1	70	1.9	0.24	30	6
Furrowing	2, 8, 1, 1, 1	100	1.0	0.4	0	6
Planting	2, 7, 1, 1, 1	50	1.0	1.0	5	5
Begin growth	7, 1, 1, 1, 1	x	x	x	x	x
Add current crop residue	3, 1, 1, 1, 1	x	x	x	x	x
Add other crop residue	4, 1, 1, 1, 1	x	x	x	x	x
Remove mulch	5, 1, 1, 1, 1	x	x	x	x	x
No operation	1, 1, 1, 1, 1	x	x	x	x	x
Burning or no burning	8, 1, 1, 1, 1	x	x	x	x	x
Harvest vegetables	6, 3, 1, 1, 1	x	x	x	x	x
Harvest	6, 3, 8, 1, 1	x	x	x	x	x

Table 2: RUSLE operation effect list.

Operation effect number	Effect
1	No effect
2	Soil surface disturbed
3	Current vegetation residue added to surface
4	Other residue added to site
5	Residue removed from site
6	Current vegetation harvested
7	Begin growth of vegetation
8	Current vegetation is killed
9	Call in a new vegetation growth set

Table 3:   RUSLE cover management code (after Renard *et al*., 1994).

Code	Description
C1	Established sod-forming grass
C2	First year grass or cut for hay
C3	Heavy cover and/or heavy rough
C4	Moderate cover and/or rough
C5	Light cover and/or moderate rough
C6	No cover and/or minimum rough
C7	Clean tilled, smooth, fallow

Table 4:   RUSLE soil hydrological classification (after Renard *et al*., 1994).

Hydrologic group	Description
A	Lowest runoff potential
B	Moderately low runoff potential
C	Moderately high runoff potential
D	Highest runoff potential

Table 5:   RUSLE surface cover function: b-value code (after Renard *et al*., 1994).

Surface Cover Function: b-value code	Description
0.025	Dominated by interril erosion if the soil is bare
0.035	Equal rill and interril erosion if the soil is bare
0.045	Coarse soil, cover strongly effects runoff
0.050	Dominated by rill erosion if soil is bare

Appendix 4: <u>SLEMSA input data and indices for soils and land use</u>

Table 1:   Soil erodibility indices used in the implementation of SLEMSA
             (after Elwell, 1976).

Soil texture	Soil type	Basic index (initial F value)
Light	Sands Loamy sands Sandy lams	4
Medium	Sandy clay loam Clay loam Sandy Clay	5
Heavy	Clay Heavy Clay	6

Subtract the following from the basic index:
1   for light textured soils consisting mainly of fine grained sands and silts
1   for restricted vertical permeability within one metre of surface, or severe soil crusting
1   for ridging practices up and down the slope for deterioration in soil structure from   excessive soil losses in previous year (about 20 t/ha, or more) or under poor management
0.5 for soils with slight to moderate surface crusts or for soil losses in the previous year of   about 10-20 t/ha.

Add the following from the basic index:
2   for deep (over two metres), well drained, light textured soils
1   for tillage techniques which encourage maximum retetion of water on the soil surface e. g.   ridging on contour
1   for tillage techniques which encourage high surface infiltration and maximum water   storage in the profile e.g. ripping, deep ploughing and wheel track
1   for first season of no tillage
2   for second and subsequent seasons of no tillage.

Table 2:   SLEMSA soil input data necessary to determine erodibility (F) values.

Soil types [1]	LHL	HL	HFL		
Family [1]	*Reduit*	*Riche Bois*	*Belle Rive*	*Sans Souci*	*Midlands*
Texture (light, medium, heavy)	Medium	Medium	Medium	Medium	Light
Restriction of permeability of subsoil (slightly, moderately, severely)	x	x	Slightly	Slightly	Slightly
A-horizon limitations (surface crusting, shrink swell, mulching)	x	x	x	x	x
Structure detereation (>20t/ha soil loss, poor management)	x	x	x	x	x
Light texture (fine grained sands, silt)	x	x	x	x	x
Deep well drained light texture	x	x	x	x	x

Note: this table is used to add or subtract values to obtain SLEMSA F-value.

