ESTIMATION OF SEDIMENT LOADING INTO A RESERVOIR IN AGRICULTURAL AREA USING WEPP(95.7) MODEL

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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Date. 31/8/98 ....

This thesis has been submitted for examination with my approval as University Supervisor

Supervisor...
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Date ..3/9/98..

DEDICATION

This thesis is dedicated to:

My late father, Opanying Attah Kwasi and My beloved mother, Madam Yaa Aboraa, My wife, Munchie, and My kids.

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ABBREVIATIONS AND SYMBOLS

ASAE - America Society of Agricultural Engineers
BB - Profile Section
B1P1 - Block 1 Plot 1
CEC - Cation exchange capacity
CNTBEAN - Tractor ploughing plot with only beans cultivation
CNTCORN - Tractor ploughing plot with only maize cultivation
COBEAN - Tractor ploughing plot with maize and beans cultivation
CREAMS - Chemicals, Runoff, and Erosion from Agricultural Management Systems
CV - Coefficient of variation
EPIC - Erosion Prediction Impact Calculator
da - day
dur - duration
ip - ratio of maximum rainfall intensity to average rainfall intensity
ILWIS - Integrated Land and Water Information System
Exp - exponent
FAO - Food and Agricultural Organisation
$FeSO_4$ - Iron (II) Sulphate
GIS - Geographical Information Systems
HOCOBE - Hand hoeing plot with maize and beans cultivation
IAHS - International Association of Hydrological Sciences
IITA - International Institute of Tropical Agriculture
K_i - interrill erodibility parameter
K_r - rill erodibility parameter
$KrCrO_7$ - Potassium dichromate
K_{sat} - Saturated hydraulic conductivity
$>$ - greater than
$<$ - less than
$\leq$ - less than or equal to

Meq - milliequivalent
mo - month
MUSLE - Modified Universal Soil Loss Equation
N - Newton
OFE - Overland flow element
ORGMAT - organic matter
P_b - Bulk density
ρ_w - Density of Water
prcp - precipitation
rad - daily solar radiation
s - second(s)
SALB - soil albedo
SCS - Soil Conservation Service
SDR - sediment delivery ratio
SEA - Science and Education Administration
SLB5P4 - B5P4 slope characteristics
SLEMSA - Soil Loss Estimator for Southern Africa
SOB5P4 - B5P4 Soil characteristics
t - tonne (s)
tdew - dew point temperature
tmax - maximum daily temperature
tmin - minimum daily temperature
tp - ratio of time to rainfall peak to rainfall duration
tw - soil water retention
UNEP - United Nations Environmental Programme
USDA - United States Department of Agriculture
USLE - Universal Soil Loss Equation
VFS - very fine sand
w-dir - wind direction
WEPP - Water Erosion Prediction Project
w-vl - wind velocity

ABSTRACT

The study aims at using a newly developed process-based model, WEPP(95.7), to estimate sediment loads in an agricultural reservoir in a semi arid area using easily available data, and to identify conservation strategies that could be used to reduce the rate of reservoir sedimentation from the catchment. The study was carried out at Ndaragwiti Reservoir and its catchment in the semi arid area of Laikipia District.

The catchment is located in the Sipili location of Ng'arua Division. The catchment covers an area of approximately 2.7 km^2 and is about 1.0 km north-west of Sipili township. The area has a mean annual rainfall of 699 mm, a maximum temperature ranging between 24°C and 27°C and a minimum temperature ranging between 7°C and 10°C. The whole catchment was under cultivation.

The reservoir had a surface area of about 1.9 ha with a mean depth of 1.2 m, and the full capacity of the reservoir was 34,000 m^3.

In accordance to the WEPP(95.7) model requirements, the catchment was divided into five main blocks, and subdivided into twenty two plots, or hillslopes.

The WEPP(95.7) model was run under two categories - Hillslope WEPP(95.7) model and Watershed WEPP(95.7) model. Some soil physical and chemical characteristics, slope characteristics, climate characteristics and plant/management characteristics were determined for each hillslope thus being necessary to run the Hillslope WEPP(95.7) model for the purpose of estimating soil loss from each hillslope. The output of the Hillslope WEPP(95.7) model for each hillslope together with the channel characteristics in terms of soil, slope, climate and plant/management were determined as well as the impoundment characteristics to run the Watershed WEPP(95.7) model.

Under the existing conditions of available data, the WEPP(95.7) model estimated the annual total sediment yield of about 1892 tonnes. This gave an average sedimentation rate of 700 $t/km^2/yr$. The WEPP(95.7) estimate was compared to the measurement made from geodetic survey on the reservoir and gave a relative difference of about 40 percent less.

Even though, the WEPP(95.7) model underestimated the sediment yield by about 40 percent, it was considered to give a fair estimation because the sediment contributed by wind,the roads on the catchment and the unconsolidated embankment of the reservoir and

the channels were not accounted for by the WEPP(95.7) model.

A comparison was made of soil loss simulated using WEPP(95.7) model on randomly selected ten plots of different sizes and slopes on the catchment under the following treatments: the current hand hoeing, and maize and beans intercropping (HOCOBE); tractor ploughing, and maize and bean intercropping (COBEAN); tractor ploughing and only maize grown (CNTCORN); and tractor ploughing and only beans grown (CNTBEAN). The soil loss reduction of HOCOBE and COBEAN, HOCOBE and CNTCORN, and HOCOBE and CNTBEAN ranged between 27- 47 percent, 16 - 29 percent and 12 - 25 percent respectively.

These figures indicated that there could be a drastic soil loss reduction if the farmers adopted tractor ploughing as the farm operation method.

CHAPTER ONE

1.0 INTRODUCTION

For many years, governments and individuals have been working cooperatively to reduce soil erosion and sedimentation on agricultural and other lands. This has been successful in protecting millions of hectares of land from ever increasing erosion (FAO, 1993). However, much remains to be done, as sediment is still the largest single pollutant of streams and lakes.

The assessment and understanding of erosion and sedimentation processes are essential components of water resource assessment. An integral part is to control erosion particularly through sound land and water management techniques, devise methods and design techniques to mitigate the harmful effects of sedimentation (Shahin, 1993).

The lower rainfall in semi-arid areas compared to that in humid climates does not mean a corresponding low level of soil erosion by water (FAO,1987). Semi arid areas have potential for generating and transporting large quantities of sediments (FAO, 1987; Magfed, 1986). This is mainly due to the torrential nature of the rains (FAO, 1987), excessive weathering or erodibility of the soil (Goudie and Wilkinson, 1977), almost total lack of natural protection against detachment of soil due to sparse vegetation especially at the beginning of the rainy season (Pilgrims, et al., 1988; FAO, 1987) and increased biotic interference (FAO, 1973).

Land development, according to Chin-Lien Yen (1985), for various purposes occurs in many parts of the world and such human activities often increase storm runoff and accelerate soil erosion. He stressed that increase in runoff results in greater flood damage whereas eroded soil settles in streams and reservoirs and pollutes their waters or even silt them. The rate at which the processes of erosion transport and deposition of sediment act are dependent on such variables as rock or soil type, topographic relief, plant cover, climate and landuse (Elwell, 1984; Shahin, 1993). These variables were considered by the model used for the study.

The flow of water in many African rivers is regulated through storage reservoirs. In semi arid areas, reservoirs are used for water conservation. The service life of most of these reservoirs is experiencing a continuous reduction due to unexpectedly high rates of erosion and sediment yields (Shahin, 1993). Although measurement of erosion and sediment yield dates back to the last century, what is known so far is limited in quantity and quality (Shahin, 1993). Misjudgment of sediment yield causes reservoir performance to differ from the design performance. Therefore to devise any effective plans for the control of sedimentation, accurate prediction of its behaviour is needed (Chin-Lien Yen, 1985).

1.1 Problem Statement

Sediment production is the main product of soil erosion due to surface water runoff. Sedimentation phenomenon is then of great significance to water resources development as it often reduces the economic life of many developed multipurpose reservoirs, thus rendering them inefficient for their initial intended use(s) (Ongwenyi et al., 1993). Therefore, the design of soil and water conservation and hydraulic structures requires information on sediment production and loading from upstream catchment. Such data can be obtained easily if the sediment monitoring systems in the catchments were adequately instrumented with automatic gauging and monitoring network (FAO, 1987).

However, this is rarely so in a developing country like Kenya because of the high cost associated with monitoring activities (Sharma, 1994). In Kenya, gauging and sediment monitoring are carried out by the Ministry of Water Development (Ongwenyi et al., 1993). According to Sharma (1994) there has not been any countrywide sediment sampling activity in operation since 1985 under this Ministry due to constraints of resources and funds.

Erosion and sediment yield need to be surveyed and recorded at different scales according to the degree of detail required (FAO, 1987). However, most semiarid regions such as Sipili location in Ng'arua Division where the study was carried out, do not have installed erosion and sediment monitoring systems. Rainfall measurements are few and far apart. Sipili location has got no rainfall gauging stations. Generally, soil surveys and studies of the physical and chemical characteristics of soils are much weaker in semi arid areas than areas of more reliable rainfall (FAO, 1987).

The sedimentation of reservoirs within Sipili location has caused scarcity of water for domestic and livestock use especially during dry seasons. In wet seasons, few people get water for domestic use from roof catchments while the majority of the people as well as the livestock get water from pools within some catchments in the location. In dry seasons, Ndaragwiti Reservoir and Sipili Borehole water supply serve as the main sources of water for both domestic and livestock use since most of the surrounding reservoirs are almost silted up. A draft report on Ndaragwiti Reservoir at the Ministry of Water Development, Nanyuki Office,(1992), indicated that there were five reservoirs within 4 km around the Ndaragwiti Reservoir. These reservoirs included Ririshwa Pam, Dim Com Dam, Ndururu Dam, Ndindika Dam and Nyakiambi Primary School Dam. According to the report, all these reservoirs including the Ndaragwiti were either not working or partly working, with the exception of Ndindika Dam, as a result of sedimentation.

According to the Assistant Chief in Sipili (1997), by 1994 almost all the dams including the Ndaragwiti had silted up. The Ministry of Water Development was unable to desilt the dams due to financial constraints (District Water Officer, 1997). However, with the intervention of Parish Development Committee, (PDC), under Ng'arua Catholic Parish, some of the dams were desilted including the Ndaragwiti Reservoir.

Due to limitations with erosion and sediment monitoring, alternative techniques of generating catchment sediment using easily obtained data was explored. In order to assess environmental problem related to landuse, Water Erosion Prediction Project, WEPP(95.7) model was adopted to estimate rates of erosion and sediment yield.

The sediment yield and erosion rates can be useful in deciding the type and size of reservoir to be constructed and when desilting is expected.

1.2 Objectives of the Study

The overall objective of the study is to estimate the amount of reservoir sedimentation and identify conservation strategies that can be used to reduce the rate of sedimentation from the agricultural catchment.

The specific objectives are:

i) to characterise the catchment area in terms of rainfall, landuse, topography, soils and conservation practices.

ii) to characterise the reservoir in terms of construction date, purpose of construction, surface area and capacity, and silting to date.

iii) to apply WEPP(95.7) model to estimate sediment loads into the reservoir from the catchment under the current landuse and management strategies.

iv) to estimate soil loss from the catchment under different land uses and management strategies and compare it with the soil loss estimate under the current farm practices.

CHAPTER TWO

2.0 BACKGROUND INFORMATION OF THE STUDY AREA

The study was carried out to estimate sediment loading into an agricultural reservoir using Ndaragwiti Reservoir as the study case.

2.1 Location

Ndaragwiti reservoir is in a semi-arid catchment in Dim Com Sub-location, Sipili location, Ng'arua Division of Laikipia District in the Rift Valley Province of Kenya (Figure 2). It is about 1.0 km north-west of Sipili township (Figure 3). The roads from Sipili to Ol'Moran, Mahiga and Wanguachi pass through the Ndaragwiti catchment. The Sipili hill lies on the western catchment boundary.

Ndaragwiti reservoir and its catchment lie along longitude 36.4° east and latitude 0.5° north. On the eastern part of the catchment, a road serves as a boundary. This road and other trenches created by the local people at the south east have reduced the size of the catchment. There is an almost silted up reservoir, a few metres off the Ndaragwiti Reservoir which collects water during rainy seasons for livestock use.

2.2 Physical Environment

The knowledge of the physical environment is important in the understanding of agricultural pressure on the land and the environment's relation to the development of erosion and sediment.

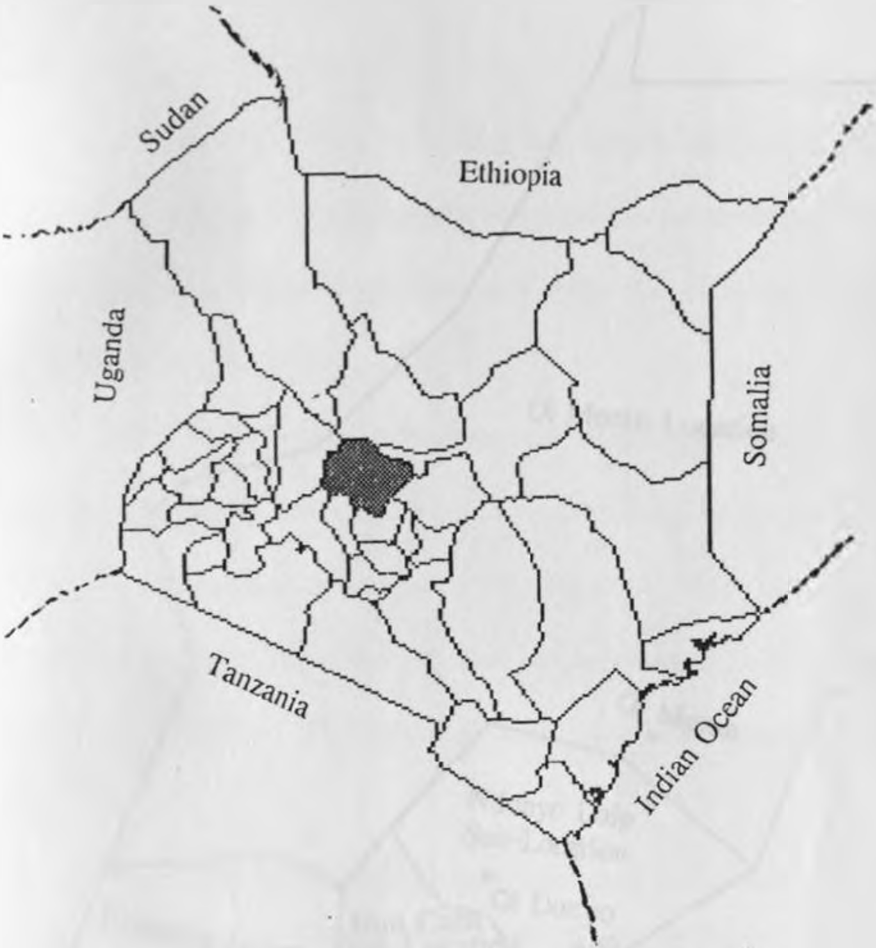


Figure 1: Map of Kenya showing Laikipia District

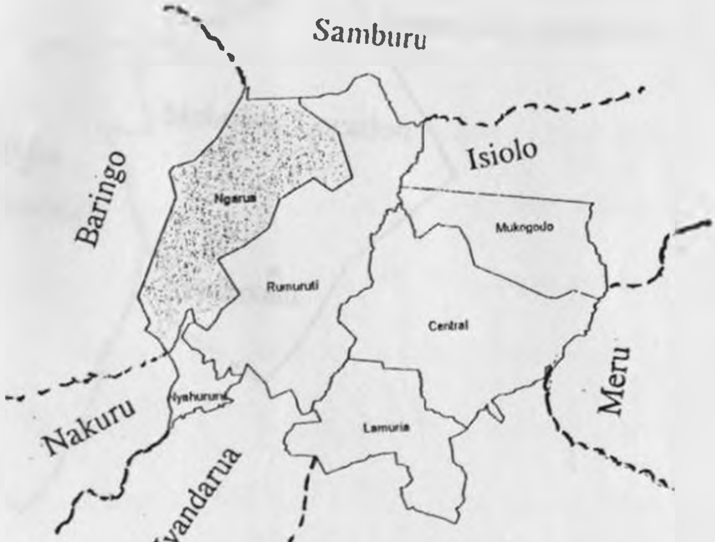


Figure 2: Laikipia District Showing Ng'arua Division

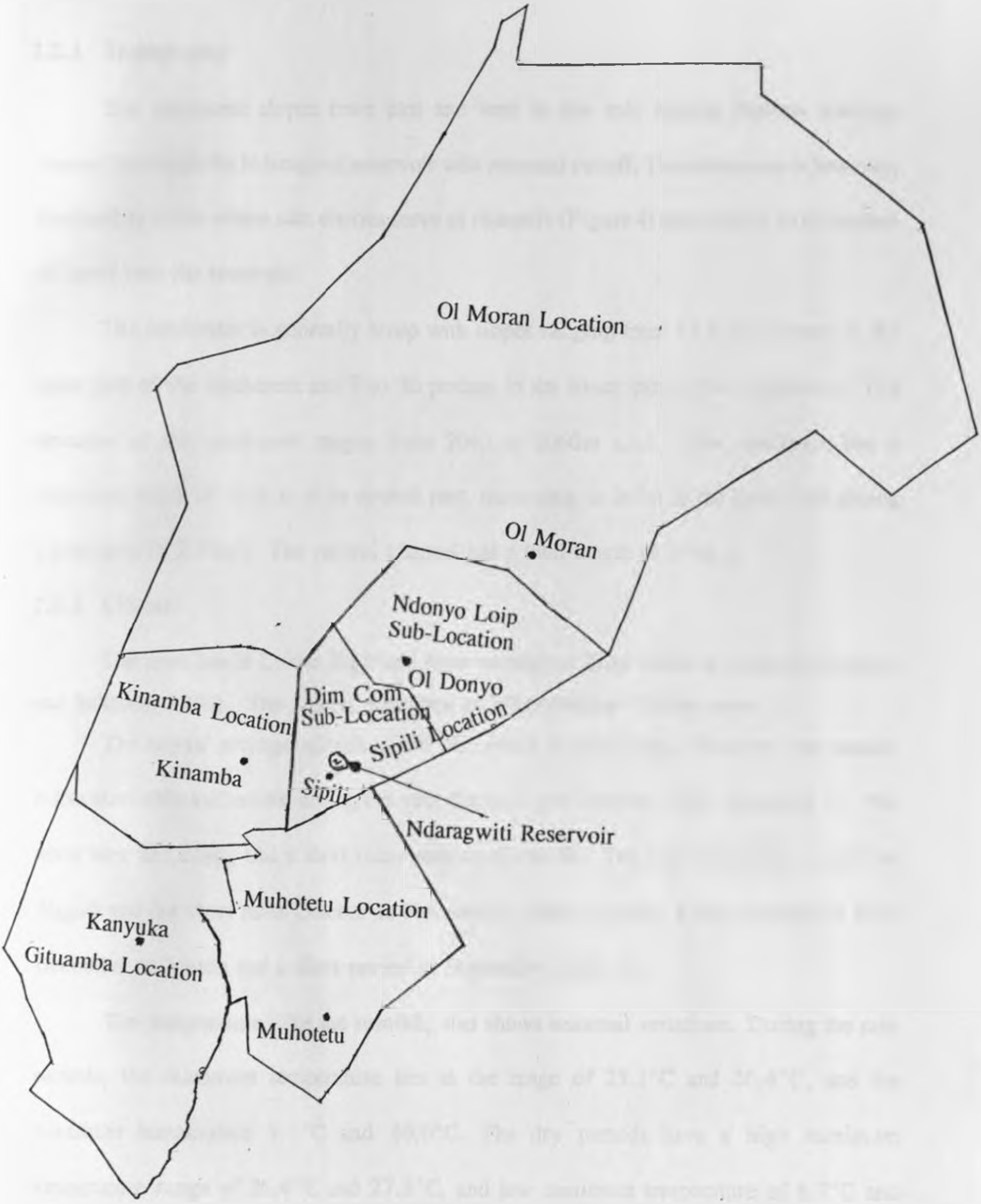


Figure 3: Ng'arua Division Showing Location of Ndaragwiti Reservoir

2.2.1 Topography

The catchment slopes from east and west to the only natural shallow drainage channel that feeds the Ndaragwiti reservoir with seasonal runoff. The catchment is however, dissected by roads whose side ditches serve as channels (Figure 4) that carry a large amount of runoff into the reservoir.

The catchment is generally steep with slopes ranging from 15 to 65 percent in the upper part of the catchment and 7 to 20 percent in the lower part of the catchment. The elevation of the catchment ranges from 2040 to 2060m a.s.l. The catchment has a maximum width of 1515 m at its central part, narrowing to 365m at the lower part giving a total area of 2.7km^2. The natural channel has a total length of 1540 m.