Table 3:   SLEMSA management input data necessary to determine erodibility (F) Values.

Land use type	Sugarcane	Intercrop	Vegetables	Banana	Tea	Scrub	Forest
Ridging practices up and down slope	x	x	x	x	x	*n.a.*	*n.a.*
Minimum tillage techniques i.e. ridging and contour	✓	✓	✓	✓	✓	*n.a.*	*n.a.*
Special tillage for surface roughness i.e. ripping, deep ploughing	x	x	x	x	x	*n.a.*	*n.a.*
First season of no tillage	✓	x	x	✓	✓	*n.a.*	*n.a.*
Second season of no tillage	✓	x	x	✓	✓	*n.a.*	*n.a.*

Note: this table is used to add or subtract values to obtain SLEMSA F-values.

Table 4:   Calculation of the SLEMSA K value for each land unit.

Rainfall region	P annual rainfall (mm)	E = P*9.28-8.38 (J.m⁻²)	Soil	Land Use	Initial F	Final F	a= 2.884-8.1209F	b= 0.74026-0.09436a	lnK= b.lnE+a (t/ha/yr)
1	3652	33881	HFL - *Sans Souci*	Forestry	4	5	-38.17	4.29	793.96
1	3652	33881	HFL - *Sans Souci*	Scrub	4	5	-38.17	4.29	793.96
1	3652	33881	HFL - *Midlands*	Scrub	4	5	-38.17	4.29	793.96
1	3652	33881	HFL - *Sans Souci*	Natural forest	4	5	-38.17	4.29	793.96
1	3652	33881	HFL - *Midlands*	Forestry	4	5	-38.17	4.29	793.96
1	3652	33881	HFL - *Sans Souci*	Tea	4	6	-46.38	5.06	638.50
1	3652	33881	HFL - *Midlands*	Natural forest	4	5	-38.17	4.29	793.96
1	3652	33881	HFL - *Midlands*	Tea	4	6	-46.38	5.06	638.50
1	3652	33881	HFL - *Midlands*	Sugarcane	4	6	-46.38	5.06	638.50
1	3652	33881	HFL - *Sans Souci*	Sugarcane	4	6	-46.38	5.06	638.50
1	3652	33881	HFL - *Midlands*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
2	2908	26977	HFL - *Midlands*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
2	2908	26977	HFL - *Midlands*	Sugarcane	4	6	-46.38	5.06	201.28
2	2908	26977	HFL - *Midlands*	Banana	4	5	-38.17	4.29	298.05
2	2908	26977	HFL - *Sans Souci*	Sugarcane	4	6	-46.38	5.06	201.28
2	2908	26977	HFL - *Sans Souci*	Banana	4	5	-38.17	4.29	298.05
2	2908	26977	HFL - *Sans Souci*	Tea	4	6	-46.38	5.06	201.28
2	2908	26977	HFL - *Midlands*	Vegetables	4	4	-29.96	3.53	441.33
2	2908	26977	HFL - *Belle Rive*	Vegetables	5	5	-38.17	4.29	298.05
2	2908	26977	HFL - *Belle Rive*	Banana	5	6	-46.38	5.06	201.28
2	2908	26977	HFL - *Belle Rive*	Intercropping	5	5	-38.17	4.29	298.05
2	2908	26977	HFL - *Belle Rive*	Sugarcane	5	6	-46.38	5.06	201.28
3	2812	26086	HFL - *Belle Rive*	Sugarcane	5	6	-46.38	5.06	169.79
4	2369	21975	HFL - *Belle Rive*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
4	2369	21975	HFL - *Belle Rive*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
4	2369	21975	HFL - *Belle Rive*	Sugarcane	5	6	-46.38	5.06	71.22
4	2369	21975	HL - *Riche Bois*	Banana	5	7	-54.59	5.83	41.10
4	2369	21975	HL - *Riche Bois*	Sugarcane	5	7	-54.59	5.83	41.10
4	2369	21975	LHL - *Reduit*	Sugarcane	5	7	-54.59	5.83	41.10
5	1971	18282	HL - *Riche Bois*	Sugarcane	5	7	-54.59	5.83	14.05
5	1971	18282	HL - *Riche Bois*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
5	1971	18282	LHL - *Reduit*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
5	1971	18282	LHL - *Reduit*	Banana	5	7	-54.59	5.83	14.05
5	1971	18282	LHL - *Reduit*	Sugarcane	5	7	-54.59	5.83	14.05
6	2102	19497	LHL - *Reduit*	Sugarcane	5	7	-54.59	5.83	20.46
6	2102	19497	LHL - *Reduit*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
7	1720	15952	LHL - *Reduit*	Urban	*n.a*	*n.a*	*n.a*	*n.a*	*n.a*
7	1720	15952	LHL - *Reduit*	Sugarcane	5	7	-54.59	5.83	6.34
7	1720	15952	LHL - *Reduit*	Banana	5	7	-54.59	5.83	6.34