2.2.2 Climate

The area lies in Lower Highland Agro-ecological Zone which is semiarid (Jaetzold and Schmidt, 1983). The zone is described as Wheat/Maize - Barley zone.

The annual average rainfall is 699 mm which is fairly high. However, the rainfall is too unreliable and erratic during the year (Jaetzold and Schmidt,1983; Appendix 2). The study area has a long and a short rainy seasons (Table 8). The long rains start in April to August and the short rains October to November. There is usually a long dry period from December to March and a short period in September (Table 8).

The temperature, like the rainfall, also shows seasonal variations. During the rain periods, the maximum temperature lies in the range of 25.1°C and 26.4°C, and the minimum temperature 8.1°C and 10.0°C. The dry periods have a high maximum temperature range of 26.4°C and 27.5°C, and low minimum temperature of 6.7°C and 7.5°C.

Figure 4: Roadside Ditch serving as a Channel (artificial channel)

2.2.3 Soils

The catchment is located on the volcanic foot ridges. The parent material of the soils consists of tertiary basic igneous rocks (Jaetzold and Schmidt, 1983). The same authors describe the soil as having moderate to high fertility. These soils are well drained, shallow to moderately deep, reddish brown, firm clay, with thick humic topsoil (ortholuvic Phaeozems).

The soils are generally clayey in texture and the clay increases in this texture with depth. The organic content is moderately high.

2.2.4 Vegetation, Settlement and Landuse

The vegetation of the Ndaragwiti catchment is basically grassland. The whole catchment is almost always covered with grass even during the dry seasons except some areas near the reservoir which are bare with scattered grass cover.

However, there are scattered trees on the catchment. These trees include Acacia species - *A. mellifira, A. tortilis* and *A. nitotica.* Also almost every homestead on the catchment has trees - *Gravelia robusta* around it. These trees are grown by the farmers as windbreak as well sources of firewood. There are also shrubs at the eastern part of the catchment which form some pockets of canopy in these areas.

The catchment was part of a ranch owned by a white settler during the colonial era. The Sipili township (Figure 3) started as workers camp. After independence, people settled on their own and started cultivation. According to the present farmers, cultivation started on the Ndaragwiti catchment in 1975. Currently, each farmer has between 2 and 6 ha of land on the catchment (personal interview)

The whole catchment is under cultivation with no portion as rangeland. According to the farmers, the main farm operation is hand hoeing with limited tractor ploughing applied during the first preparation of the 'virgin' land. Even though the area has two rainy seasons (Table 8), the farmers have only one cropping season due to the unreliability of the second rains (Section 5.4).

Maize is the main crop grown on the farm intercropped with beans in between the rows. However, there are few plots of wheat cultivation. Planting time is usually between March and April and the harvesting time between August and October. After harvesting, the catchment lies fallow till the next cropping season in March.

Some of the farmers have small herds of livestock (cattle, goats and sheep) ranging from 2 to 6 in number per farmer. Probably because of the small number of livestock they have, none of the farmers leave a portion of their plot as pasture. The livestock are fed during cropping time on stover of the maize collected during the previous harvest period. However, the farmers allow their animals to feed on the catchment during the fallow period.

2.3 The Ndaragwiti Reservoir

The reservoir was constructed in 1960's (Ministry of Water Development,1992) by a white settler as a source of water for his livestock and workers. The reservoir is basically a farm pond with the excavated soil used to form embankment around it. The embankment covers about two thirds of the reservoir circumference.The reservoir got silted up by 1992 and only collected very little water during the rainy season and dried up soon after the rains. It was desilted in 1995 by the local community under the supervision and motivation of Parish Development Committee (PDC) of Ng'arua Catholic Parish (Waiganjo, 1997). The PDC has installed a hand pump on it to avoid contamination of the water and to make fetching of water safe and easy.

The reservoir has no permanent stream that feeds it. It collects runoff during rain periods through three main channels (trenches) constructed and directed to it (Figure 7). It has a channel spillway. There is a fence around the reservoir to prevent livestock from drinking from it.

The reservoir is the main source of water for the people and livestock of Sipili township and those on the catchment especially during dry periods. A borehole at Sipili trading centre, 1.0 km from the reservoir also provides water but the water is salty therefore, the people the water from the reservoir thereby imposing high pressure on it. On average, the study indicates that about 12,000 litres of water is fetched from the reservoir per day.

CHAPTER THREE

3.0 LITERATURE REVIEW

3.1 Erosion Mechanism

In water erosion, rainfall and runoff are the erosive agents. Rainfall energy is expended to detach soil particles, transport them by splash and runoff (Hillel, 1980).

The process of sediment detachment, transport and deposition have been studied by many researchers (Foster et al.1981; Schwab et al.,1981; Storm et al.,1994; Spraberry and Bowie, 1969). According to Spraberry and Bowie (1969), sediment yield from a catchment is dependent on gross erosion and all the processes which affect the delivery from the point of detachment to a point of measurement. They categorise gross erosion as: sheet and rill erosion, gully erosion and channel erosion. Ward et al. (1980) in their studies reckoned that even though the particle sizes from samples found on a disturbed area may be fairly uniform, the distribution of coarse and fine materials being transported downstream to a reservoir will depend on many factors and will vary throughout the storm event. They explain that detachment and transport of sediment is dependent on factors such as rainfall intensity, runoff depth on the watershed, topography of the watershed, on site cultural practices, soil particle characteristics, hydraulic characteristics and ground cover on the watershed.

Foster et al.(1981) in their study singled out topography, soil, ground cover and rainfall/runoff characteristics as factors affecting sediment detachment and transport capacity. They concluded that the effect of these factors change from season to season and from storm to storm. Deposition occurs when the sediment available for transport exceeds the transport capacity of the flow (Alonso et al.,1981). Erosion taking place within a catchment leads to sediment yield to streams and reservoirs.

3.2 Background of Soil Erosion and Sedimentation in Kenya

According to Ongwenyi et al.(1993), Kenya is basically an agricultural country. and about three quarters of its adult population are engaged in agriculture . They stated that large scale changes in agriculture in the last 75-80 years have occurred and these are linked with changes in methods of cultivation practices. These changes coupled with population increase have led to expansion of agricultural lands into more fragile marginal lands in the semi arid and arid areas (Ongwenyi et al.,1993). This has resulted in accelerated soil erosion rates and also high sedimentation rates.

Soil erosion in Kenya is mainly due to surface water runoff from 'bare' soil surface (Ongwenyi et al., 1993). The problem is more pronounced in the marginal lands as a result of intensive cultivation and overstocking. In the colonial days, big ranches were found in these semi arid areas but since 1970's, it is quite densely populated with active cultivation and stocking (Jaetzold and Schmidt, 1983).

The problem of soil erosion in Kenya was identified by the year 1935 and between 1948 and 1965, a network for monitoring sediment yield in some parts of the country had been established (Ongwenyi et al.,1993 ; Sharma, 1994). However, these networks are rarely in operation presently due to financial constraints and negligence (Sharma, 1994).

Ongwenyi et al.(1993) compared soil erosion and sediment yields from different catchment areas under different landuse pattern in Kenya. They concluded that the rates of erosion and sediment loading increase in catchments under agricultural activities. They stressed that these soil losses are much greater in semiarid and arid parts of the country especially where the catchment is under grazing.

3.3 Problems of Reservoir Sedimentation in Relation to Landuse

Changes of landuse have an influence on reservoir sedimentation and this has been investigated by many researchers. Muya (1990) reported that Dunne and Ongwenyi in 1976, studied on sediment yield in the upper Tana catchment at Kamburu and found that the Upper Tana river has suspended sediment yield of 500-600 t/km^2/year. They reported that the sediment delivery ratio shows a rate of erosion from a cultivated field to be at least 10 times the sediment yield value. Not taking into account the bedload, soil erosion would seem to be too high for low efficiency subsistence agriculture to survive without drastic fall in yields.

According to Muya (1990), Dunne and Ongwenyi in 1976 in another study, found a sediment yield of 1075 t/km^2/year in a cultivated and grazed Kalundu basin. The basin is a little to the south of the Upper Tana area in pre-cambrian basement hills of Kitui, Kenya.

Edwards (1977) reported that the Kalundu river had a calculated suspended yield of 550 metric tonnes/km^2/year. He estimated the rate of bedload transport from the sedimention of Kalundu reservoir to be of the same order. He noted that the Kalundu water supply reservoir built in 1958 for Kitui township lost a quarter of its 210x10^3 m^3 capacity during the 1961/1962 floods in six months. Subsequently, the dam completely silted up by 1974 due to bad land management and drought. He estimated the average rate of sediment deposition in the region to be 23,000 t/year representing a minimum sediment yield of 733 t/km^2/year. He assumed that the trap efficiency of the reservoir was 60-65 percent which indicated that the bedload was at least 50 percent of the total load.

Reservoir sedimentation has been studied on Maruba dam which was built in 1958. The dam which is near Machakos received a combined suspended sediment and bedload of about 500 t/km^2/year (Edwards, 1977). This reservoir with a capacity of 1470x10^{3}m^3 had, by 1974, lost more than half its storage.

Kinama (1980) also studied Mithini reservoir in Kitui District which was built in 1948. He did an estimate of sediment rate and found it to be 486 m^3/km^2/year. He attributed the rapid sedimentation to lack of soil conservation and overgrazing within the catchment. The reservoir got filled up with sediment and collapsed in 1973.

From the review, it could be said that, all the evidence from Kenya indicates that the rates of sedimentation in the semi arid area on the basement of land formation are relatively high and much higher than from the volcanic landforms in the more humid areas (Ongwenyi et al.,1993; FAO, 1987).

Sedimentation of reservoirs is, however, not only a problem in Kenya but other parts of Africa and the world at large. Stall (1961) studied the loss of a reservoir capacity at White Hall, Illinois, (USA), and showed that the reservoir had lost 11.2 percent of its capacity at an average loss of 0.2 percent annually. Murray-Rust (1972) carried out a study on sedimentation in Kisongo catchment, a grazing area, west of Arusha, Northern Tanzania. His study showed an accumulated sediment volume of 49,3000 m^3 during the period of 1960 to 1971 with a catchment area of 9.3 km^2. Rapp et al. (1972) carried out sedimentation study in Dodoma, Tanzania, on four reservoirs. The average annual sediment yield of the reservoirs are: Imagi (1.5 km^2), 600 m^3/km^2; Ikowa (640 km^2), 195 m^3/km^2 ,from 1957 to 1969; Matumbulu (18.1 km^2), 729 m^3/km^2,from 1962 to 1977; and Msalatu (8.7 km^2), 406 m^3/km^2 from 1944 to 1971. Chakela (1981) also did soil erosion assessment in Khomo-Khoana catchment in Northern Lesotho and a sediment yields survey in Central Lesotho on six reservoirs in Roma Valley and two reservoirs in Maliele catchments. Landuse in these catchments consisted of cultivation and grazing. Settlement had taken place in some parts of Roma Valley. The main problem in these catchments was limited farming lands as a result of some cases of bare bedrock outcrops, and soil erosion in the form of gullies and rills on the catchments. Rates of sedimentation measured in reservoirs of Roma Valley and Maliele catchments were in the range of 100 to 200 $t/km^2/year$.

Thus to curb the menace of soil erosion and sedimentation in semi arid areas especially in Africa, appropriate methods of landuse or conservation measures have to be adopted.

3.4 Soil Loss Equation Models

According to Wischmeier and Smith (1978), developing equations to calculate field soil loss began around 1940 in the Corn Belt, USA, by Zingg as a regional method for estimating soil loss and was referred to as the slope-practice method.

Physically-based simulation models of erosion and sedimentation yield require the coordinated use of several submodels (Bogardi et al., 1985). Several simulation models such as regional regression produced by Flaxman in 1972 (Elwell, 1984; Bogardi et al.,1985), the CREAMS model (Knisel, 1980), the USLE, the modified USLE, the SLEMSA and the recently developed WEPP are available. However, the practical application of some of these models is limited due to the uncertainty in input parameters.

This section reviews the USLE, the modified USLE and the SLEMSA and points out some of their shortcomings.

3.4.1 The Universal Soil Loss Equation

The USLE which could be referred to as the 'father' of all soil loss models was introduced in 1958 under the leadership of W.H. Wischmeier (Foster, 1991). It has been a valuable and successful tool for soil loss prediction for nearly four decades, and is now the most widely used equation (FAO , 1993; Hadley, 1984).

The USLE as expressed in Schwab et al.(1981) is;

$$A = RKCLSP \quad \cdots\cdots (1)$$

where;

A = average annual soil loss (tonnes/ha)

R = rainfall and runoff erosivity index

K = soil erodibility factor (tonnes/ha)

C = cropping management factor

LS = topographic factor

P = conservation practice factor

The equation was basically developed from data collected from small runoff plots in the east of the Rocky Mountains (USA.), but has been extended in use. It provides an estimate of long-term avarage annual soil loss from segments of arable land under various cropping conditions (SCS, 1972). Its appeal has led to attempts to use it for purposes it was not initially designed for, and this has resulted in sometimes unjust criticism (FAO, 1993).

According to FAO (1993), Wischmeier in 1976 reported the following points the USLE is not for use:

1. Predicting sediment yield from a watershed because it does not include deposition and delivery ratios.
2. Predicting soil loss from a single storm, because the factors are all long-term averages which smooth out the large variations.
3. Prediticing soil loss outside the range of its own database without determining

appropriate different values for the factors, e.g. the slope factor has only been experimentally determined up to 16 percent and extrapolation beyond this value should be tested by experimental studies.

4. Separating the factors as if they were each independent e.g. rainfall and runoff erosivity index, R, reflects the interaction of storm size and rain intensities, though the basic assumption is that each factor is an independent variable.
5. Being used as a precise tool to study the process of erosion.
6. Testing it as a mathematical equation which can be solved for one of the input factors, e.g. by estimating all the factors but the erodibility factor, K. when measuring soil loss and then solving for K.

However, research needs for further extension and refinement in different areas have been suggested by Singer et al.(1977) for California rangeland; El-Swafy and Dangler (1977) for tropical soils; Aina et al.(1977) for Western Nigeria rainforest; Roose (1977) for West Africa conditions; and Brooks (1977) in Hawaii. According to Foster (1990) the USLE has some limitations which include not having explicit terms of hydrologic and erosion processes for the effects of runoff. He stated that this decreases the effectiveness of the equation for practices that reduce runoff greatly.

3.5.2 Modified Universal Soil Loss Equation (MUSLE)

Although the USLE is a powerful tool that has been widely used almost throughout the world, sediment yield can be predicted if the USLE is calculated with sediment delivery ratio (SDR) (Elwell, 1984). However, there is an uncertainty in the delivery ratio determination (Borgardi et al., 1985). Elwell (1984) reported that Williams and Hann in 1973 and Williams in 1975 modified the USLE and eliminated the SDR in the predicting of sediment yield. Research and experience since 1970's have provided improved technology that is incorporated in the USLE to what is known as Modified USLE (MUSLE) (Renard et al., 1991).

The MUSLE as expressed in Bogardi et al.(1985) is as follows;

$$Z = 11.8(Vq)^{0.56}KCPLS \cdot \qquad (2)$$

where;

Z = sediment yield from the catchment (tonnes)

V = surface runoff from the catchment (m^3)

q = peak flow rate from the catchment(m^3/s)

K = soil erodibility factor (tonnes)

C = crop management factor

P = erosion control factor practice factor

LS = topographic factor

As stated earlier, the MUSLE is the update of the USLE based on an extensive review of the USLE. It addresses the USLE database, analysis of data previously not included, and theory describing fundamental hydrologic and erosion proceses.

The updated USLE includes the following (Renard et al., 1991);

i) New rainfall - runoff erosivity term value (R) based on more than 1,200 gauge locations.

ii) Corrections for high R-factor for areas with flat slopes to adjust for runoff parameters such as storm volume and peak flow rate.

iii) Development of a seasonally variable soil erodibility term (K).

iv) A subfactor approach for calculating the cover management term (C), with subfactors representing considerations of prior landuse, crop canopy, surface cover and surface roughness.

v) New slope length and steepness (LS) algorithms reflecting rill to interrill erosion ratios.

vi) The capacity to calculate LS products for slopes of varying shape.

vii) New conservation practice value (P) for rangelands, stripcrop rotations, contour values and subsurface drainage.

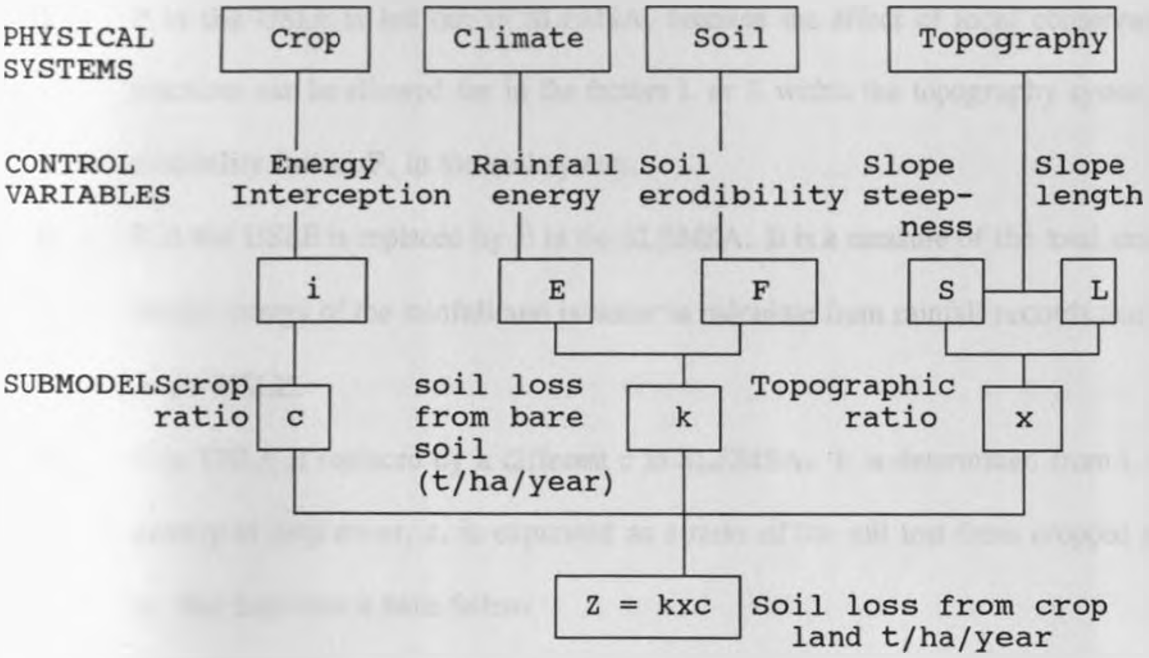
Inspite of these improvements MUSLE estimates average annual soil loss by sheet and rill erosions only on those portions of landscape profiles where erosion but not depositions is occurring (Renard et al., 1991).

3.5.3 Soil Loss Estimator for Southern Africa (SLEMSA)

The USLE factors were developed in USA which at times become inappropriate to use in other countries of different conditions (Elwell, 1984). Elwell in 1981,and Elwell, et. al. in 1982 modified the USLE for conditions in Zimbabwe as documented in Elwell (1984); FAO (1993); and Hadley (1984). This has become known as SLEMSA. The purpose of the SLEMSA is to make use of limited data in a system that allows progressive improvement as more data are required. It follows closely to the USLE and both the SLEMSA and USLE estimate long-term average annual soil loss (FAO, 1993).

According to Elwell (1984) and FAO (1993),the SLEMSA model is built by first dividing the soil erosion environment into four physical systems: Crop, Climate, Soil and Topography. The physical systems are further divided into five control variables:the amount of rainfall energy intercepted by the crop (i); seasonal rainfall energy (E); soil erodibility (F); slope length (L); and slope steepness (S). These control variables are the major overriding factors controlling soil losses within each system (Elwell, 1984).

The building of SLEMSA is diagramatically represented as follows:



Source: FAO, 1993.

The control variables are then arranged into three submodels to suit field conditions: a submodel to account for cropping practices (c); a submodel to estimate soil loss from bare soil(k); and a submodel to account for differences in topography (x).

The SLEMSA model is then formulated (Elwell, 1984; FAO, 1993) as:

$$Z = kxc \qquad (3)$$

where,

Z = the predicted mean annual soil loss (t/ha/year) from the land under cultivation.

k = the mean annual soil loss (t/ha/year) from a standard conventionally-tilled plot.

x = the ratio of soil loss from a field of slope length, L (m), and slope percent,S, to that lost from the standard plot, 30 m x 30 m at a 4.5 percent slope .

c = the ratio of soil loss from a cropped plot to that from bare fallow.

FAO (1993) enumerates the difference between USLE and SLEMSA as:-

i) P in the USLE is left out in SLEMSA, because the effect of local conservation practices can be allowed for in the factors L or S within the topography system or erodibility factor, F, in the soil system.

ii) R in the USLE is replaced by E in the SLEMSA. E is a measure of the total annual kinetic energy of the rainfall and is easier to calculate from rainfall records than EI in the USLE.

iii) C in USLE is replaced by a different c in SLEMSA. It is determined from i, the density of crop cover, c, is expressed as a ratio of the soil lost from cropped plot to that lost from a bare fallow.

iv) K in the USLE is replaced by F in SLEMSA. This is a soil erodibility index and is based on soil type.

v) LS in the USLE is replaced by x in SLEMSA. It is calculated in a very similar manner as LS in USLE but with slightly different equations.

According to Elwell (1984), the SLEMSA model has performed sufficiently well during field test. He acknowledged that it was not fully developed and hence having a problem with the linkage of the F and k. He also appreciated the fact that its suitability may be in doubt if applied to other localities at present.

3.6 Water Erosion Prediction Project (WEPP)

Since the introduction of USLE some four decades ago, there has been much research and many improvements to reduce the limitations of the USLE (FAO, 1993). These developments have come out with a process- based model, Water Erosion Prediction Project (WEPP), expected to replace both USLE and MUSLE (Laflen et al.,1991; FAO, 1993). The WEPP is basically an upgrade of the USLE to cover other factors which affect water erosion but are not considered by both USLE and MUSLE (Flanagan and Livingston, 1995).

According to Foster (1990), the WEPP model, unlike the USLE, MUSLE and SLEMSA which are empirical-based, is a process-based. He however stated that even though the WEPP is a process-based, it contains empirical parameters whose values must be determined by experiments since it is intended for field applications. Laflen,Lane and Foster (1991) indicated that the WEPP models soil erosion as a process of rill and interrill detachment, transport and deposition.

In WEPP, the sediment delivery from interrill areas to rills, according to Laflen et al.(1991), is estimated as;

$D_i = K_i I_e^2 G_e C_e S_f$........................4

where,

D_i = sediment delivery from interrill area to a nearby rill(kg/m^2/s)

K_i = interrill erodility (kg/m^4/s)

I_e = effective rainfall intensity (m/s)

G_e = ground cover adjustment factor

C_e = canopy cover adjustment factor

S_f = slope adjustment factor

and $S_f = 1.05\text{-}0.85e^{-4 \sin a}$

where,

a = slope of the surface towards a nearby rill.

while the detachment capacity of flowing water in rill erosion is expressed as;

$D_c = K_r(t_s\text{-}t_c)$

where,

D_c = rill detachment capacity(Ns/m^3)

K_r = rill erodibility(s/m)

t_s = hydraulic shear stress of flowing water(N/m^2)

t_c = critical hydraulic shear stress(N/m^2)

As the flow fills with sediment, rill detachment rate becomes less than the detachment capacity. In WEPP, the detachment rate of the flowing water is expressed as;

$D_r = D_c(1\text{-}G/T_c)$

where,

D_r = rill detachment(deposition) rate(kg/m^2/s)

G = sediment load (kg/m/s)

T_c = transport capacity of the rill flow (kg/m/s)

In WEPP, the erosion process is estimated using steady state continuity equation of sediment transport as;

$\delta G/\delta x = D_i + D_r$

where,

x = distance downslope(m)

The WEPP model combines knowledge of soil erosion process with other important proceses in a simulation model to predict soil erosion by water (Laflen et al.,1991). Because WEPP deals with soil erosion prediction in a different and more comprehensive manner than the other models, it was used for this study.The version of the model used for the study was WEPP(95.7) which is the current one and the modification of the previous WEPP(91.5) (Flanagan and Livingston,1995)

The WEPP(95.7) model could be used in both hillslope and watershed applications

(Flanagan and Livingstone, 1995). A hillslope is a language understood by the WEPP(95.7) model to mean a plot on a watershed. The model is a distributed parameter, continuous simulation, erosion prediction model, implemented as a set of computer programmes. The WEPP(95.7) model can provide daily, monthly, annual and/or average runoff, soil loss, sediment deposition, sediment yield depending upon the user's interest. For the study the WEPP(95.7) provided an average annual soil loss and sediment yield.

According to Laflen et al.(1991), and Flanagan and Livingston (1995), the WEPP model as applied to hillslope can be subdivided into nine conceptual conponents of which only seven are briefly described here because the other two,(winter and irrigation) components were not applicable to the study catchment:

a) **Hydrologic Component:** The hydrology componenet of the WEPP(95.7) computes infiltration,runoff, soil-evaporation, plant transpiration, soil water percolation, plant and residue interception of rainfall, depressional storage and soil profile drainage by subsurface drains.All these parameters are internally calculated during the run of the model.Infiltration is calculated using a modified Green and Ampt infiltration equation. Runoff is computed using the kinematic wave equation.

b) **Soil Component** : The impacts of tillage on various soil properties and model parameters are computed within the soil component of the WEPP(95.7) model.

c) **Hydraulic Component** : The impacts of soil roughness, residue cover, and living plant cover runoff rates, flow shear stress and flow sediment transport capacity are computed in the hydraulics of overland flow section of the WEPP(95.7) model.

d) **Erosion Component** : The erosion component of the WEPP(95.7) model uses a steady state sediment continuity equation to estimate the change in sediment load in the flow with distance downslope. Soil detachement in interrill areas is modelled as a function of rainfall intensity and runoff rate, while delivery of interrill sediment to rills is a function of slope and surface roughness.

e) **Climate Generation** : Climate requirements for WEPP(95.7) is normally generated using the CLIGEN model which is a computer programme run separately from the WEPP(95.7) erosion model or can be provided by the user. CLIGEN creates input data files for the model which contain daily values for rainfall amount, duration, maximum intensity, time to peak intensity, maximum and minimum temperatures, solar radiation, wind speed, wind direction and dew point temperature. For this study, the climate data were provided. The rainfall for a day is disaggregated into a simple single-peak storm pattern using time-rainfall intensity format for use by the infiltration and runoff components of the model.

f) **Plant Growth Component** : The plant growth component for cropland calculates above and below ground biomass production for both annual and perennial crops in cropland situation. The plant growth routines in the model are based on an EPIC model approach, which predicts potential growth based on daily heat unit accumulation.

g) **Plant Residue Component** : The WEPP(95.7) model tracks the type and amounts of residue from the previous three years.

In addition to the model components used in hillslope applications, the watershed simulations use three more components: channel hydrology and hydraulics, channel erosion and impoundments.

a) **Channel Hydrology and Hydraulic Components** : The channel hydrology and hydraulic components compute infiltration, soil evaporation,soil water percolation, rainfall interception, flow shear stress and flow sediment transport in the same way as the hillslope hydrology and hydraulic components.

b) **Channel Erosion Component** : The channel erosion component of the WEPP(95.7) predicts detachment and deposition in a similar manner as for rills on a hillslope.

c) **Impoundment Component** : The impoundment routines in WEPP(95.7) route runoff and sediment through an impoundment determining the total amount of runoff leaving the structure and the amount of sediment deposited in the structure. The component allows calculation of outflow hydrographs and sediment for various types of structures suitable for both large and small impoundments. The model uses a continuity or mass balance equation to predict outflow concentration, assuming complete mixing in the impoundment.

The USLE and the SLEMSA estimate only the soil loss over the catchment (Wischmeier and Smith, 1978; Elwell, 1984). These models can predict sediment load into a reservoir only when calculated with sediment delivery ratio, SDR (Elwell, 1984). Bogardi et al. (1985) used the USLE with sediment delivery ratio to estimate sediment loads into reservoirs and reported high overestimate value. They attributed the high overestimate to the uncertainty in determining the sediment delivery ratio. Both USLE and SLEMSA do not consider erosion along well defined concentrated water flow courses on cropland (Gilley et al.,1988; Elwell, 1984). The MUSLE on the other hand can be used to predict sediment loading into reservoir when the surface runoff, V, and the peak flow rate, q, parameters are calculated by a runfall-runoff model using the Soil Conservation Service (SCS) method (Bogardi et al.,1985). Bogardi et al.(1985) attributed the lower accuracy of the MUSLE in their study to the uncertainty in the rainfall-runoff calculations.

Evaluation simulation model to estimate sediment loading:

a) the input data should cover a wider parameters of the factors of soil, climate, topography, plant management and the reservoir.

b) the input data must be easily available.

c) the model should estimate both the sediment inflow and outflow of the reservoir.

d) the model must be able to consider sediment flow from the catchment as well as along well defined sediment water flow course.

By condering the above criteria, the WEPP model which can satisfy all was then used for study.

CHAPTER FOUR

4.0 MATERIALS AND METHODS

The reservoir used for the study was Ndaragwiti Reservoir of agricultural catchment in the Sipili location of Ng'arua Division. The methods for the study could be put into categories as:

(1) Field work (2) Laboratory measurement (3) Climatic data collection and (4) WEPP (95.7) model simulation.

4.1 Field Work

The field work comprised catchment survey and collection of soil samples; reservoir survey and collection of soil samples in the reservoir; and landuse and conservation survey in the catchment.

4.1.1 Catchment Survey and Collection of Soil Samples

The catchment survey began with reconnaissance to determine the geometry of the catchment. The shape and size of the catchment were measured by chain survey using the main roads on the catchment as baselines. The catchment was divided into five blocks identified with the main roads and the valley as boundaries. The slope length and steepness of each plot were measured along one or two lines on the plot depending on the size and shape of the plot and the average found. The slope steepness was then determined using the reduced level values with the corresponding measured slope length.

The slope lengths, slope steepness and the widths of the drains along the roads were also measured as they served as channels as well as the valley since WEPP(95.7) model required channel characteristic for its running.

Two types of soil samples were collected from each plot - disturbed and undisturbed for physical and chemical analyses. On each plot, three or four points, well distributed over the plot were selected (Babalola, 1978). The undisturbed soil samples were collected at these points using cores of 5.6 cm inside diameter and 4.1 cm long at the centres of 0-10 cm, 10-20 cm and 20-30 cm depths. Similarly, three soil samples were augered with a sample from each layer at the same depths as the core samples.

4.1.2 Reservoir Survery and Collection of Sediment Samples

A grid survey method was used to survey the reservoir. A baseline was established using a rope along the side of the spillway. The baseline was made longer than the reservoir length by 30 m at both ends of the reservoir. From this baseline, grid squares of 15 m by 15 m were made over the reservoir using ropes. A point at the top of a masonry wall of the spillway channel was used as a temporary benchmark. The elevation at the grid points on the embankment were taken using quickset level.

The depth of the reservoir was measured using an inflated tube to float on the water. Swimming along the ropes, the depth at each grid was measured with a long, calibrated pole. The original depth was also measured with similar procedure but using a pointed pole. The pointed pole was driven through the sediment in the reservoir till there was a sudden increase in penetration resistance, thus indicating the location of the original bed as recommended by Rausch and Heineman (1984).

A contour map was then drawn using the reduced level values of the embankment and the depth reading of the reservoir. The total surface area of the reservoir was calculated using a Geographical Information Systems (GIS) tool of Integrated Land and Water Information System (ILWIS).

The sediment volume of the reservoir as in February 1997 was also calculated using the same ILWIS. The present and the original volumes were calculated using the present and original depths respectively. The difference of these two volumes gave the volume of the sediment in the reservoir.

Two types of sediment deposit samples were also taken - disturbed and undisturbed. They were taken at the mouths of the three channels that fed the reservoir since sampling from the reservoir itself was difficult. There was sediment desposits at these mouths which gave the depths required for the samples. Core and augur samples were taken for undistrubed and disturbed soils respectively at depth 0-10 cm, 10-20 cm and 20-30 cm. It was assumed that the sediment deposits at the mouths of the three channels were similar to the sediments in the reservoir.

4.1.3 Landuse and Conservation Survey on the Catchment

A survey of the effectiveness of the different landuse and soil conservation measures was done by direct observation and interviews. Data was recorded on a questionnaire (Appendix 1). Information on the following was obtained:

- Types of crops grown by the farmers on the catchment
- Type of farming operation practised on the catchment
- Planting and harvesting dates
- Intercrop and row distances
- When the reservoir was desilted
- measures taken to prevent the pollution of the reservoir
- vegetative cover on the embankment etc.

The survey was carried out on about 25 farmers.

4.2 Laboratory Measurement

The soil and sediment samples collected during the fieldwork were brought to Kabete Campus for both physical and chemical analysis.

4.2.1 Physical Analysis

The disturbed samples were air dried till almost free from moisture. They were sieved through a 2mm sieve before using for the various analysis except the gravel concentration.

4.2.1.1 Gravel Concentration

The gravel concentration was determined by 'wet' sieving as described by Kemper and Rosenau (1986) because there were a lot of clods which were not gravels but fine soils stuck together due to the clayey nature of the soils. An unsieved sample of 100g was taken and sieved through a 2mm sieve while allowing water to flow through it. Coarse fragment left on the sieve was then oven-dried and weighed.

4.2.1.2 Particle Size Distribution

The particle size distribution of the samples was determined by hydrometer method (IITA, 1979). The analysis involved initial destruction of the soil organic matter with hydrogen peroxide, dispersion with sodium hexametaphosphate and machine shaking, then analysis by the hydrometer. The sand, clay and silt percentages were calculated as:

$$\text{Sand} = 100[H1 + 0.36 * (T1-68) - 2.0] - 2$$

$$\text{Clay} = [H2 + 0.36 * (T2-68) - 2.0] - 2$$

$$\text{Silt} = 100 - [\%\ \text{Sand} + \%\ \text{Clay}]$$

where,

H1 = Hydrometer reading at 40 seconds

T1 = Temperature at 40 seconds (°C)

H2 = Hydrometer reading at 3 hours

T2 = Temperature at 3 hours (°C)

0.36*(T-68) = Temperature correction to be added to the hydrometer reading

4.2.1.3 Saturated Hydraulic Conductivity (K_{sat})

The core samples were used to determine the saturated hydraulic conductivity of the soil, applying constant head method as described by Klute and Dirksen (1986). The samples were trimmed and cheese cloth tied at the lower end, then saturated for at least 24 hours before mounting them on the constant head hydraulic conductivity apparatus. About 10 minutes were allowed for stabilization after set-up before timing the flow. Volumes of water collected were measured and K_{sat} computed as:

$$K_{sat} = \frac{VL}{At\Delta h} \quad (4)$$

where,

V = volume of water (cm^3) collected after time, t (hr)

L = length of soil samples (cm)

A = cross-sectional area of the soil samples (cm^2)

Δh = the hydraulic head difference imposed across the soil sample (cm).

t = time (hr)

4.2.1.4 Bulk Density

The bulk density was determined by core method as spelled out by Blake and Hartge (1986). The core samples were placed in an oven at 105°C for 24 hours to dry to constant weight. The bulk density was then calculated as:

$$P_b = \frac{W_d}{V_s} \quad (5)$$

where,

P_b = bulk density of the soil (g/cm^3)

W_d = Oven dry mass of the soil (g)

V_s = Volume of moist soil (field condition, cm^3)

4.2.1.5 Soil Water Retention

The pressure chamber method (Klute, 1986) was used for soil water characterization in the 0.0 to 1500 kPa range. The core samples were subjected to 10, 30, 50, 100, 300, 700, 1000 and 1500 kPa suction pressures. Depending on the soil type, equilibrium was attained after 2 to 4 days for low pressures and 6 to 10 days for the high pressures. After the 1500 kPa equilibrium, samples were oven dried at 105°C for 24 hours. Soil water retention was computed as:

$$\theta_w = \frac{W_t - W_d}{V_t \rho_w} \quad (6)$$

where,

Θ_w = soil water retention (cm^3/cm^3)

W_t = mass of soil samples at given tension (g)

W_d = oven dry mass of the sample (g)

V_t = volume of moist sample (field condition, cm^3)

ρ_w = density of water (taken as 1 g/cm^3)

The soil water retention was used to determine the initial saturation of the soil required in the WEPP(95.7). The initial saturation is the field capacity of the soil

(Flanagan and Livingston, 1995) which was determined as the water retention of 10 - 30 kPa (Lal, 1981; Mulla, 1987).

Also determined was the very fine sand (VFS) using aggregate stability method as described by Kemper and Rosenau (1986).

4.2.2 Chemical Analysis

Organic matter and Cation Exchange Capacity (CEC) were the chemical properties of the soil determined. These two properties are the chemical properties required to run the WEPP(95.7) model.

The organic matter was determined by Walkley-Black method as outlined by Nelson and Sommers (1986). The percentage of easily oxidizable organic carbon in the soil was determined by digesting the soil with potassium dichromate in the presence of concentrated sulphuric acid. The organic carbon was determined as:

$$OC = \frac{Meq\ KrCrO_7 - (Meq\ FeSO_4)(0.003)(100)f}{Ww - Wfs} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

where,

OC = Organic carbon (%)

Ww = mass of water (g)

Wfs = mass of free soil (g)

Meq = volume of the reagent used * Normality of the reagent

f = correction factor = 1.30

To obtain the organic matter (%), the organic carbon (%) was multiplied by a factor 1.724 (Nelson and Sommers, 1986). Thus Organic matter (%) = 1.724* organic carbon (%).

The CEC was determined following the procedure described by Udo and Ogunwale (1978) in a soil science practicals handout. The CEC was computed using the formula:

$$CEC = \frac{Titre \ x \ HCl_{norm} \ x \ KCl_{ext} \ x \ 100}{Ws \ x \ KCl_{dist}} \qquad \textbf{(8)}$$

where,

CEC = Cation exchange capacity (Meq/100g)

Titre = amount of distilate (KCl) titrated (ml)

HCl_{norm} = normality of HCl

KCL_{ext} = extracted KCl (ml)

Ws = mass of soil (g)

KCl_{dist} = distilled KCl after pipetting (ml)

4.2.3 Soil Parameters Estimated

In addition to the soil parameters determined in the laboratory the WEPP(95.7) required soil erodibility, critical shear and soil albedo parameters.These parameters were estimated using formulae documented in Flanagan and Livingston (1995) as follows:

4.2.3.1 Soil Erodibility and Critical Shear

(i) For cropland soils containing 30% or more sand;

$K_i = 2728000 + 192100 * VFS$

$K_r = 0.00197 + 0.00030 * VFS + 0.03868 * Exp(-1.84*ORGMAT)$

$\tau_c = 2.67 + 0.065 * CLAY - 0.058 * VFS$

where,

K_i = interill erodibility parameter (kgs/m^4)

VFS = very fine sand (%) $\leq$ 40% (if > 40%, use 40%)

K_r = rill erodibility parameter (s/m)

ORGMAT = organic matter (%) in the surface soil > 0.35%

(if $\leq$ 0.35%, use 0.35)

τ_c = critical shear parameter (N/m^2)

CLAY = clay (%) < 40% (if > 40%, use 40%)

(ii) For cropland soils containing less than 30% sand,

K_i = 6054000 - 55130 * CLAY

K_r = 0.0069 + 0.134 * EXP (-0.20 * CLAY)

τ_c = 3.5

CLAY $\geq$ 10% (if < 10%, use 10%)

Soil albedo was estimated as:

SALB = 0.6/EXP(0.4 * ORGMAT)

where,

SALB = soil albedo

ORGMAT = organic matter (%) in the surface soil

4.3 Climatic Data Collection

Climatic data of Rumuruti station number 8936064 was collected from Kenya Meteorological Department, Dagoretti and the Hydrology Division of the Ministry of Land Reclamation, Regional and Water Development, Kenya to supplement each other in terms of data quality. This station was the closest with similar climate to the study area.

Two types of climatic data were collected. Climatic data for 21 years (1976 -

1996) of which mean monthly maximum and minimum temperatures, solar radiation and rainfall were calculated. The solar radiation was calculated from the formula as recommended by Kenya Meteorological Department (1997):

Radiation (Langley) = 23.8d + 106

where d = radiometer reading - reset value of the radiometer.

Annual and mean annual rainfall for the 21 years were analysed to assess the rainfall distribution of the area. Climatic data for the simulation year (1996) was used to determine the daily values of rainfall amount, rainfall duration, maximum and minimum temperatures, solar radiation, wind speed, wind direction and dew point temperature as required by the model. The reservoir was desilted in late 1995 and therefore it was assumed that the sediment deposit by February 1997 was the effect of 1996 rainfall and hence 1996 was chosen as the simulation year.

4.4 WEPP (95.7) Model Simulation

The WEPP(95.7) is a comprehensive, field-scale simulation model capable of estimating soil loss and sediment yield. The model and input data requirements have been fully documented by Flanagan and Livingston (1995). The WEPP(95.7) input files were constructed for each hillslope on the catchment during the study.

4.4.1 Input Files Descriptions

The WEPP(95.7) model for hillslope requires a minimun of four input data files to run: (1) a climate file, (2) a slope file, (3) a soil file and (4) a plant/management file.