Table 5:   Calculation of the SLEMSA C value (dimensionless) for each cropping system.

Crop	Stages	%Rainfall	Average %cover	i-value= %R*%C	Sum of i	C-value (equation 3.9)
Sugarcane	Jun-Aug	0.18	5	0.89	70.69	0.053105
	Sep-Oct	0.08	30	2.30		
	Nov-Jan	0.28	75	20.69		
	Feb-May	0.47	100	46.79		
Intercrop	Jun-Aug	0.20	5	1.00	63.88	0.055375
	Sep-Oct	0.08	40	3.06		
	Nov-Jan	0.26	70	18.39		
	Feb-May	0.46	90	41.43		
Vegetables	Sep	0.04	0	0.00	30.64	0.066453
	Oct	0.04	12	0.43		
	Nov	0.04	60	2.41		
	Dec	0.10	75	7.24		
	Jan	0.13	20	2.52		
	Feb	0.15	0	0.00		
	Mar	0.12	12	1.48		
	Apr	0.11	60	6.39		
	May	0.08	75	6.16		
	Jun	0.07	20	1.36		
	Jul	0.07	20	1.30		
	Aug	0.07	20	1.35		
Banana	Jan-Dec	1.00	52	52.00	52.00	0.059333
Tea	Jan-Dec	1.00	70	70.00	70.00	0.053333
Scrub	Jan-Dec	1.00	90	90.00	90.00	0.046667
Forest	Jan-Dec	1.00	100	100.00	100.00	0.043333

Appendix 5: <u>**Land use factor values from studies conducted in Africa**</u>

Table 1:   Examples of dimensionless C factor values from other sources.

	Cooley and Williams (1985; cited in El-Swaify *et al.*, 1985: 509)	(R)USLE C factor
S U G A R C A N E	Bare soil with low to moderate runoff potential	0.04 – 0.30
	Limited cover with low to moderate runoff potential	0.03 – 0.26
	Partial cover with low to moderate runoff potential	0.02 – 0.23
	Complete cover with low to moderate runoff potential	0.01 – 0.20
P I N E A P P L E	Bare soil with low to moderate runoff potential	0.10 – 0.55
	Limited cover with low to moderate runoff potential	0.08 – 0.45
	Partial cover with low to moderate runoff potential	0.06 – 0.35
	Complete cover with low to moderate runoff potential	0.04 – 0.25
	Elwell (1976)	**SLEMSA C factor**
S U G A R C A N E	Ratoon cane trashed	0.043
	Ratoon cane burned	0.048
	Planted cane first year	0.052
	Mature cane	0.043
P I N E A P P L E	First year	0.30
	Second Year	0.06
	Third to fourth year	0.04
	Roose (1975; cited in Bergsma *et al.*, 1996: 87)	**(R)USLE C factor**
P I N E A P P L E	On contour with burned residue	0.2 – 0.3
	On contour with buried residue	0.1 – 0.3
	On contour with surface residue	0.01
	With tied ridging	0.1

	Penman (1963)	(R)USLE C factor
V E G E T A B L E S	Land preparation to planting (1 month)	0.7 – 0.6
	Planting to full growth (3 months)	0.6 – 0.4
	Closing to full growth (1month)	0.4 – 0.1
	Full cover to harvest (1-3 months)	0.2 – 0.1
	Wischmeier and Smith (1978)	(R)USLE C factor
N A T U R A L V E G E T A T I O N	Tall weeds or short brush with average drop fall height of 0.5m and 80% cover	0.011 – 0.038
	Tall weeds or short brush with average drop fall height of 0.5m and 95% cover	0.003 – 0.011
	Appreciable brush with average drop fall height of 2m and 80% cover	0.012 – 0.040
	Appreciable brush with average drop fall height of 2m and 95% cover	0.003 – 0.011
	Trees, but no appreciable brush with average drop fall height of 4m and 80% cover	0.012 – 0.041
	Trees, but no appreciable brush with average drop fall height of 4m and 95% cover	0.003 – 0.011
	Undisturbed forest with 45 – 75% cover including undergrowth	0.002 – 0.004
	Undisturbed forest with 75 – 100% cover including undergrowth	0.0001 – 0.001
	Donald (1997)	(R)USLE C factor
	Thicket, brushland, scrub forest and high fynbos with fall height 2-5m and more than 50% canopy cover and more than 60% ground cover	0.003 – 0.013
	Graded thicket, brushland, scrub with fall height 2-5m and less than 30% canopy cover and less than 20% ground cover	0.19 – 0.42
	Forest and woodland with fall height more than 5m and canopy cover 50-70% and ground cover more than 80%	0.003 – 0.013
	Forest and forest plantations with fall height more than 5m and canopy cover more than 75% and ground cover more than 80%	0.0001 – 0.001
	Roose (1975; cited in Bergsma *et al*., 1996: 87) [1]; Elwell (1976) [2]; McPhee & Smithen (1984) [3];	
A V E R A G E V A L U E S	Dense forest or crop in thickly straw covered field	0.001[1]
	Forest or dense shrub	0.001[1]
	Vegetables with average cover of 70%	0.053[2]
	Vegetables (annual value for complete crop cycle)	0.80[3]
	Potatoes (annual value for complete crop cycle)	0.75[3]
	Sugarcane (annual value for complete crop cycle)	0.16[3]
	Pineapple green manured and ridges down slope	1.13[3]
	Pineapple minimum tillage and mulched	0.09[3]

Table 2:   Examples of P factor values from other sources.

McPhee & Smithen, (1984)	(R)USLE P factor
Contour tillage on contour lands with 0 – 3% slope	0.6
Contour tillage on contour lands with 3 – 8% slope	0.5
Contour tillage on contour lands with 8 – 15% slope	0.6
Singh *et al*. (1985; cited in El-Swaify, S. A., Moldenhauer)	**(R)USLE P factor**
Contour farming	0.68
Up and down cultivation	1.00