In addition to the files required to run WEPP(95.7) model on each hillslope, a watershed simulation requires three more files:

1) a hillslope information pass file

2) a structure file and

3) a channel file.

The pass and structure files are automatically created upon running the WEPP(95.7) model and by the interface respectively. If impoundment is present in the watershed, then an impoundment input file is necessary.

4.4.1.1 Climate Input File

The climate data required by the WEPP(95.7) model included values for precipitation, temperatures, solar radiations, and wind information. Table 1 below gives the description of the input variables in the WEPP(95.7) climate input files for continuous simulation (Flanagan and Livingston, 1995).

Table 1: Climate Input File Description

Line 1: a) CLIGEN version number - integer

0.0 - use actual storm ip values in this file

4.0 - WEPP(95.7) will internally multiply ip by a factor of 0.7 to compensate for the steady-state erosion model assumption.

Line 2 : a) Simulation mode - integer

1 - Continuous

2 - single storm

b) breakpoint data flag - integer

0 - no breakpoint data used

1 - breakpoint data used

c) wind information ET equation flag - integer

0 - wind information exists - use Penman ET equation

1 - no wind information exists - use Priestley-Taylor ET equation

Line 3 : a) Station - character

Line 4 : a) degrees latitude (+ is North, - is South) - real

b) degrees longitude (+ is East, - is West) - real

c) station elevation (m) - real

d) Weather station years of observation - integer

e) beginning year of simulation - integer

f) number of climate years simulated and in file - integer.

Line 5 : monthly maximum temperature variable name leader

Line 6 : observed monthly average maximum temp. (°C) - real

Line 7 : monthly minimum temperature variable name header

Line 8 : observed monthly average minimum Temp (°C) - real

Line 9 : monthly average daily solar radiation variable name header

Line 10 : observed monthly average daily solar radiation (langleys)

Line 11 : monthly average precipitation variable name header

Line 12 : observed monthly average precipitation (mm) - real

Line 13 : daily variables name header and dimensions

Line 14 : (Repeated for the number of simulation days)

a) day of simulation - integer

b) month of simulation - integer

c) year of simulation - integer

d) daily precipitation amount (mm) - integer

e) duration of precipitation (hr) - real

f) ratio of time to rainfall peak/rainfall duration - real (tp)

g) ratio of maximum rainfall intensity/average rainfall intensity - real (ip)

h) maximum daily temperature (°C) - real

i) minimum daily temperature (°C) - real

j) daily solar radiation (langley/day) - real

k) wind velocity (m/s) - real

l) wind direction (degrees from North) - real

m) dew point temperature (°C) - real

4.4.1.2 Slope Input File

The WEPP (95.7) model requires information about the landscape, which was entered by way of the slope input file. Required information includes slope orientation, slope length, and slope steepness at points down the profile. Table 2 gives the description of the slope input file.

Table 2: Slope Input File Description

Line 1 : version control number (95.7) - real

Line 2 : number of overland flow elements - integer

Line 3 : a) aspect of the profile (degrees from North) - real

b) representative profile width (m) - real

Repeat lines 4 & 5 for the number of overland flow elements

Line 4 : a) number of slope points on the OFE - integer

b) length of the OFE (m) - real

Line 5 : (Repeat 5a & 5b for the number of slope points indicated on line 4a)

a) distance from top of OFE to the point (m/m) - real

b) slope steepness at the point (m/m) - real

Overland Flow Element (OFE) on a hillslope is a subdivision of the hillslope of homogeneous soils, cropping and management. WEPP(95.7) allows simulation of up to 10 OFE's on an individual hillslope. A minimum of two slope points are required to describe the slope on OFE - a point at the beginning of the OFE (distance = 0.0) and a point at the end of the OFE (distance = 1.0)

4.4.1.3 Soil Input File

WEPP (95.7) model can accept soil properties to a maximum of 1.8 metres (Flanagan and Livingston, 1995). Soil parameters must be input for each and every OFE on the hillslope and for each channel in watershed, even if the soil on all OFE's are the same. Table 3 provides the input parameters required for soil file.

Table 3: Soil Input File description

Line 1 : version control number (95.7) - real

Line 2 : a) number of OFE - integer

b) flag to use internal hydraulic conductivity adjustment - integer

0 - do not use adjustments

1 - use internal adjustments

Lines 3 & 4 are repeated for the number of OFE's on line 2a

Line 3 : a) soil name for current OFE - character

b) soil texture for current OFE - character

c) number of soil layers for current OFE - integer

d) albedo of the bare dry surface soil on the current OFE - real

e) initial saturation level of the soil profile porosity(m/m) - real

f) baseline internal erodibility parameter (kgs/m^4) - real

g) baseline rill erodibility parameter (s/m) - real

h) baseline critical shear parameter (N/m^2) - real

Line 4 : (Repeated for the number of soil layers on Line 3)

a) depth from soil surface to bottom of soil layer (mm) - real

b) percentage of sand in the layer (%) - real

c) percentage of clay in the layer (%) - real

d) percentage of organic matter in the layer (%) - real

e) cation exchange capacity in the layer (meq/100g of soil) - real

f) percentage of rock fragments by volume in the layer (%). - real

4.4.1.4 Plant/Management Input File

The plant/management input file contains all the information needed by the WEPP(95.7) model related to plant parameters, tillage sequence and tillage implement parameters, plant and residue management, initial conditions, subsurface drainage and crop rotations. The management file contains the following sections (Flanagan and Livingston, 1995).

- Information Section - contains the WEPP(95.7) version
- Plant Growth Section - plant growth parameters
- Operation Section - tillage and other implement parameters
- Initial Conditions Section - contains initial conditions and parameters which are OFE or channel specific
- Surface Effects Section - tillage sequence and other surface-disturbing dated-sequence of implements
- Contour Section - contouring parmeters

- Drainage Section - drainage parameters
- Yearly Section - management information
- Management Section - indexes into the Yearly Section

For the study, the Drainage and Contour Sections were not used because these two parameters were not practised on the catchment.

More information about input file description and sample input data file could be found in appendices 7 and 12 respectively.

4.4.1.5 Channel Input File

The channel input file is essential in running the watershed WEPP(95.7) model. The watershed component requires information about each channels slope file, soil file, management file and climate file.

a) The channel input slope file is similar to the hillslope input slope file with some small differences:

(i) instead of the number of OFES's on the hillslope, the file must contain the number of channels in the watershed.

(ii) channel width can be different and is specified for every channel. For a hillslope profile, all OFE's have the same representative width. According to Flanagan and Livingston (1995), the length of channels that are laterally fed by hillslope should be equal to the width of the hillslope.

(b) The channel soil file includes information about each channel's soil characteristics. The file content is identical to the soil file for a hillslope in which the number of channels would replace the number of OFE.

(c) The channel management file includes information about each channel management practices. Each channel may have its own management practices which may be different from the practices in surrounding hillslope.The channel management file content is identical to the management file for a hillslope profile in which the number of channels would replace the number of OFE's

(d) The channel climate input file is identical to the hillslope climate. It is advisable to use single input climate file for both hillslope and channel in a watershed (Flanagan and Livingston, 1995).

It could be noted that the WEPP(95.7) model uses all spectra of factors that affect soil erosion hence its usage for this study.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSIONS

5.1 Catchment Profile

The catchment was divided into twenty two plots/hillslopes on five blocks (Figure 5) according to the orientation of the slope. Each hillslope had only one overland flow element (OFE). The number of slope points on the hillslopes ranged from two to four (Table 4). The slope points described the shape of the slope of a hillslope. Any sharp drop or rise of the reduced level of a hillslope was taken as a point where the slope changed and therefore the slope point. The slopes steepness were taken at these points. The number of slope points did not depend on the size of a hillslope but the shape of the slope.

B2P3 was the largest hillslope of size 30.08 ha and B3P1 was the smallest of size 2.53 ha (Figure 5 and Table 4). Large hillslopes were away from the reservoir (Figure 5) indicating uniform orientation of slopes as moving away from the reservoir. The hillslopes were generally steep with a hillslope having as high as 69 percent slope steepness. The slopes of the hillslopes were steep at their upslopes and more or less gentle at their downslopes. Generally, hillslopes near the reservoir (Figure 5) slope gently towards the reservoir (Table 4) although B2B1 had a very steep slope at its upslope. The direction of the slopes of the catchment profile indicated that the cachment sloped from east and west towards the centre where the valley was (Figure 5). The aspect of the profile was determined by following the traces of runoff on the catchment and personal judgement.

The total area of the catchment was approximately 2.7 km^2. There were 54 homesteads on the catchment as at February 1997. Each of these homesteads covers about 0.1 hactare. It was noted during the reconnaissance survey that the oldOl'Moran road

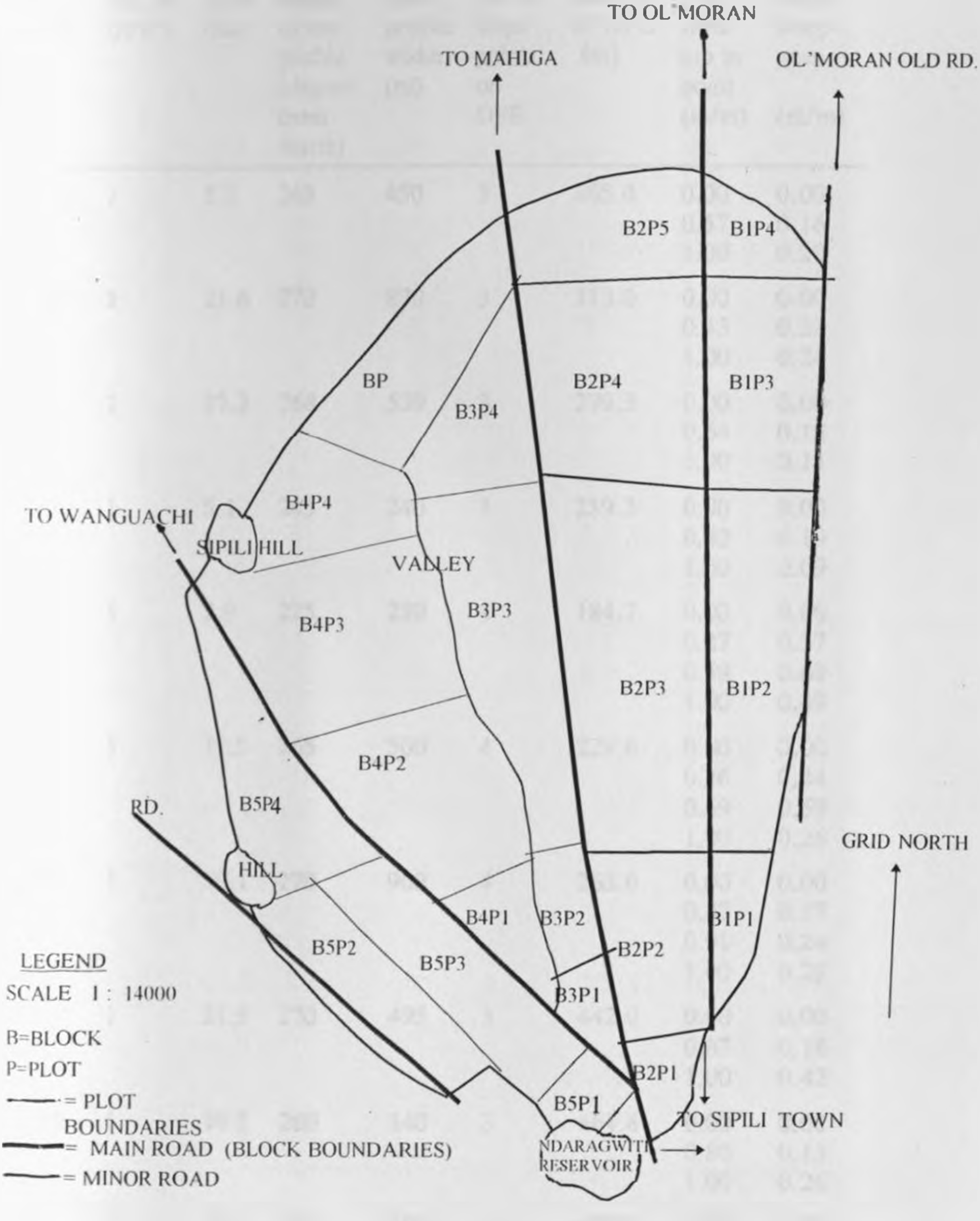


Figure 5 : Survey Map of the Ndaragwiti Catchment

Table 4: Basic Data of the Hillsopes

Hill-slopes	No. of OFE's	Area (ha)	Aspect of the profile (degree from North)	Repr. profile width (m)	No. of slope points on OFE	Length of OFE (m)	Dist from top to point (m/m)	slope steep-ness (m/m)
B1P1	1	5.2	265	450	3	165.0	0.00	0.00
							0.57	0.16
							1.00	0.20
B1P2	1	21.6	270	870	3	313.0	0.00	0.00
							0.43	0.33
							1.00	0.24
B1P3	1	17.2	268	539	3	279.3	0.00	0.00
							0.64	0.15
							1.00	0.11
B1P4	1	5.1	245	240	3	259.3	0.00	0.00
							0.42	0.19
							1.00	0.09
B2P1	1	2.9	225	230	4	184.7	0.00	0.00
							0.27	0.57
							0.59	0.69
							1.00	0.49
B2P2	1	11.5	265	500	4	229.6	0.00	0.00
							0.26	0.44
							0.69	0.59
							1.00	0.26
B2P3	1	30.1	270	900	4	263.6	0.00	0.00
							0.37	0.17
							0.91	0.24
							1.00	0.29
B2P4	1	21.9	270	495	3	442.0	0.00	0.00
							0.67	0.18
							1.00	0.42
B2P5	1	10.2	260	140	3	464.8	0.00	0.00
							0.80	0.13
							1.00	0.26
B3P1	1	2.5	180	100	4	477.0	0.00	0.00
							0.17	0.47
							0.50	0.08
							1.00	0.06

B3P2	1	4.9	220	330	3	184.9	0.00 0.69 1.00	0.00 0.39 0.28
B3P3	1	20.9	270	890	3	193.0	0.00 0.88 1.00	0.00 0.20 0.29
B3P4	1	9.9	270	100	3	183.7	0.00 0.53 1.00	0.00 0.19 0.05
BP	1	11.1	180	150	2	194.7	0.00 1.00	0.00 0.09
B4P1	1	5.6	90	330	2	86.2	0.00 1.00	0.00 0.14
B4P2	1	16.8	90	400	4	245.0	0.00 0.17 0.89 1.00	0.00 0.30 0.32 0.39
B4P3	1	21.8	90	410	4	552.3	0.00 0.31 0.92 1.00	0.00 0.14 0.39 0.14
B4P4	1	9.3	97	170	4	364.2	0.00 0.13 0.57 1.00	0.00 0.66 0.48 0.17
B5P1	1	3.7	240	150	2	178.3	0.00 1.00	0.00 0.14
B5P2	1	11.5	180	130	3	492.7	0.00 0.75 1.00	0.00 0.48 0.16
B5P3	1	13.5	145	150	4	621.3	0.00 0.39 0.79 1.00	0.00 0.33 0.24 0.13
B5P4	1	9.98	100	150	2	237.5	0.00 1.00	0.00 0.19

(Figure 5) had reduced the size of the catchment since it diverts runoff and sediment from its eastern part from entering the reservoir.

5.2 Reservoir Survey

5.2.1 Basic Data on the Reservoir

Basic data on the reservoir (Table 5) was obtained by the grid survey method carried out in February 1997. Some of the original values could be higher or lower than the values shown in Table 5 since there was rehabilitation the previous year and also the possibility of erosion within the year.

Table 5: Basic Data on the Reservoir (February 1997)

Name of Reservoir	Ndaragwiti
Year of Construction	1960's
Year of desilting	1995
Area of Catchment (km^2)	2.7
Altitude (a.s.l) of site (from topo map) (m)	2020
Assumed level of reference bench mark during survey (m)	10
Earth work (m^3)	-
Length of embankment (m)	215
Width of crest of embankment (m)	2.0
Maximum height of embankment (m)	2.3
Upstream slope of embankment	3:1
Downstream slope of embankment	1.5:1
Maximum depth of reservoir (m)	2.9
Surface area of reservoir (ha)	1.9
Length of spillway channel (m)	30
Width of spillway channel (m)	10

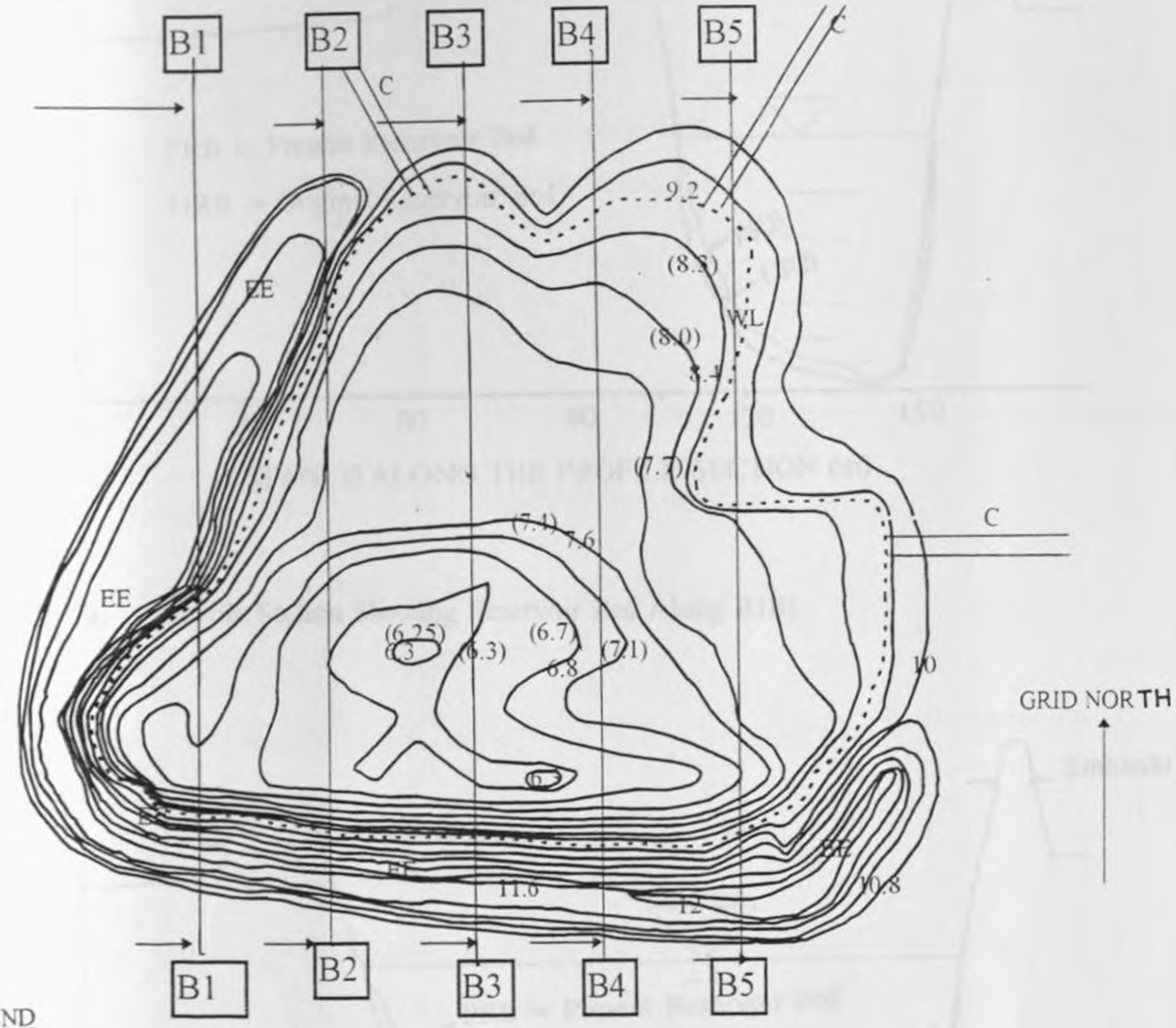
The contour map (Figure 6) was drawn for the reservoir from the reduced levels calculated for the staff readings at the grid points on the embankment and the depth values of the reservoir. The reservoir bed was shallow from the northern section of the reservoir and got gently deep towards the southern section (Figure 6). This is demonstrated by the wider space of the contours at the north which are closer at the south. The maximum depth of 2.9 m as in February 1997 was found in two pockets (Figure 6) enclosed by contour of 6.3 m.

The spotheights enclosed in brackets were for the original bed while the other values were the bed depth at the time of the measurement. The reservoir did not have any permanent stream feeding it but was fed by runoff only through the three channels. These channels were trenches excavated by the community. The embankment was L-shaped stretching from the north-west to cover the whole of the south of the reservoir (Figure 6).

5.2.2 Profile Section Across the Reservoir

The profile sections B1B1 - B5B5 (Figure 6) were developed to view the reservoir bed profile for both the present and the original. Figures 7a-e show the present and original reservoir bed profiles. The depth of sediment deposited after the desilting of the reservoir (1995) along each profile section was determined by the difference of the original and present depths. The shape of the deposited sediment can be seen in the profile sections (Figures 7a-e).

Generally the reservoir slanted gently from the north (upstream) to the south (downstream) (Figures 7a-e). It however deepens sharply just after the middle of the reservoir as can easily be seen on the profile sections. The bed seemed uniform after the sharp fall and then rise steeply at the embankment.



LEGEND
SCALE 1: 1700
---WL= WATER LEVEL
10 =COTOUR LINES (V.I. 0.4)
BB =CROSS PROFILE
C = CHANNEL
( ) = ORIGINAL SPOTHEIGHT
EE = EMBANKMENT

Figure 6: Contour Map of the Reservoir

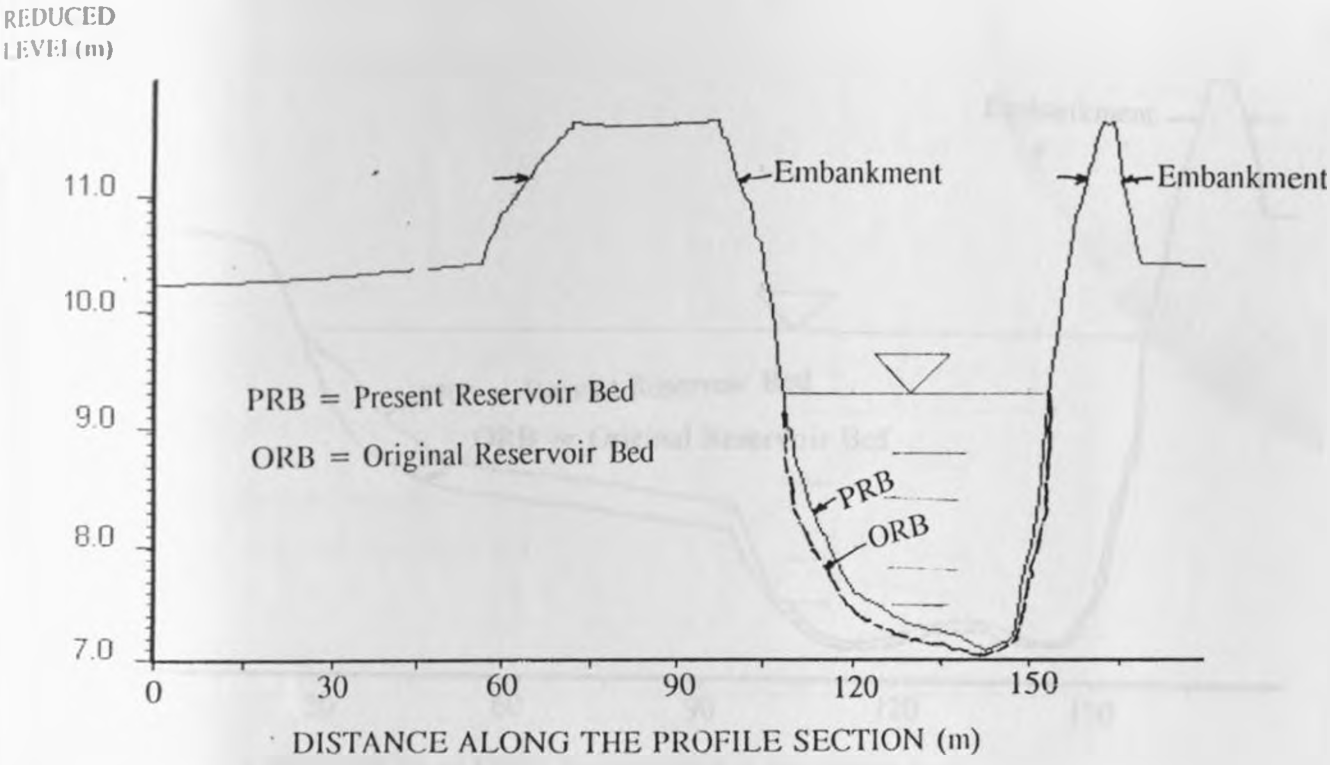


Figure 7a: Profile Section Showing Reservoir Bed Along B1B1

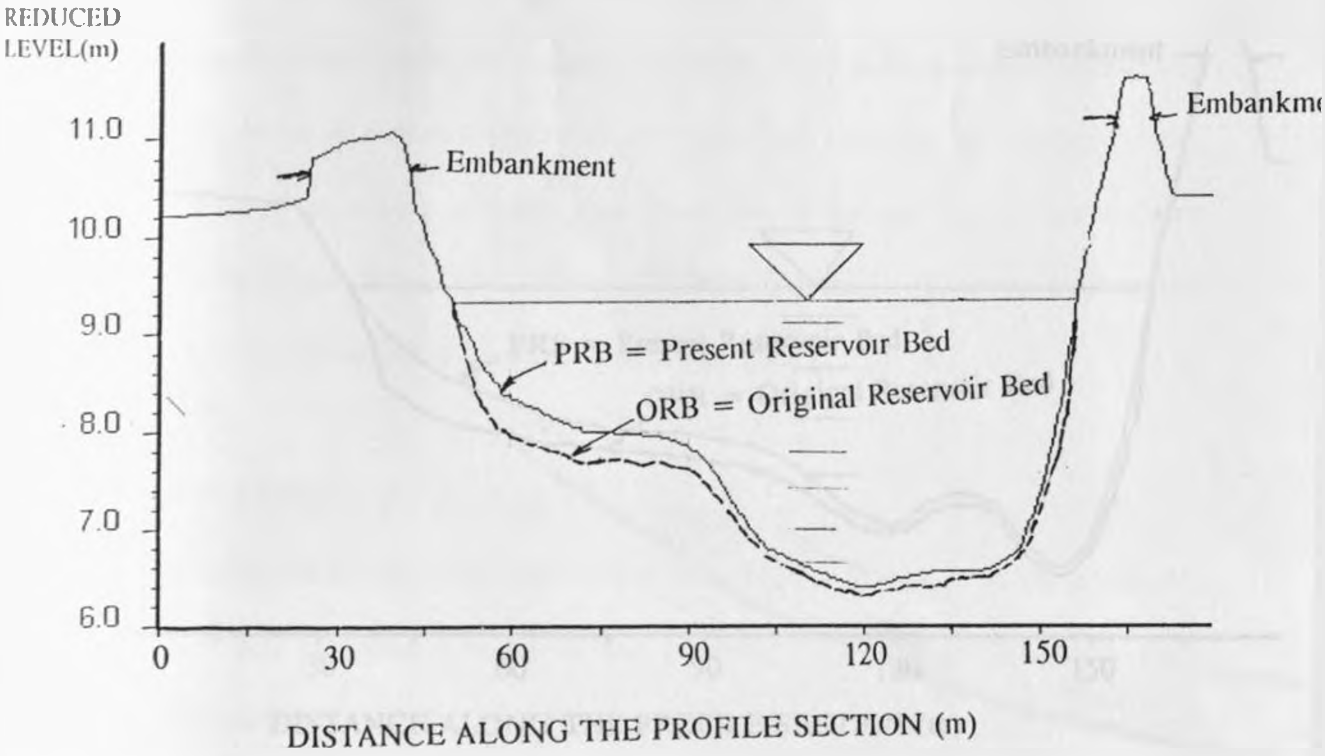


Figure 7b: Profile Section Showing Reservoir Bed Along B2B2

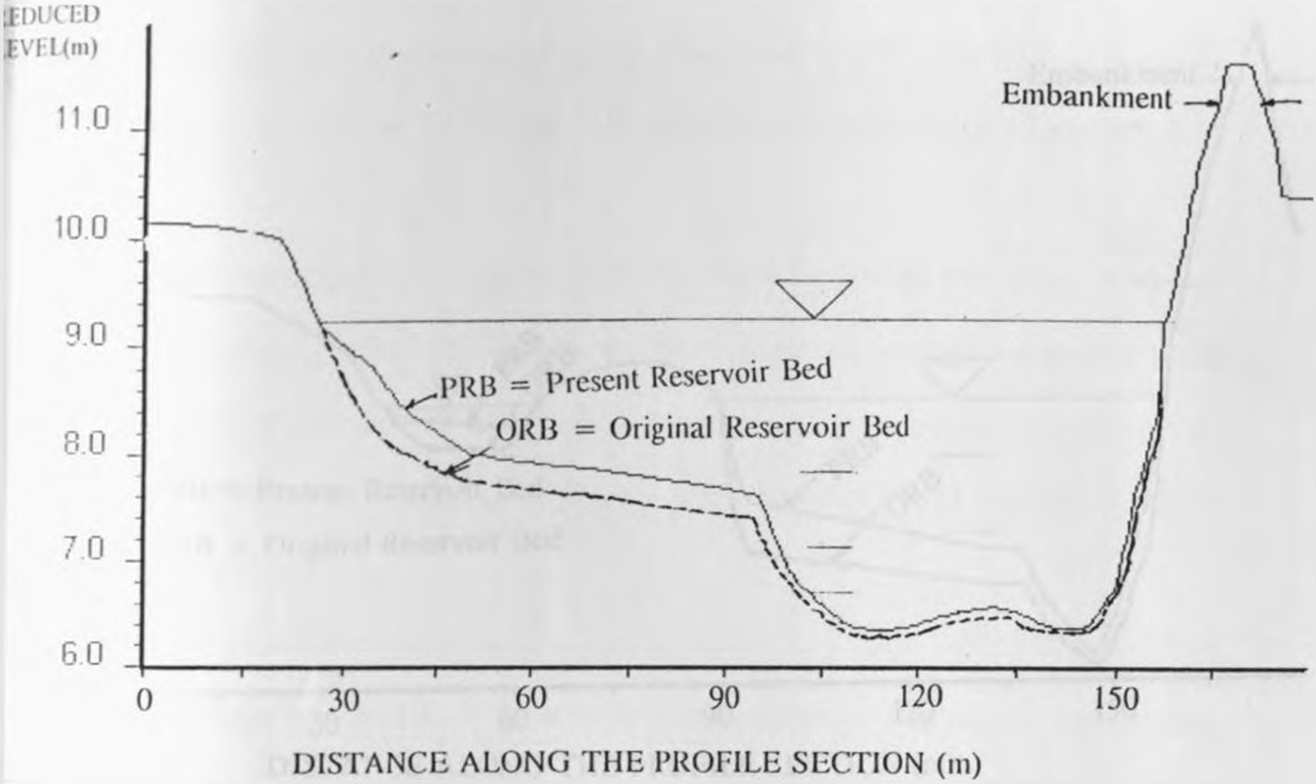


Figure 7c: Profile Section Showing Reservoir Bed Along B3B3

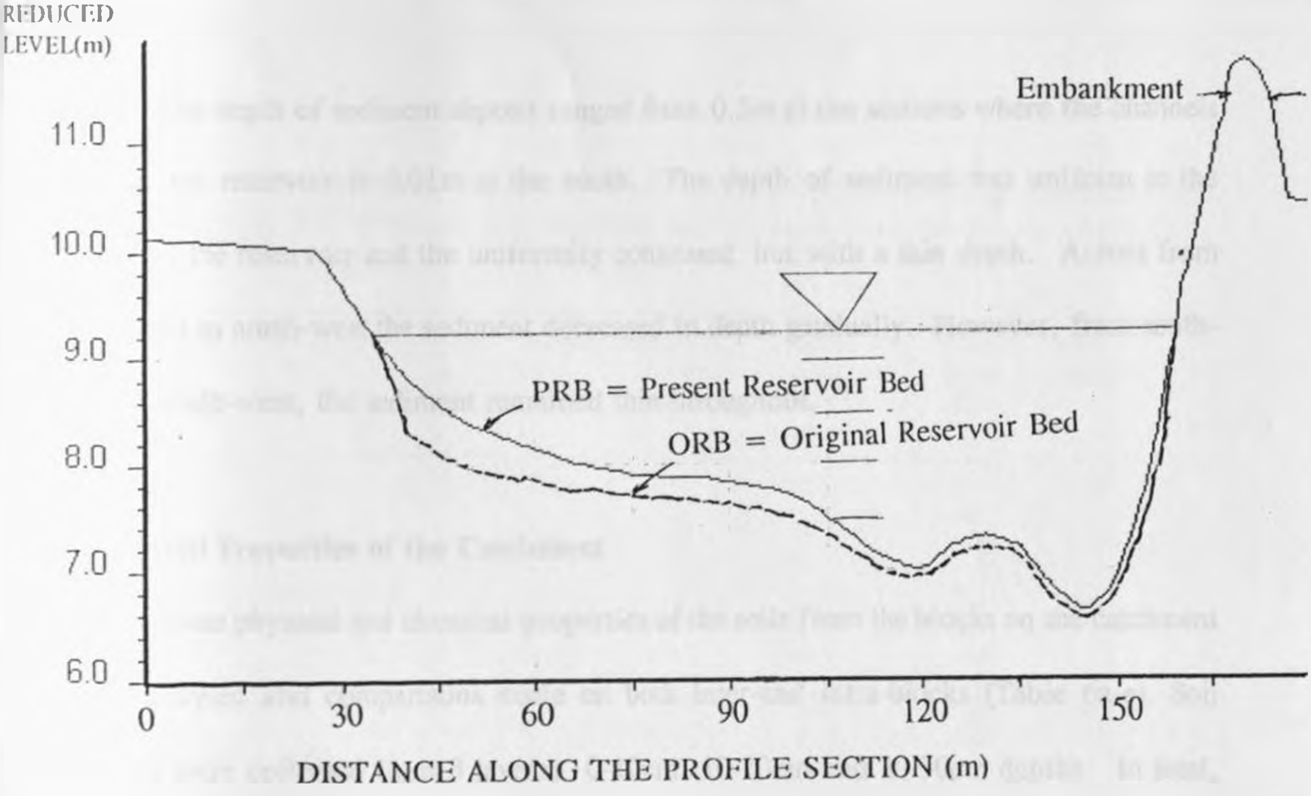


Figure 7d: Profile Section Showing Reservoir Bed Along B4B4

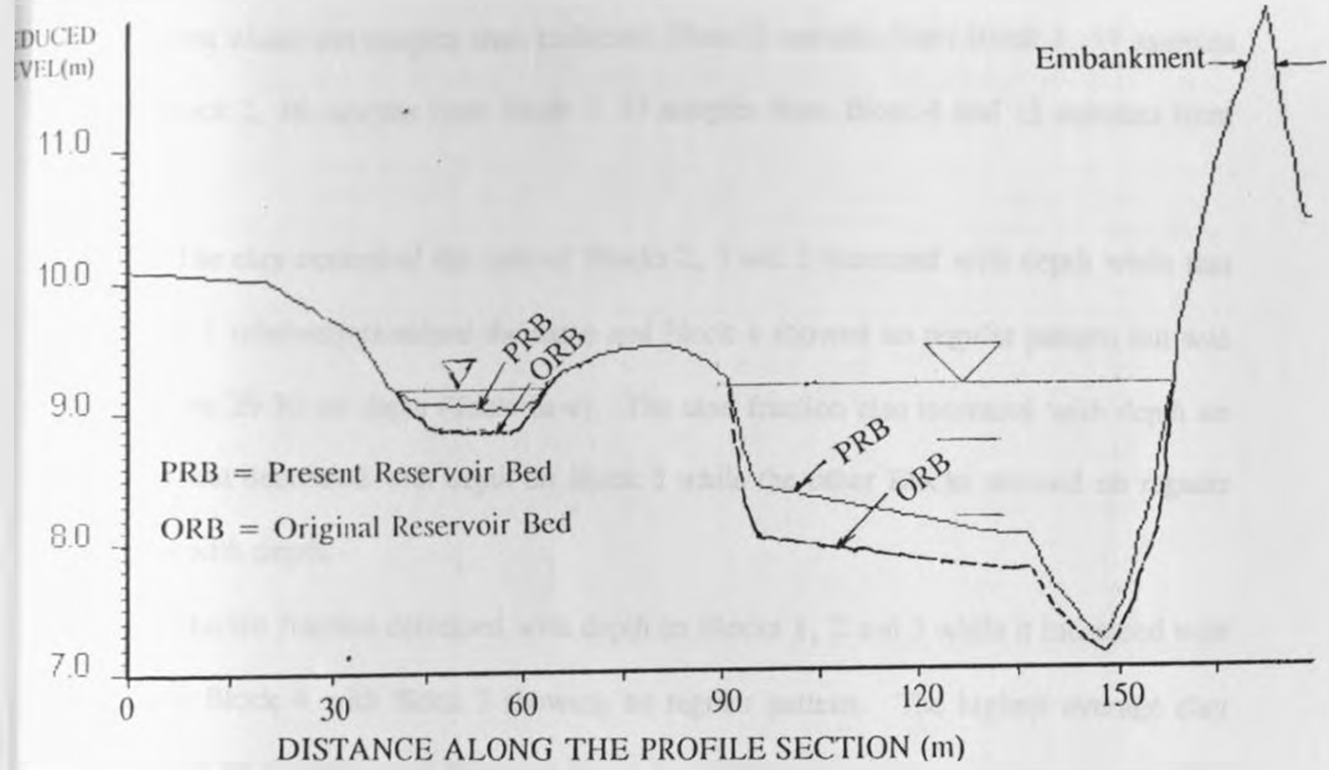


Figure 7e: Profile Section Showing Reservoir Bed Along B5B5

The depth of sediment deposit ranged from 0.5m at the sections where the channels entered the reservoir to 0.01m at the south. The depth of sediment was uniform to the centre of the reservoir and the uniformity continued but with a thin depth. Across from north-east to north-west the sediment decreased in depth gradually. However, from south-east to south-west, the sediment remained thin throughout.

5.3 Soil Properties of the Catchment

Some physical and chemical properties of the soils from the blocks on the catchment were analysed and comparisons made on both inter-and intra-blocks (Table 6a-e). Soil samples were collected from 3 layers; 0-10cm, 10-20cm and 20-30cm depths. In total, three were 72 samples from each layer which included 3-4 replicates depending on the size of the plot where the samples were collected. Thus 13 samples from Block 1, 17 samples from Block 2, 16 samples from Block 3, 13 samples from Block 4 and 13 samples from Block 5.

The clay content of the soils of Blocks 2, 3 and 5 increased with depth while that of Block 1 relatively remained the same and Block 4 showed no regular pattern but was least at the 20-30 cm depth (Table 6a-e). The sand fraction also increased with depth on Block 1 but decreased with depth on Block 5 while the other Blocks showed no regular patterns with depth.