Appendix 6: <u>Cumulative percentage size distributions for soils in the RDAC</u>
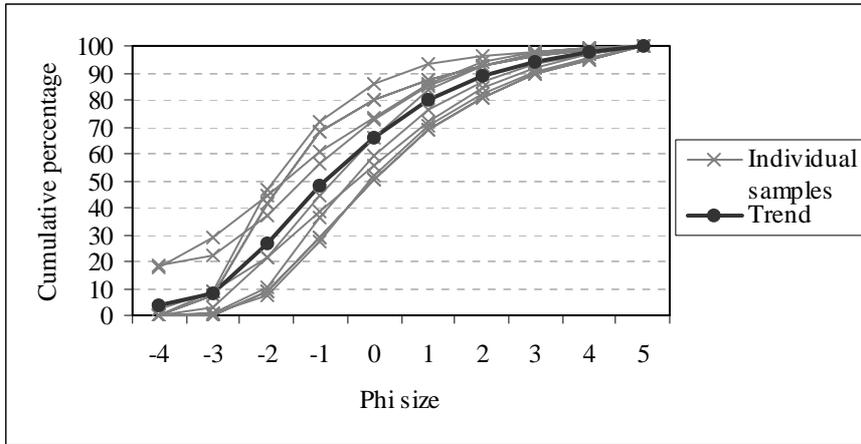
Figure 1:   Cumulative percentage size distributions for LHL *Reduit* soil samples.
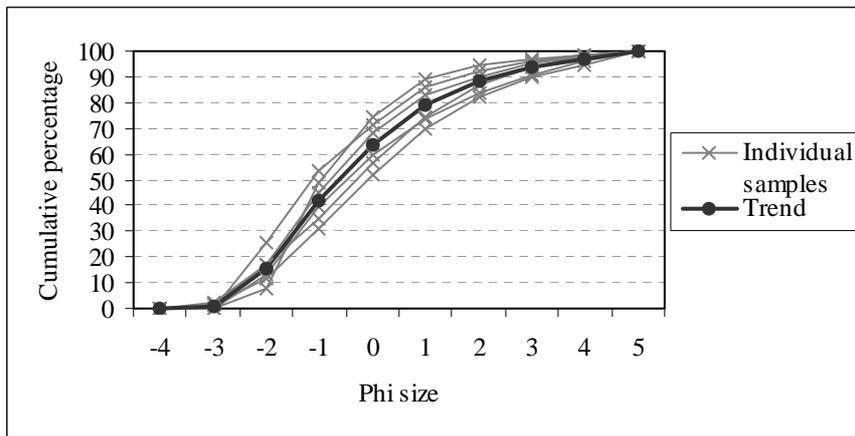
Figure 2:   Cumulative percentage size distributions for HL *Riche Bois* soil samples.
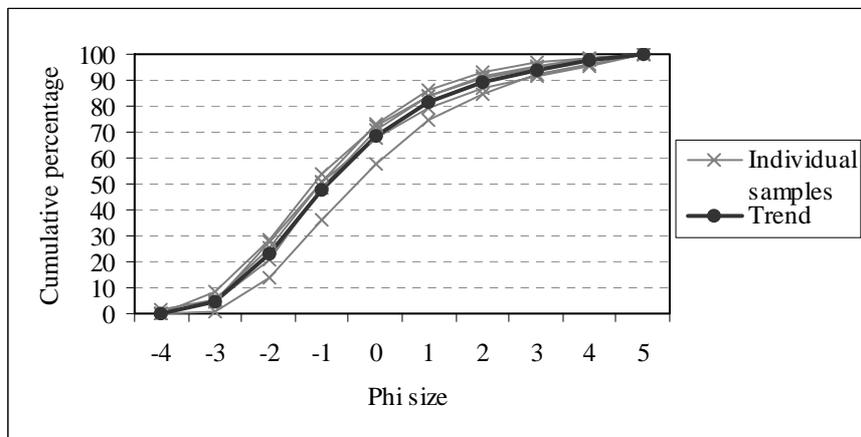
Figure 3:   Cumulative percentage size distributions for HFL *Belle Rive* soil samples.
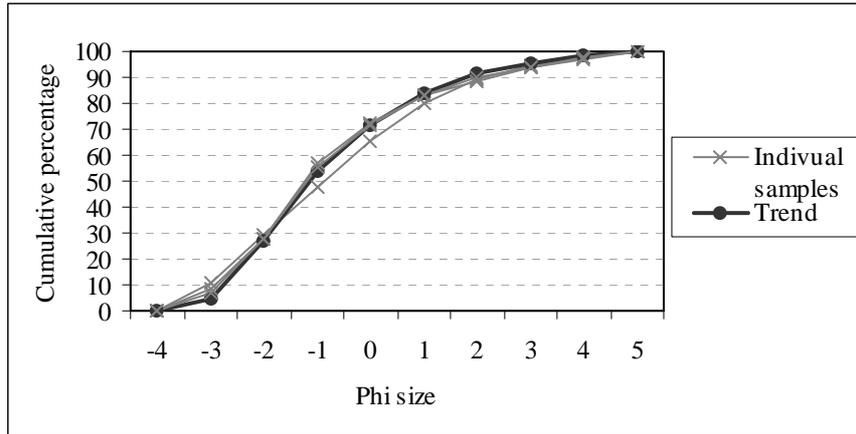
Figure 4:   Cumulative percentage size distributions for HFL *Sans Souci* soil samples.
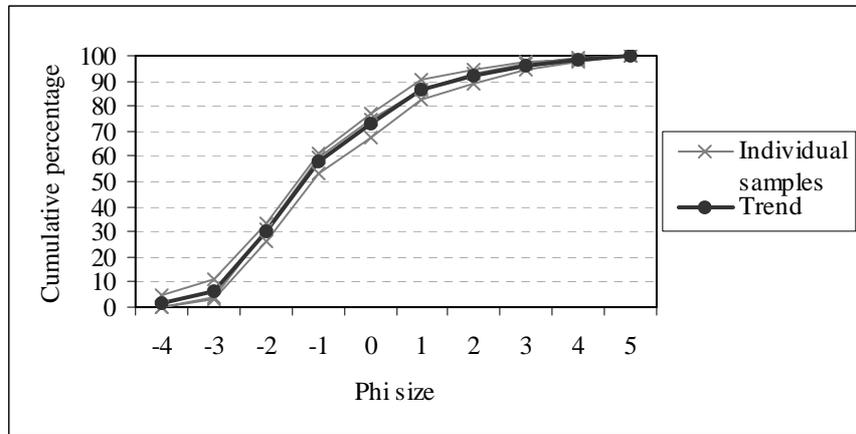
Figure 5:   Cumulative percentage size distributions for HFL *Midlands* soil samples.