The silt fraction decreased with depth on Blocks 1, 2 and 3 while it increased with depth on Block 4 with Block 5 showing no regular pattern. The highest average clay fraction of 58.7 percent was found on Block 1 at 10-20 cm depth and the lowest was 42.2 percent on Block 5 at 0-10 cm depth. The highest average sand fraction of 30.2 percent was

Table 6a : The Mean ($\overline{x}$), Standard Deviation (σ) and Coefficient of Variation (CV in %) of Some Soil Physical and Chemical Properties in BLOCK 1 (49.1ha)

Depth cm	Para-meters	Sand %	Silt %	Clay %	Gravel Conc. g/100g	Bulk density g/cm^3	Saturated hydraulic conductivity mm/hr	Organic matter %	CEC meq/100g
0-10	$\overline{x}$	22.5	19.0	58.5	1.2	1.17	0.74	3.8	39.2
	σ	1.7	3.4	4.7	1.2	0.08	0.21	0.2	2.6
	CV	7.6	17.9	8.0	100	6.8	28.4	5.2	6.6
10-20	$\overline{x}$	24.8	16.5	58.7	3.7	1.21	0.77	3.2	36.2
	σ	1.3	4.3	3.3	3.3	0.10	0.14	0.4	0.9
	CV	5.2	26.1	5.6	89.2	8.3	19.7	12.5	2.5
20-30	$\overline{x}$	26.6	15.4	58.0	3.8	1.23	0.87	2.3	33.7
	σ	5.3	3.5	8.0	2.3	0.18	0.25	0.3	1.1
	CV	19.9	22.7	13.7	60.5	14.6	28.7	13.0	3.3

Table 6b: The Mean ($\bar{x}$), Standard Deviation (σ) and Coefficient of Variation (CV in %) of Some Soil Physical and Chemical Properties of BLOCK 2 (76.5ha)

Depth cm	Para-meters	Sand %	Silt %	Clay %	Gravel Conc. g/100g	Bulk density g/cm^3	Saturated hydraulic conductivity mm/hr	Organic matter %	CEC meq/100g
	$\bar{x}$	28.8	28.1	43.1	4.4	1.22	2.60	3.8	32.6
0-10	σ	5.3	7.7	9.4	4.2	0.24	2.06	0.6	5.1
	CV	18.4	27.4	21.8	95.5	19.6	79.2	15.7	15.6
	$\bar{x}$	29.0	22.6	48.4	5.1	1.29	1.46	3.3	33.0
10-20	σ	5.7	2.7	6.8	5.0	0.17	1.09	1.2	5.3
	CV	19.6	11.9	14.0	98.0	13.3	74.7	36.4	16.1
	$\bar{x}$	26.1	20.9	53.0	7.2	1.26	1.2	2.7	29.6
20-30	σ	2.4	6.9	8.0	5.5	0.07	1.07	0.5	4.6
	CV	9.2	33.0	15.0	79.4	5.6	89.2	18.5	15.5

Table 6c: The Mean ($\bar{x}$), Standard Deviation (σ) and Coefficient of Variation (CV in %) of Some Soil Physical and Chemical Properties of BLOCK 3 (49.4ha)

Depth cm	Para-meters	Sand %	Silt %	Clay %	Gravel Conc. g/100g	Bulk density g/cm^3	Saturated hydraulic conductivity mm/hr	Organic matter %	CEC meq/100g
	$\bar{x}$	26.9	25.6	47.5	3.0	1.21	1.41	3.9	40.2
0-10	σ	3.3	5.8	4.0	2.0	0.13	0.74	0.3	8.2
	CV	12.3	22.7	8.4	66.7	10.7	52.3	7.7	20.4
	$\bar{x}$	27.4	22.1	50.5	3.7	1.22	1.27	3.4	39.2
10-20	σ	5.0	6.3	6.2	2.3	0.12	0.63	1.5	6.6
	CV	18.2	28.5	12.3	62.2	9.8	49.6	44.1	16.8
	$\bar{x}$	26.8	18.5	54.7	5.6	1.28	0.91	2.9	36.2
20-30	σ	4.9	5.5	3.0	3.8	0.08	0.16	0.2	7.9
	CV	18.3	29.7	5.5	67.9	6.3	17.6	16.9	21.8

Table 6d: The Mean ($\bar{x}$), Standard Deviation (σ) and Coefficient of Variation (CV) in %) of Some Soil Physical and Chemical Properties of BLOCK 4 (53.5ha)

Depth cm	Para-meters	Sand %	Silt %	Clay %	Gravel Conc. g/100g	Bulk density g/cm^3	Saturated hydraulic conductivity mm/hr	Organic matter %	CEC meq/100g
	$\bar{x}$	25.0	21.2	53.8	3.0	1.29	0.88	3.7	46.2
0-10	σ	2.7	2.5	4.1	1.7	0.10	0.13	0.7	3.4
	CV	10.8	11.8	7.6	56.7	7.7	14.7	18.9	7.3
	$\bar{x}$	21.5	22.7	55.8	5.3	1.32	0.80	2.9	40.4
10-20	σ	4.0	2.4	4.6	3.8	0.09	0.21	0.3	2.1
	CV	18.6	10.6	8.2	71.6	6.8	26.3	10.3	5.2
	$\bar{x}$	28.3	24.4	47.3	7.8	1.23	1.77	2.3	38.5
20-30	σ	9.9	6.3	15.9	5.6	0.15	2.09	0.5	1.7
	CV	34.9	25.8	33.6	71.8	12.2	118.1	21.7	4.4

Table 6e: The Mean ($\bar{x}$), Standard Deviation (σ) and Coefficient of Variation (CV in %) of Some Soil Physical and Chemical Properties of BLOCK 5 (38.3ha)

Depth cm	Para-meters	Sand %	Silt %	Clay %	Gravel Conc. g/100g	Bulk density g/cm^3	Saturated hydraulic conductivity mm/hr	Organic matter %	CEC meq/100g
	$\bar{x}$	30.2	27.6	42.2	1.5	1.27	2.39	3.1	35.7
0-10	σ	8.1	6.0	7.1	0.7	0.24	1.65	0.7	6.5
	CV	26.8	21.7	16.8	46.7	18.9	69.0	22.6	18.2
	$\bar{x}$	28.8	25.4	45.8	3.6	1.24	1.76	2.8	33.6
10-20	σ	8.9	6.0	11.7	2.4	0.22	1.76	0.5	5.4
	CV	30.9	23.6	25.5	66.7	17.7	100.0	17.9	16.1
	$\bar{x}$	26.8	25.9	47.3	4.1	1.32	1.27	2.5	32.4
20-30	σ	4.9	2.1	3.7	2.3	0.20	0.46	0.5	5.6
	CV	18.3	8.1	7.8	56.1	15.2	36.2	20.0	17.3

on Block 5 at 0-10 cm depth and the lowest average of 21.5 percent was found on Block 4 at 10-20 cm depth. The soils generally showed clayey texture. The mean contents of sand, silt and clay and their corresponding coefficients of variation on each block is shown in Table 7 below.

Even though the clay content had a high value, generally, plot B4P4 on Block 4 indicated a low percentage of 24.5 clay content and a high sand fraction of 42.8 percent at 20-30 cm depth (Appendix 3). The blocks can be arranged in increasing order of sand, silt and clay as: Block 1, Block 4, Block 3, Block 2 and Block 5; Block 1, Block 3, Block 4, Block 2 and Block 5; Block 2, Block 3, Block 4 and Block 1 respectively.

Table 7: Mean and Coefficient of Variation (CV in %) of Sand, Silt and Clay for the Different Blocks (B_i)

		B1	B2	B3	B4	B5
Sand (%)	Mean	24.7	28.0	27.0	24.9	28.6
	CV	14.2	16.4	15.6	25.7	24.5
Silt (%)	Mean	16.9	23.8	22.1	22.8	26.3
	CV	22.5	27.3	28.5	17.5	17.8
Clay (%)	Mean	58.4	48.2	50.9	52.3	45.1
	CV	8.7	17.8	10.2	19.1	17.0

The relative difference between soil particles among blocks was not wide ranging from 3.9 percent for sand, 9.4 percent for silt and 13.3 percent for clay (Table 7).

The average gravel concentration of all the blocks increased with depth. The coefficient of variation ranged from 46.7 to 100 percent (Table 6a-e). Blocks 1,2 and 3 showed slight variation of the average gravel concentration with depth while Blocks 4 and 5 indicated slightly high variation. Block 4 had the highest average gravel concentration of 7.8 percent at 20-30 cm depth (Table 6d) and Block 1 had the least value of 1.2 percent at 0-10 cm depth (Table 6a). In general, however, Block 2 had the highest gravel concentration ranging from 4.4 to 7.2 percent and Block 1 had the lowest ranging from 1.2 to 3.8 percent (Table 6a-e).

The bulk density of the soils varied little with depth in both inter-and intra-blocks. The hydraulic conductivity also indicated little variation with depth. The hydraulic conductivity followed the same pattern as the clay content. It was noted that, blocks with high clay content had low hydraulic conductivity and those with low clay content had high hydraulic conductivity. Thus the mean clay percentage of Blocks 1, 2, 3, 4 and 5 were respectively 58.4, 48.2, 50.9, 52.2 and 45.1 and their corresponding mean hydraulic conductivities were 0.79, 1.75, 1.23, 1.15 and 1.81 mm/hr.

The average organic matter contents of the soil on all the blocks decreased with depth. The variations were not much, both among and within plots. The average organic matter contents ranged around 3 percent at 0-10 cm to around 2 percent at 20-30 cm depth on all the blocks. The values of the organic matter contents reflected low fertile soils as fertile soils should have organic matter content greater than 6 percent (Landon,1991). The CEC followed similar trend as the organic matter contents. The CEC values ranged from 29.6 meq/100 g on Block 2 at 20-30 cm depth to 46.2 meq/100 g on Block 4 at 0-10 cm depth. The higher values of the CEC indicated the clayey content of the soil (Flanagan and Livingston, 1995)

5.3.1 Soil Water Retention Characteristics

Soil water characteristic is the relationship between soil water content and matric suction in a drying soil (Klute, 1986; Reeve and Carter, 1991). Soil water data from the different layers within each block on the catchment were combined and the averages found to represent soil water characteristics on each block (Figure 8a-e).

Total water storage capacity for the top layer (0-10 cm) was 0.53 up to 0.55 cm^3/cm^3,for the second layer (10-20 cm), 0.50 to 0.54 cm^3/cm^3 and the third layer (20-30 cm), 0.5 to 0.53 cm^3/cm^3 . At 1500 kPa suction equilibrium, the soil water retention for the top, second and third layers were respectively 0.25 to 0.26 cm^3/cm^3, 0.27 to 0.28 cm^3/cm^3 and 0.26 to 0.31 cm^3/cm^3. This indicated that the soils retained more than half of the saturation water content. This could be attributed to the clayey nature of the soils since water retention is enhanced by fine particles of the soil. (De Jeng et al., 1983; Klute. 1986).

Soil water retention characteristics presented in Figure 8a-e illustrate the behaviour of the mean soil water retention within horizons on each block. The water retention followed the trend of the clay content in the soils. Top soils in general retained less water than the subsurface horizons except on Block 1.

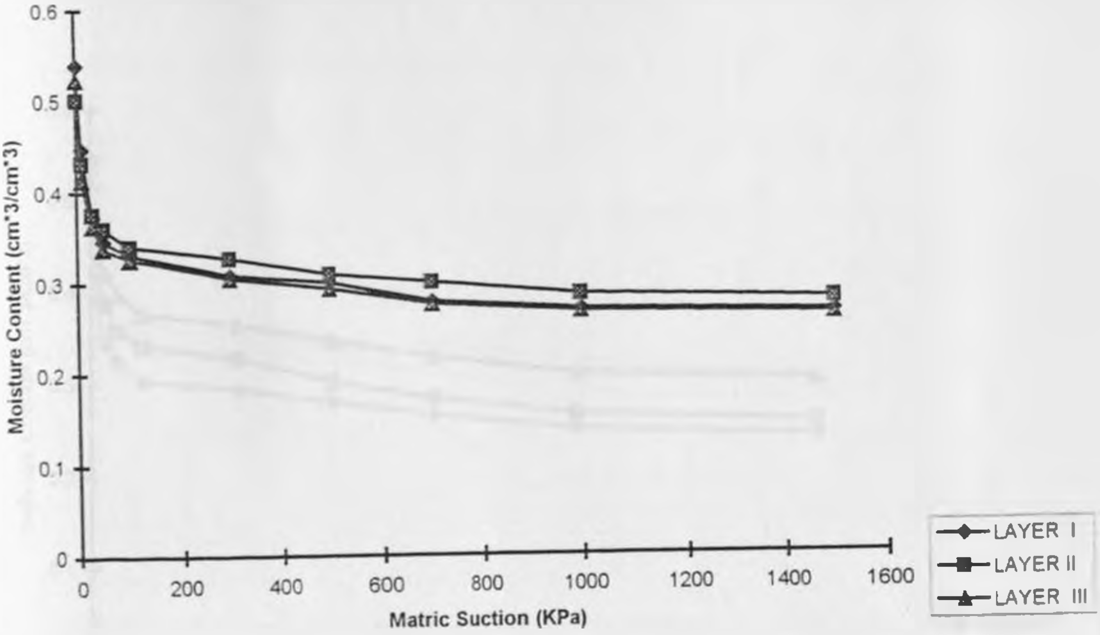


Figure 8a: Soil Water Retention Characteristics of the Soil Layers on Block 1

cm), 0.5 to 0.53 cm^3/cm^3 . At 1500 kPa suction equilibrium, the soil water retention for the top, second and third layers were respectively 0.25 to 0.26 cm^3/cm^3, 0.27 to 0.28 cm^3/cm^3 and 0.26 to 0.31 cm^3/cm^3. This indicated that the soils retained more than half of the saturation water content. This could be attributed to the clayey nature of the soils since water retention is enhanced by fine particles of the soil. (De Jeng et al., 1983; Klute. 1986).

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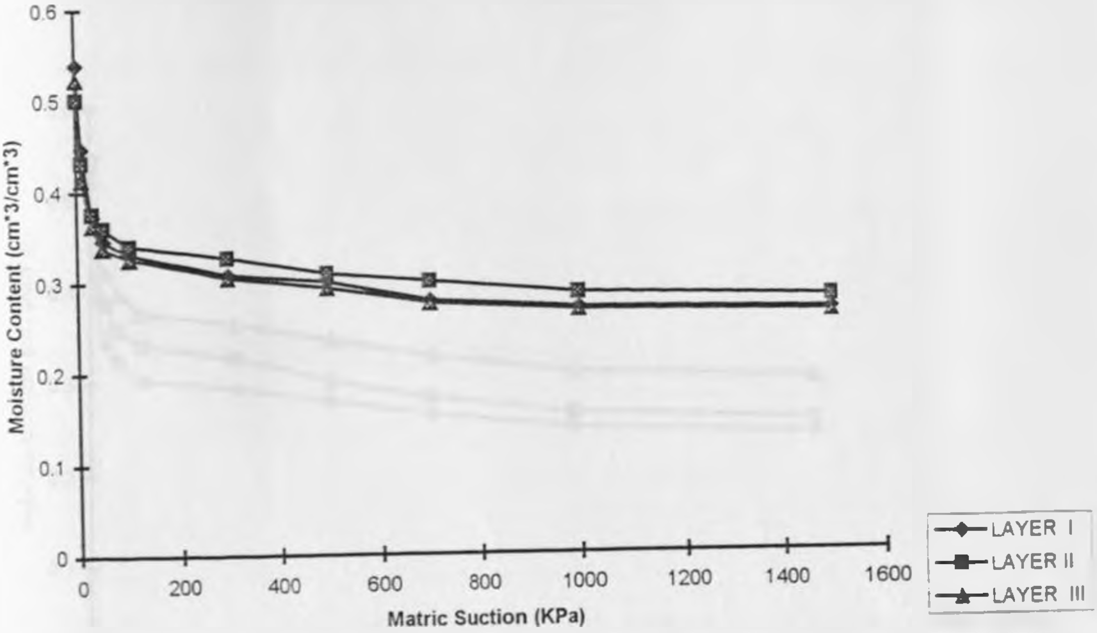