Appendix 7: <u>Infiltration rates for soils in the RDAC</u>
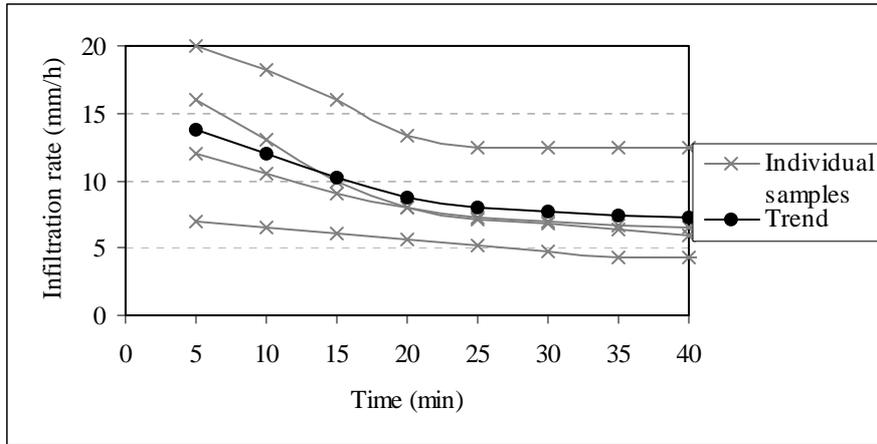
Figure 1:   Infiltration rates for LHL *Reduit* soil samples.
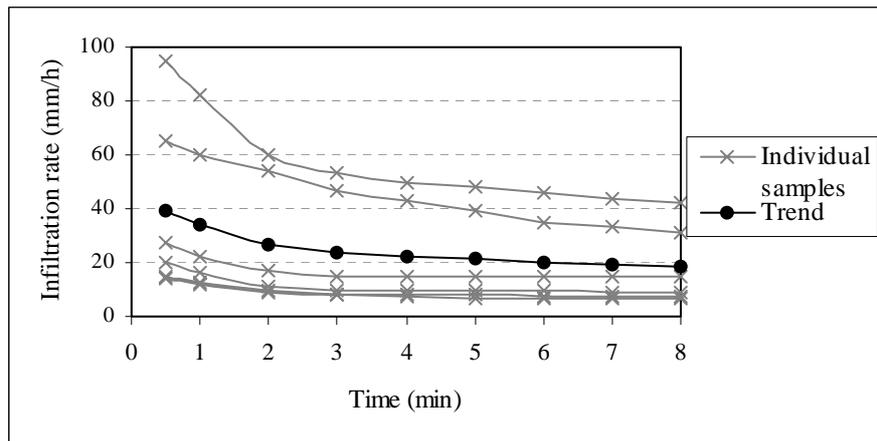
Figure 2:   Infiltration rates for HL *Riche Bois* soil samples.
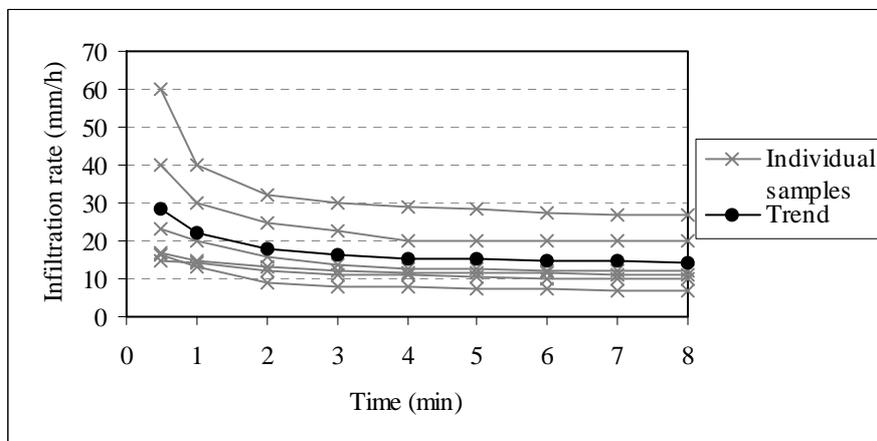
Figure 3:   Infiltration rates for HFL *Belle Rive* soil samples.
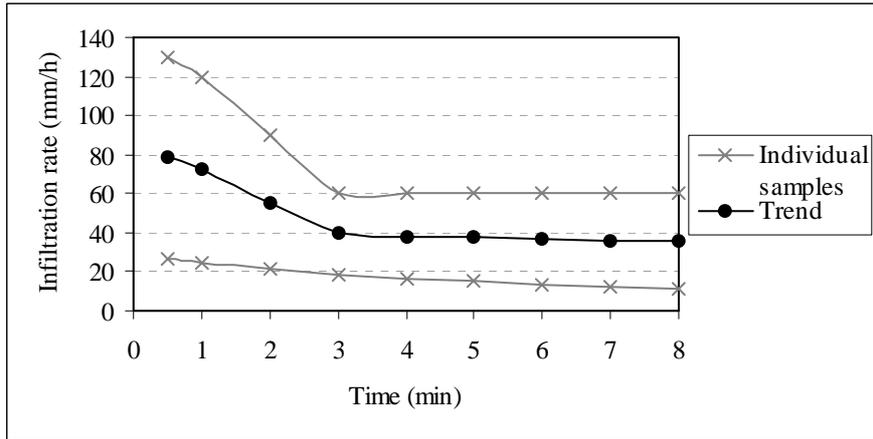
Figure 4:   Infiltration rates for HFL *Sans Souci* soil samples.
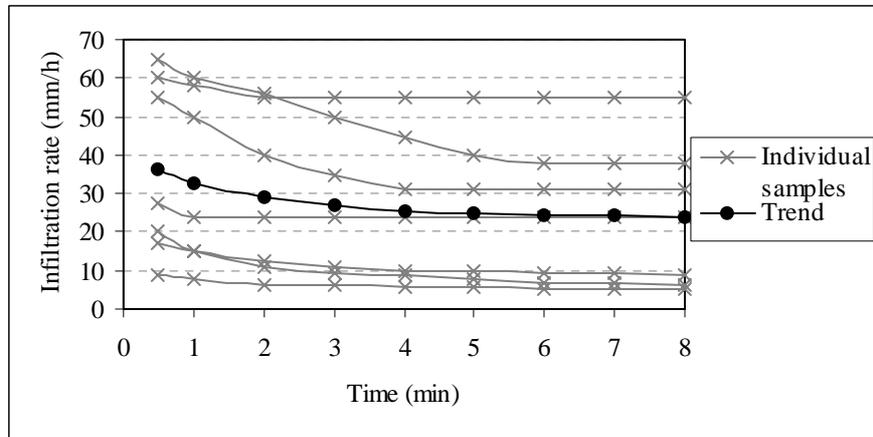
Figure 5:   Infiltration rates for HFL *Midlands* soil samples.

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