Figure 8a: Soil Water Retention Characteristics of the Soil Layers on Block 1

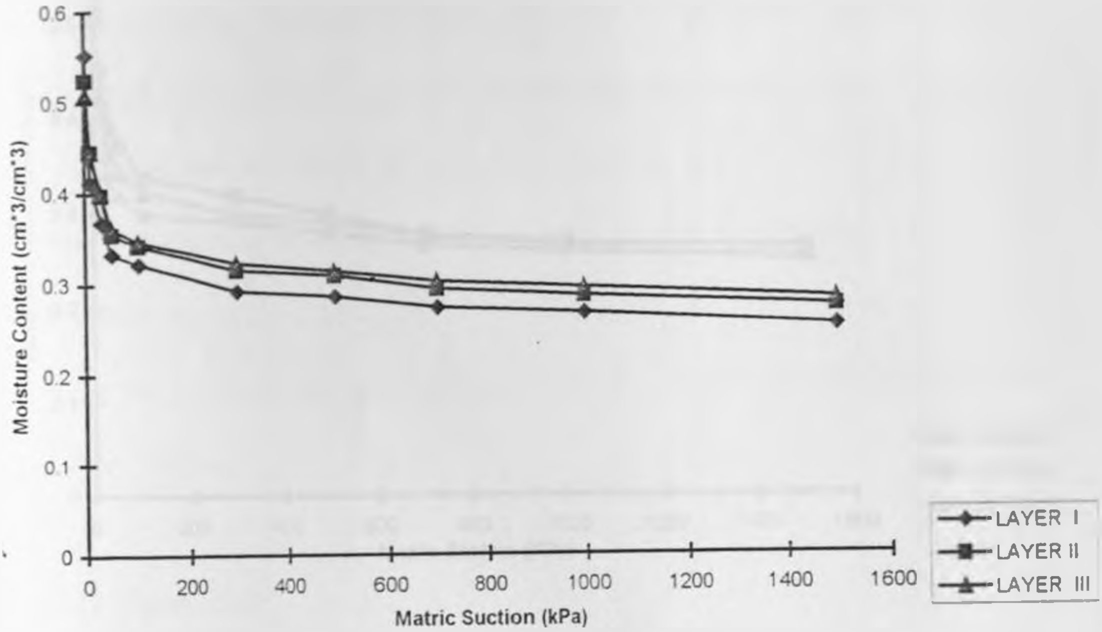

Figure 8b: Soil Water Retention Characteristics of the Soil Layers on Block 2

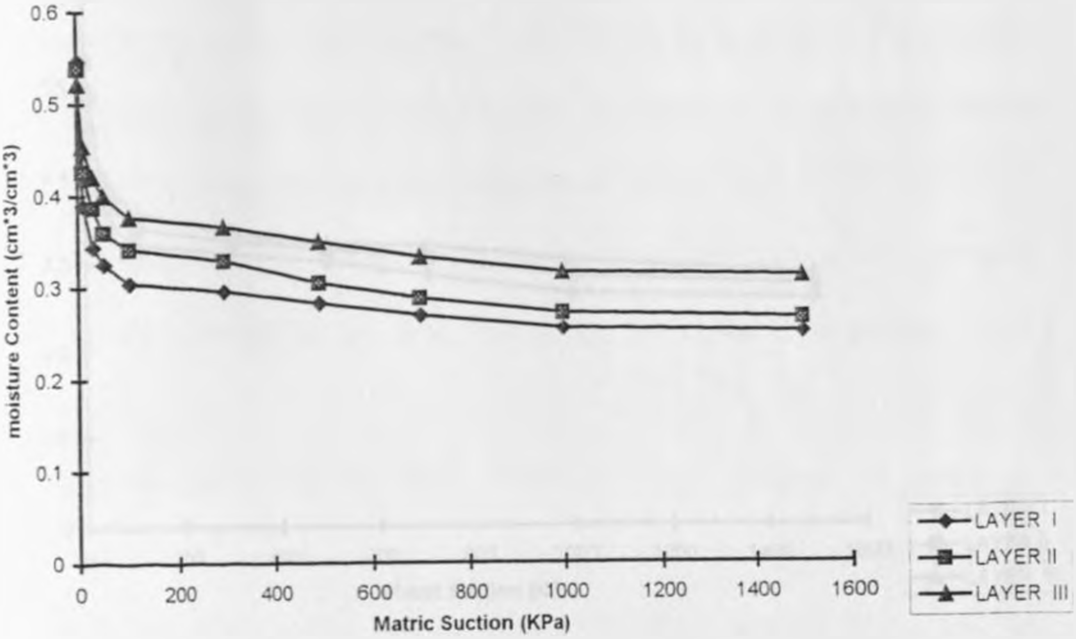

Figure 8c: Soil Water Retention Characteristics of the Soil Layers on Block 3

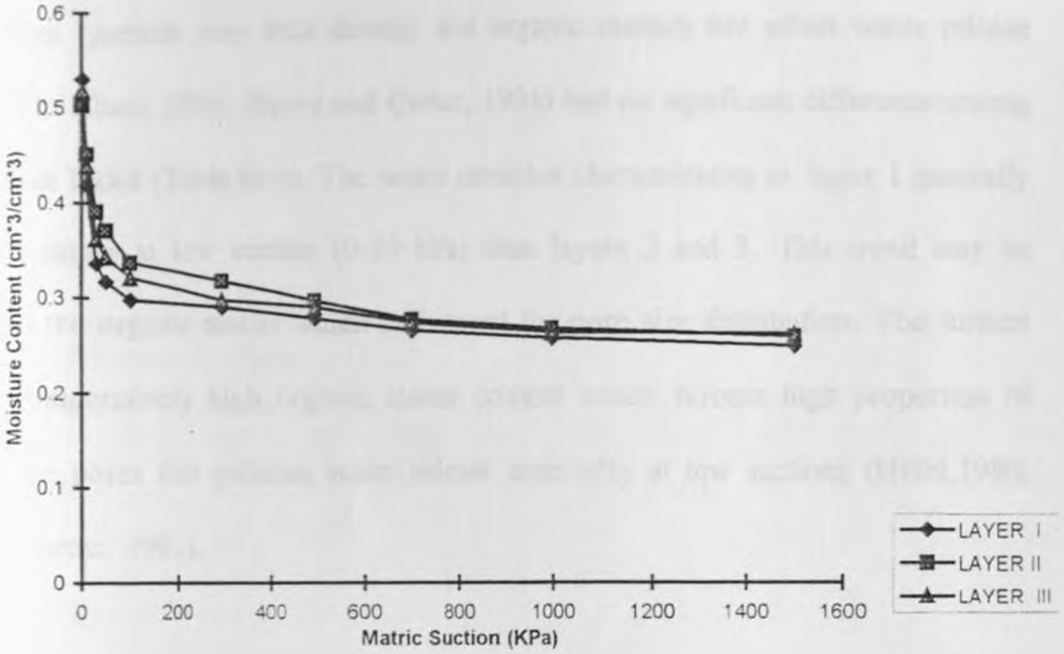

Figure 8d: Soil Water Retention Characteristics of the Soil Layers on Block 4

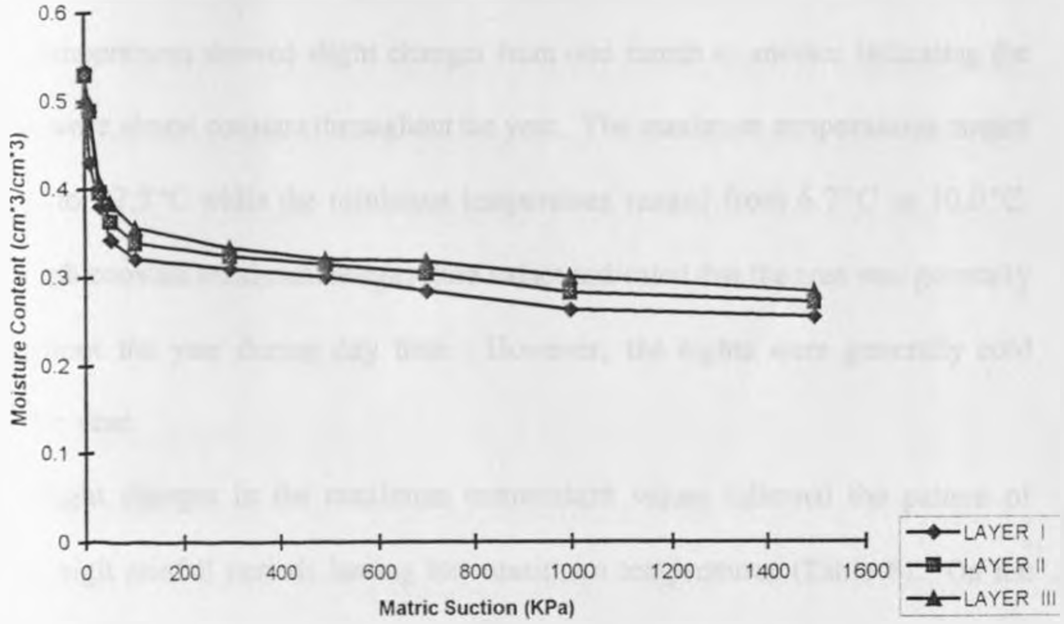

Figure 8e: Soil Water Retention Characteristics of the Soil Layers on Block 5

The water retention of the layers on each Block were close to each other since the soil properties (particle size, bulk density and organic matter) that affect water release (Hillel, 1980; Klute, 1986; Reeve and Carter, 1991) had no significant difference among layers on each Block (Table 6a-e). The water retention characteristics at layer 1 generally had steeper slopes at low suction (0-50 kPa) than layers 2 and 3. This trend may be attributed to the organic matter which influenced the pore size distribution. The surface layer had comparatively high organic matter content which favours high proportion of interaggregate pores that enhance water release especially at low suctions (Hillel,1980; Reeve and Carter, 1991).

5.4 Climatic Conditions

Climatic data for 21 years (1976-1996) was collected from Rumuruti station number 8936064 and analysed. It gave the general climatic trend of the study area. Table 8 shows the monthly pattern of three climatic parameters.

The temperatures showed slight changes from one month to another indicating the temperatures were almost constant throughout the year. The maximum temperatures ranged from 24.6°C to 27.5°C while the minimum temperatues ranged from 6.7°C to 10.0°C. The almost high constant maximum temperature values indicated that the area was generally warm throughout the year during day time. However, the nights were generally cold throughout the year.

The slight changes in the maximum temperature values followed the pattern of rainfall, with high rainfall periods having low maximum temperatures (Table 8). On the other hand, the minimum temperature values followed the direct opposite with respect to rainfall periods. April had the highest mean rainfall amount of 110mm but also had the highest mean minimum temperature of 10.0°C. The warmest months were February and March with a mean temperature of 27.5°C and September equally warm had a mean temperature of 27.0°C. Cooler nights occured in January and February with temperatures of 6.7°C and 7.2°C respectively.

Table 8: **Monthly Values of Some Climatic Data (1976-1996) of Rumuruti Station Number 8936064**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainfall (mm)	24.9	32.7	46.8	110	59	70.2	85.1	81.8	35.3	51.0	62.8	40.1
Max. Temp (°C)	26.4	27.5	27.5	26.4	26.1	25.7	24.6	25.1	27.0	26.4	24.8	2.51
Min. Temp. (°C)	6.7	7.2	8.2	10.0	10.0	8.3	8.3	8.1	7.5	9.1	9.5	8.1
Solar Radiation (langleys)	560	579	575	539	558	531	507	540	576	540	515	547

The solar radiation values were more or less constant throughout the year. They ranged from 507 to 576 langleys. The values were high indicating light cloud cover in the study area. The pattern of the solar radiation is similar to the maximum temperatures (Table 8). The light cloud cover contributes to the warm conditions in the area during day times and also causing the low minimum temperatures thereby making the area cold during the nights.

5.4.1 Rainfall Characteristics

Rainfall characteristics were discussed extensively as the major force for erosion and sedimentation is influenced by rainfall (Renard et al., 1983).

Annual and mean annual rainfall from 1976 to 1996 are shown in Figure 9 to explain the pattern of the annual rainfall distribution. The annual rainfall ranged from

410.6 mm to 1181.6 mm being to the annual rainfall for 1984 and 1977 respectively (Figure 9).

The mean annual rainfall was 699 mm. The rainfall sequence followed a 'zig-zag' pattern with nine years below and eight years above the mean rainfall while the remaining four years were almost in line with the mean rainfall. This depicted that a 'high' rainfall was likely to be followed by a 'low' rainfall the following year taking the mean rainfall as reference rainfall. All the rainfall values clustered along the mean rainfall except 1977 and 1990 which were far above, and 1980, 1984 and 1985 were far below the mean rainfall. This indicated that generally the rainfalls were more or less uniform.

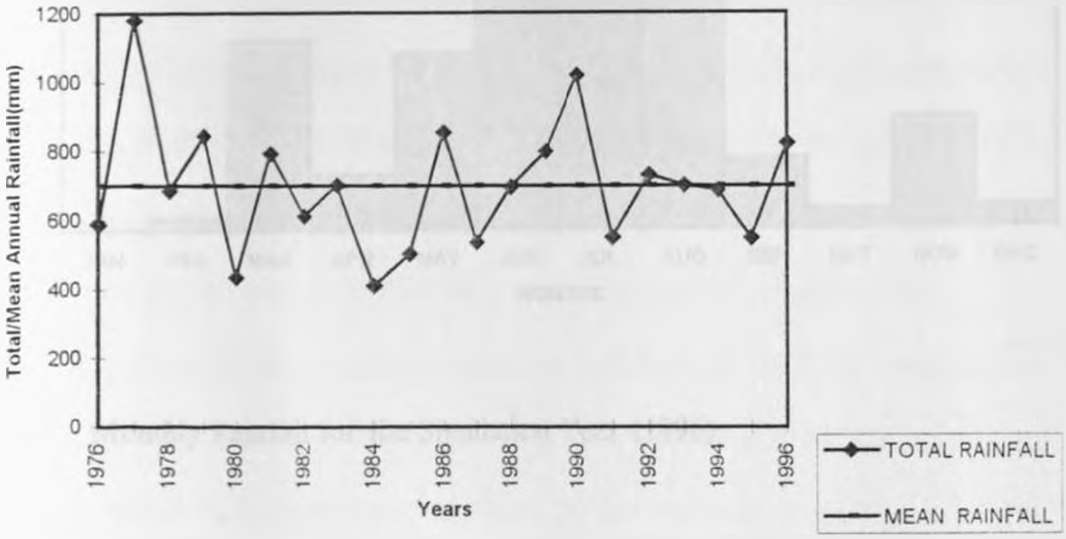

Figure 9: Annual and Mean Annual Rainfall of Rumuruti

Table 8 and Appendix 2 indicate that only very few months of rainfall in a year can bring the rainfall close or further above the mean rainfall. In 1996, June, July and August alone contributed 68.4 percent of the annual rainfall (Figure 9).In 1990, February, March and April contributed 45 percent. In 1985, April and July alone contributed 46 percent. In 1980, May alone contributed 51.3 percent and in 1977, April, May and November contributed 53.4 percent. Appendix 2 clearly shows the rainfall distribution of all the years with very few months contributing to achieve the 699 mm mean. This indicated the distribution in the area. The high variability of the rainfall distribution contributes to large erratic nature of the rainfallquantity of soil erosion and sedimentation even though the area is semiarid with minimum mean annual rainfall. This is in accordance with the observation made by FAO (1987) and Magfed (1986) about sediment production in relation to rainfall distribution in semiarid areas.

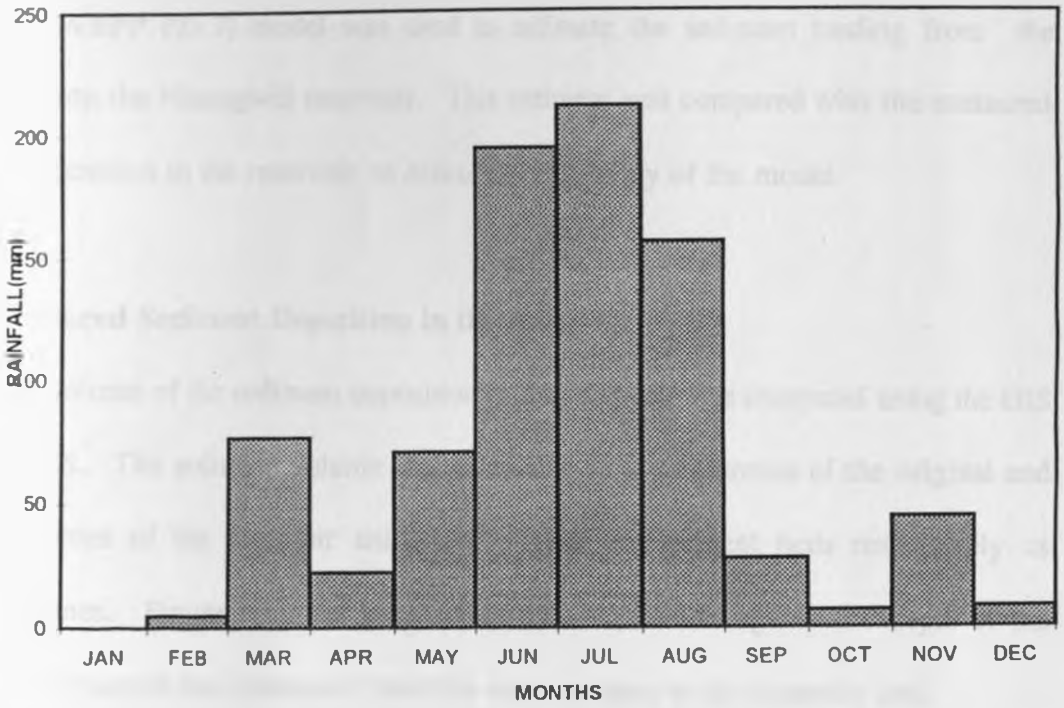

Figure 10: Monthly Rainfall for the Simulation Year (1996)

The area has two rainy seasons (Table 8). The first rains start in April and end in

August while the second rains start in October and end in December. However, only the first rainy season is reliable and the second rainy season is unreliable (Appendix 2). Hence, the farmers on the catchment practise only one cropping season.

5.5 Sedimentation in the Reservoir

The WEPP (95.7) model was used to estimate the sediment loading from the catchment into the Ndaragwiti reservoir. This estimate was compared with the measured sediment deposition in the reservoir to assess the efficiency of the model.

5.5.1 Measured Sediment Deposition in the Reservoir

The volume of the sediment deposition in the reservoir was computed using the GIS tool of ILWIS. The sediment volume was calculated as the difference of the original and present volumes of the reservoir using the original and present beds respectively as reference planes. Figure 11 is the graph of cumulative volume against the depth of the reservoir. The depth was measured from the water surface to the reservoir bed.

The sediment survey in the reservoir was done in February, 1997. The total present volume of the reservoir was 29,756 m^3 and the original volume was 32,326 m^3 (Figure 1). Thus the volume of the sediment deposition in the reservoir was 2590 m^3. The deposition was for 1996 since the reservoir was desilted in 1995 and measurement was done in February 1997 when there had not been any rainfall since January 1997. The average bulk density of the sediment was 12 t/m^3 (Appendix 4). Thus the total sediment deposition was about 3,108 tonnes.

The total deposition measured or calculated in the reservoir came from a catchment of 2.7 km^2. Therefore, the sedimentation rate was approximately 1151 $t/km^2/year$. The sedimentation rate is comparable to the rate of Kamburu basin between Grand Falls and Garissa of 1560 t/km²/year reported by Ongwenyi et al.(1993).

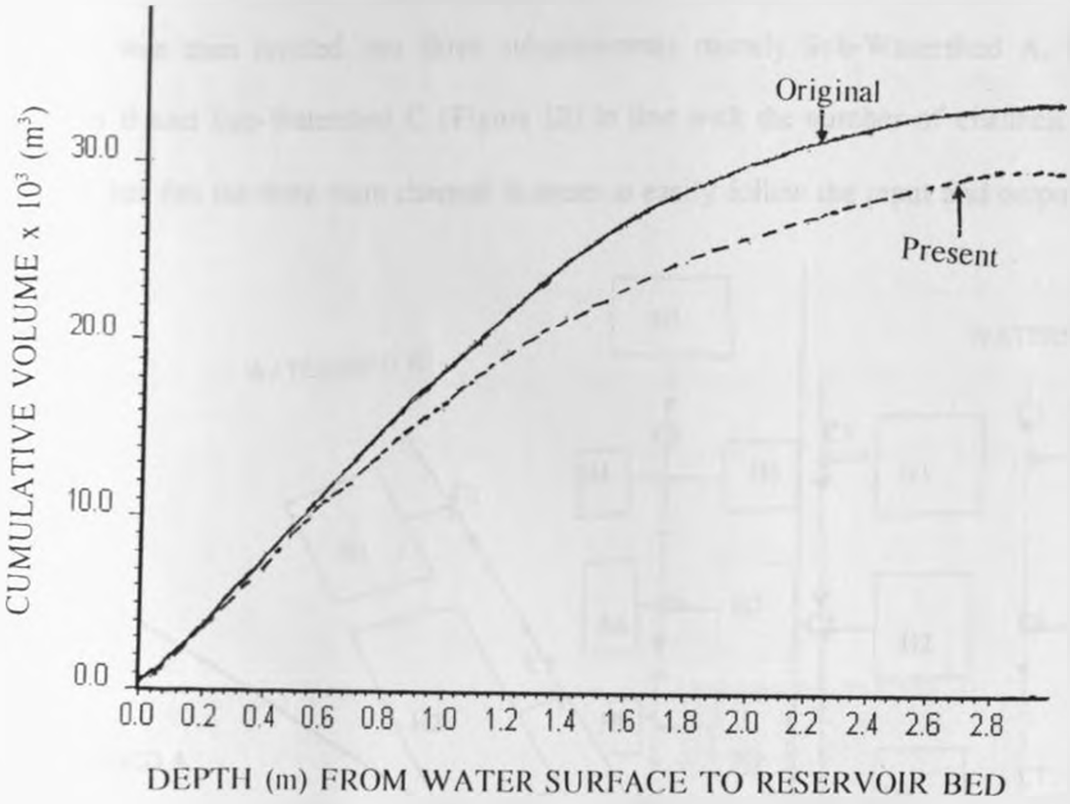

Figure 11: Volume - Depth Relation of the Reservoir

It is also comparable to sediment yield of 1265t/km²/year derived from Thwake basin between Fourteen Falls and Mavindiric gauging station as reported by Muya (1990). These comparables have been made because the Kamburu and Thwake catchments had cultivation and some grazing activities similar to the Ndaragwiti catchment and again they are all in semi arid areas.

5.5.2 Estimation of the Sediment Loading by WEPP(95.7)

As the reservoir was fed by three main independent channels from the catchment,the sediment yield was assumed to come from three subcatchments on the catchment.The catchment was then divided into three subcatchments namely Sub-Watershed A, Sub-Watershed B and Sub-Watershed C (Figure 12) in line with the number of channels and hillslopes that fed the three main channel in order to easily follow the input and output of

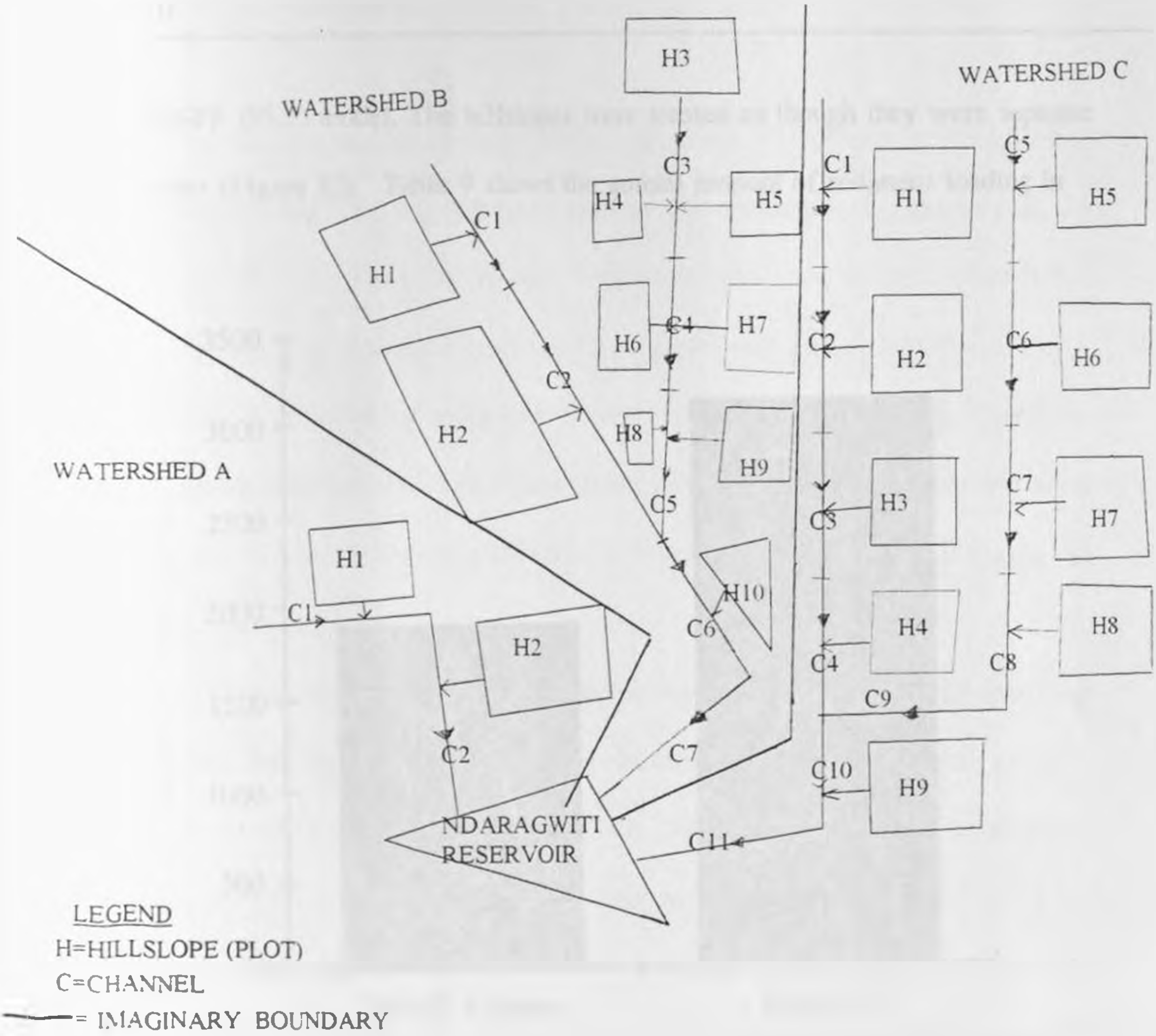

Figure 12: Simplified Map of the Ndaragwiti Catchment Demarcated for Watershed WEPP(95.7) Model Running

Table 9: **Sediment Loading from Sub-Watersheds (tonnes)**

	Sub-Watershed A	Sub-Watershed B	Sub-Watershed C	Total
Sediment into the reservoir (t)	950.8	372.9	764.0	2987.7
Sediment out of reservoir (t)	89.5	35.1	71.9	196.5
Sediment remain in the reservoir (t)	861.3	337.8	692.1	1891.2

watershed WEPP (95.7) model. The hillslopes were treated as though they were separate from each other (Figure 12). Table 9 shows the annual amount of sediment loading in

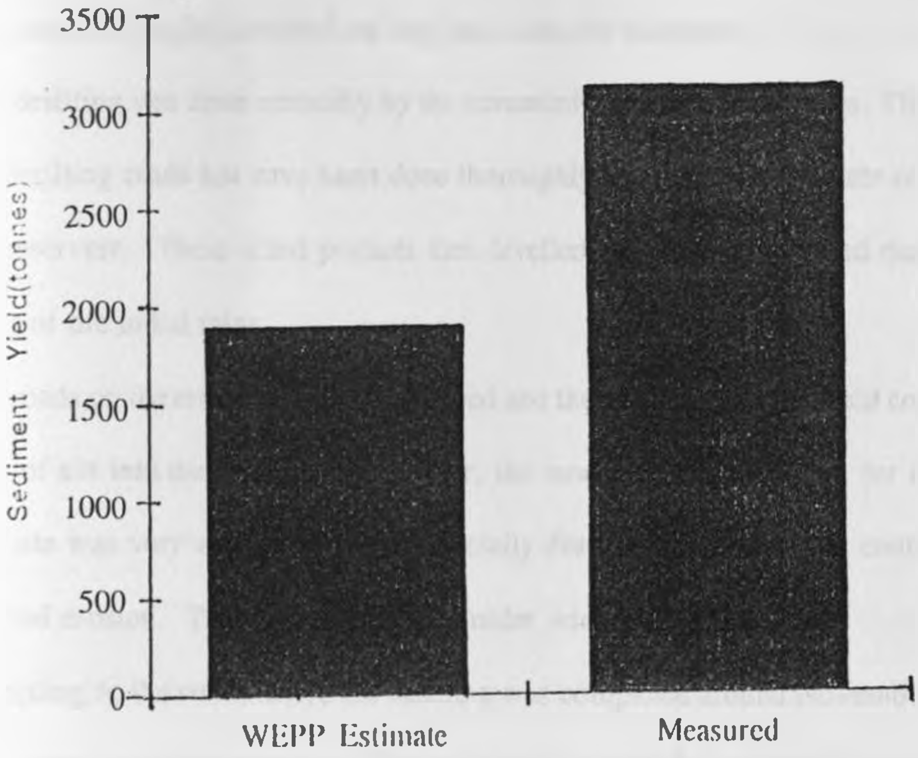

Figure 13: Comparison of WEPP Estimate and Measured Sediment Yield

tonnes from each sub-watershed into the reservoir as estimated by the WEPP (95.7) model. The total annual sediment loading estimated by the WEPP(95.7) model was approximately 1891 tonnes. Thus the average sedimentation rate from the catchment was about 700 t/km²/year. The relative difference between the annual sediment yield measured and the estimated by the WEPP(95.7) model was almost 40 percent (Figure 13). The model seemed to underestimate the sediment load as clearly shown on Figure 13.

The difference between the measured and the estimated could be attributed to the following :

a) The reservoir was desilted recently (1995), hence the silt dumped on the banks of the channels that feed the reservoir and on the embankment especially at the upstream was not consolidated enough before the onset of the rains. Part of this silt, therefore might have had its way back into the reservoir.

b) The desilting was done manually by the community on individual bases. Therefore, the desilting could not have been done thoroughly leaving some pockets of silts in the reservoir. These silted pockets then levelled on the reservoir bed during the onset of the initial rains.

c) The roads on the catchment were not tarred and therefore dusty and could contribute a lot of silt into the reservoir. However, the model had no provision for roads.

d) The site was very windy and dusty especially during dry periods thus contributing to wind erosion. The model did not consider wind erosion.

e) According to the community, the desilting was completed around November, 1995 and it even rained the very day. The study did not consider the rains from that time to December 1995, and therefore all silts generated during that period were not accounted for.

f) The pole used for the original depth measurement was pointed and therefore there was the possibilty that it went beyond the required depth.

g) The parameters used to determine the rill and interrill erodibility and critical shear stress may be different with different soil characteristics.

The WEPP(95.7) model showed a fair estimate of sedimentation and was very comparable to other studies with conditions similar to Ndaragwiti.

5.6 Estimation of Soil Loss Under Different Farm Managements

Maize and beans were the main crops intercropped on the catchment though there were isolated patches of wheat cultivation. The main farm operation used by the farmers was hand hoeing with very few instances of tractor ploughing.

Ten plots, B1P2, B1P3, B2P2, B2P3, B3P1, B3P3, B4P2, B4P4, B5P1, and B5P4 (Figure 6) were randomly selected. These plots were of different sizes and slopes (Table 3). Soil loss by these plots were synthesized by WEPP(95.7) model if the plots were:

1. to maintain the present farm management of hand hoeing and the cultivation of maize and beans (HOCOBE).
2. to be ploughed by tractor, and maize and beans cultivated (COBEAN).
3. to be ploughed by tractor, and only maize cultivated (CNTCORN).
4. be ploughed by tractor and only beans cultivated (CNTBEAN).

The mean annual soil loss produced by each plot as estimated by the model were shown in Figure 14. Generally, tractor ploughing produced less soil loss than the hand hoeing irrespective of the combination of crops grown (Figure 14). Tractor plough with beans and maize (COBEAN) produced the least soil loss, followed by tractor plough with only maize (CNTCORN). and then tractor plough with only beans (CNTBEAN) while the hand hoeing with maize and beans cultivation (HOCOBE) had the highest soil loss. The soil loss reduction compared HOCOBE and COBEAN; HOCOBE and CNTCORN; and HOCOBE and CNTBEAN ranged between 27-47 percent, 16-29 percent and 12-25 percent respectively depending on the size and slope steepness of the plot.

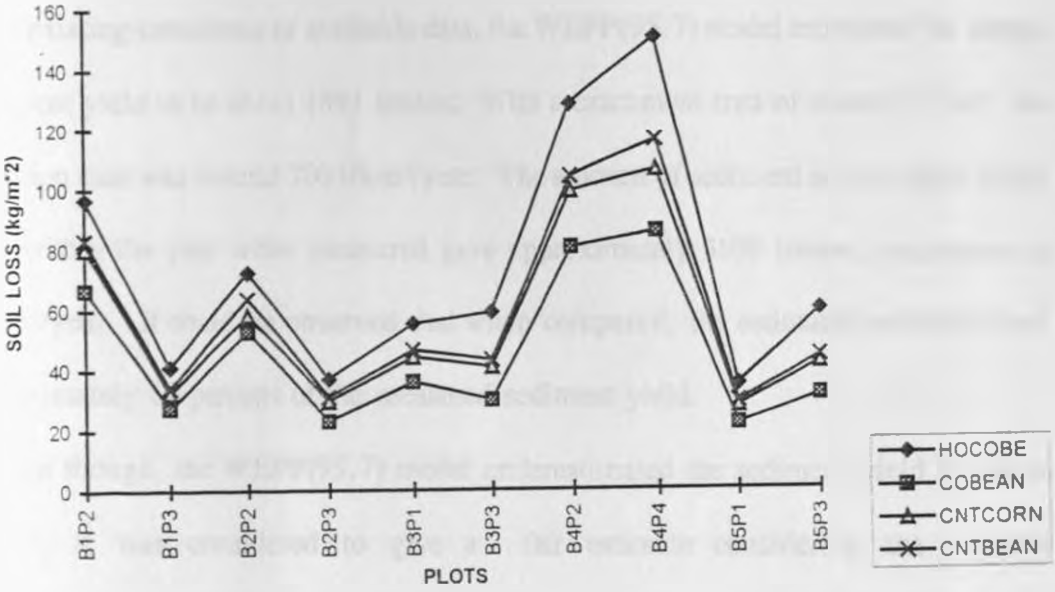

Figure 14 : Soil loss Estimated from the Plots under Different Farm Management

It could be seen that a single crop cultivation produced high soil loss, as tractor plough with a single crop cultivation showed higher soil loss than tractor plough with two crops cultivation (Figure 14). This indicates that a single crop cultivation on hand hoeing operation would produce higher soil loss than the current operation of hand hoeing with two crops cultivation, with regard to maize and beans.

The tractor plough generally produced lower soil loss compared to hand hoeing. This could be attributed to an increase of surface roughness and porosity of the soil by tractor ploughing which enhance soil surface water collection and percolation.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The WEPP(95.7) model was tested on Ndaragwiti catchment which is an agricultural land in a semi arid area and the sediment deposition in the reservoir was for one year. Under the existing conditions of available data, the WEPP(95.7) model estimated the annual total sediment yield to be about 1891 tonnes. With a catchment area of about 2.7 km², the sedimentation rate was around 700 t/km²/year. The amount of sediment accumulated in the reservoir within the year when measured gave approximately 3108 tonnes, equivalent to 1151 t/km²/year. It could be observed that when compared, the estimated sediment load was approximately 60 percent of the measured sediment yield.

Even though, the WEPP(95.7) model underestimated the sediment yield by about 40 percent, it was considered to give a fair estimate considering the possible unconsolidated embankment of the reservoir after the desilting when the onset of the first rains, the possible pockets of silts during the manual desilting, the untarred roads on the catchment, the wind erosion and the human error in measuring the original depth of the reservoir which might have contributed a lot of sediment yield but were not accounted for.

It must be emphasized that the WEPP(95.7) model is a process-based and is in a relatively early stage of development. The weakest link observed was the plot slope length and width, and the plot size. However, the WEPP(95.7) model estimated sufficiently well and could give a very accurate estimate if the study was carried out on a reservoir which embankment had been consolidated long enough before the onset of the rains, the desilting was done by excavator to reduce pockets of silt on the reservoir bed, the catchment was free of roads, wind erosion was taken care of by the model and there was a possible way of reducing the human error.

It is therefore worthy to adopt WEPP(95.7) model as a predictor of soil losses from agricultural lands in semi arid areas and apply it in design, planning and extension in Africa.

There was a comparison made of soil loss produced by randomly selected ten plots of different sizes and slopes on the catchment under: the current hand hoeing, and maize and beans intercropping (HOCOBE), tractor ploughing, and maize and beans intercropping (COBEAN), tractor ploughing and only maize cultivation (CNTCORN), and tractor ploughing and only beans cultivation (CNTBEAN). It was found that there was a soil loss reduction ranging between 27-47 percent if COBEAN were to be practised instead of HOCOBE, 16-29 percent if CNTCORN were to be practised instead of HOCOBE and 12-25 percent if CNTBEAN instead of HOCOBE.

One can conclude from the figures that, there could be a drastic soil loss reduction and therefore, the reservoir life-span could be, prolonged if the farmers could adopt tractor ploughing as the farm operation.

6.2 Recommendations

i) The rill-erodibility, K_r, the interrill erodibility, K_i and the critical shear stress, τ_c, parameters should be experimentally determined thoroughly on African soils especially in semi arid areas in order to calibrate the WEPP model to perfectly suit African conditions.

ii) The WEPP(95.7) model should be tested in other areas of similar or different conditions which have long deposited sediments in their reservoirs.

iii) The WEPP(95.7) model used for the study, offers fair prediction of erosion and sediment yield. It should therefore be adopted by engineers during planning, designing and the management of any reservoir.

iv) The present crops cultivated on the Ndaragwiti catchment should be maintained but the farm operation should be modified to involve tractor ploughing as much as possible to reduce soil loss and soil fertility and also to prolong the life-span of the reservoir.

REFERENCES

Aina, P.O., Lal, R. and Taylor, G.S. 1977. Soil and Crop Management in Relation to Soil Erosion in the Rainforest of Western Nigeria. In: G.R. Foster(ed.) Soil Erosion : Prediction and Control Soil. Concerv. Soc. of Amer., Ankeny, Iowa: 75-82.

Alonso, C.V., Neibling, W.H. and Foster, G.R. 1981. Estimating Sediment Transport Capacity in Watershed Modelling. Trans. of the ASAE 24 (5) : 1211-1220.

Babalola, O. 1978. Spatial Variability of Soil Water Properties in Tropical Soils of Nigeria. Soil Science Journal, Vol. 126 (5) : 269-279.

Blake, G.R. and Hartge, K.H. 1986. Bulk density. In: A. Klute(ed.) Methods of Soil Analysis Part 1. 2nd Edn. Agron. Ser. No. 9. Amer. Soc. of Agron. Inc. and Soil Sci. Soc. of Amer., Inc. Madison, Winsconsin USA: 363-375

Bogardi, I., Fogel, M., Duckstein, L. and Bardossy, A. 1985. Estimation of Sediment Loading in Agricultural Reservoirs with Scarce Data. In: E. Plate and N. Buras(eds.) Scientific Procedures Applied to the Planning, Design and Management of Water Resources Systems. IAHS Publ. No. 147: 87-98.

Brooks, F.L., 1977. Use of the Universal Soil Loss Equation in Hawaii. In: G.R. Foster (ed.) Soil Erosion: Prediction and Control. Soil Conserv. Soc. of Amer., Ankeny, Iowa: 23-30.

Chakela, K.Q. 1981. Soil Erosion and Reservoir Sedimentation in Lesotho. Scadinavian Studies, Uppsala, UNGI Report No. 51. Dept. of Physical Geography. Univ. of Uppsala. Pp. 150

Chin-Lien Yen, 1985. Simulation of Runoff and Erosion on Slopeland with Drainage System. In: E. Plate and N. Buras(eds.) Scientific Procedures applied to the Planning, Design and Management of Water Resources Systems. IAHS Publ. No. 147: 77-86.

De Jeng. R., Campell, C.A. and Nicholaichuk, W. 1983. Water Retention Equations and their Relation to Soil Organic Matter and Particle Size Distribution for Disturbed Samples. Can. J. Soil Sci. 63 : 291-302.

District Water Officer, Nanyuki, Kenya. 1997. Personal Contact.

Edwards, K.A. 1977. Water Resources and Soil Conservation. The Kenyan Situation. The Role of Water Resources in Development. East African Academy, 1979 : 167-176.

El-Swaify, S.A. and Dangler, E.W. 1977. Erodibilities of Selected Tropical Soils in

Relation to Structural and Hydrologic Parameters. In : G.R. Foster(ed.) Soil Erosioin: Prediction and Control. Soil Conserv. Soc. of Amer. Ankeny, Iowa: 105-114.

Elwell, H.A. 1984. Soil Loss Estimation: A Modelling Technique. In : R.F. Hadley and D.E. Walling(eds.) Erosion Sediment Yield: Some Methods of Measurement and Modelling Cambridge Univ. Press. London.: 15-36

FAO. 1973. Man's Influence on the Hydrological Cycle. Soils Bulletin 17: FAO, Rome.

FAO. 1987. Soil and Water Conservation in Semiarid Areas. Soils Bulletin 57: FAO, Rome.

FAO. 1993. Field Measurement of Soil Erosion and Runoff. Soils Bulletin 68: FAO, Rome.

Flanagan, D.C. and Livingston, S.J.(eds.). 1995. WEPP - User Summary Document. USDA - Water Erosion Prediction Project. WEPP Technical Support. USDA-ARS NSERL. West Lafayette IN 47907 - 1196.

Foster, G.R. 1982. Modelling the Erosion Process. In : C.T. Haan, D.L. Johnson and K. Brakensiek(eds.) Hydrologic Modelling of Small Watershed ASAE, St. Joseph, Michigan.

Foster, G.R. 1990. Process-Based Modelling of Soil Erosion by Water on Agricultural Land. In : J. Boardman, I.D.L. Foster and J.A. Dearing(eds.) Soil Erosion on Agricultural Land. John Willey & Sons: 429-446

Foster, G.R. 1991. Advances in Wind and Water Erosion Prediction. J. Soil and Water Conserv. Vol. 46: 27-29.

Foster, G.R., Lane, L.J., Nawlin, J.D., Laflen, J.M. and Young, R.A. 1981. Estimating Erosion and Sediment Yield on Field-Sized Areas. Trans. ASAE 24(5): 1253-1262.

Gilley, J.E.,Lane, L.J.,Laflen, J.M.,Nicks, A.D. and Raws, W.J. 1988. USDA - Water Erosion Prediction Project : New Generation Erosion Prediction Technology. In : Modelling Agricultural, Forest and Rangeland Hydrology. Proc. Int. Symposium. ASAE: 260-263.

Goudie, A. and Wilkinson, J. 1977. The Warm Desert Environment. Cambridge University Press. London.

Hadley, R.F. 1984. Measuring and Predicting Soil Erosion. In: R.F. Hadley and D.E. Waling(eds.) Erosion and Sediment Yield: Some Methods of Measurement and

Modelling. Cambridge Univ. Press. London : 1-14

Hillel, D. 1980. Application of Soil Physics. Academic Press.

IITA (International Institute of Tropical Agriculture). 1979. Hydrometer Method of Soil Mechanical Analysis. In: Selected Methods for Soil and Plant Analysis Manual Series 1: 4-5.

Jaetzold, R. and Schmidt, H. 1983. Farm Management Handbook of Kenya Vol. II B. Ministry of Agric., Kenya, GAT and GTZ Publication.

Kemper, W. D. and Rosenau, R.C. 1986. Aggregate Stability and Size Distribution. Wet Aggregate Method. In: A. Klute(ed.) Methods of Soil Analysis. Part 1. 2nd Edn. Agron. Ser. No.9. Amer. Soc. of Agron. Inc. and Soil Sci. of Amer. Inc. Madison, Winsconsin USA: 435-436.

Kinama, J.M. 1981. A Study of Sedimentation and its Causes in Semiarid Area of Tulia in Kitui District, Kenya. Postgraduate Diploma Thesis. Dept. of Agric. Eng., Univ. of Nairobi.

Klute, A. 1986. Water Retention: Laboratory Methods. In: A. Klute(ed.) Methods of Soil Analysis. Part 1. 2nd. Edn. Agron. Ser. No. 9. Amer. Soc. of Agron. Inc. and Soil Sci. Soc. of Amer. Inc. Madison, Wisconsin USA: 635-660.

Klute, A. and Dirksen, C. 1986. Hydraulic Conductivity of Saturated Soils. Constant Head Method. In: A. Klute(ed.) Methods of Soil Analysis. Part 1. 2nd Edn. Agron, Ser. No. 9. Amer. Soc. of Agron. Inc. and Soil Sci. Soc. of Amer. Inc. Madison, Wisconsin USA: 694-700.

Knisel, W.G.(ed.) 1980. CREAMS, A Field-Scale Model for Chemical, Runoff and Erosion from Agricultural Management System. USDA Conserv. Res. Report No. 26.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C.S. and Kohl, K.D. 1991. WEPP Soil Erodibility of Experiments for Rangeland and Cropland soils. J. Soil and Water Conserv. Vol. 46: 39-44.

Laflen, J.M., Lane, L.J. and Foster, G.R. 1991. WEPP. A New Generation of Erosion Prediction Technology. J. Soil and Water Conserv. Vol. 46 : 34-38.

Lal, R. 1981. Physical Properties. In: D.J. Greenland(ed.) Characterisation of soils. Clarendon Press. Oxford: 135-148

Landon, J. R.(ed.) 1991. Booker Tropical Soil Manual. A Handbook for Survey and

Agricultural Land Evualuation in the Tropics and Subtropics. Booker Agric. Intl. Ltd.

Magfed, Y.A. 1986. Assessment of water resources in arid and semiarid regions. UNEP, Kenya.

Meteorological Department, Dagorretti, Kenya. 1997. Personal Contact.

Ministry of Water Development. 1992. Water Conservation Plan for Small Earth Dams and Pans. Proposed Projects for Implementation from the District Development Committee. A Draft Document on Ndaragwiti Dam. Nanyuki.

Mulla, D.J. 1987. Soil Spatial Variability and Methods of Analysis. In: Soil, Crop and Water Management in the Sudan-Sahelian Zone. ICRISAT : 241-251.

Murray-Rust, D.H. 1972. Soil Erosion and Reservoir Sedimentation in a Grazing Area, West of Arusha, Northern Tanzania. Studies of Soil Erosion and Sedimentation in Tanzania.

Muya, F.S. 1990. Reservoir Sedimentation and Catchment Landuse. M.Sc. Thesis. Dept. of Agric. Eng., Univ. of Nairobi.

Nelson, D.W. and Sommers, L.E. 1982. Total Carbon, Organic Carbon and Organic Matter. In: A. L. Page, R. H. Miller and D. R. Keeney(eds.) Methods of Soil Analysis. Part 2. 2nd Edn. Agron. Ser. No. 9. Amer. Soc. of Agron. Inc. and Soil Sci. Soc. Amer. Inc. Madison, Wisconsin USA : 570-574.

Ongwenyi, G.S., Kithiia, S.M. and Denga, F.O. 1993. An Overview of the Soil Erosion and Sedimentation Problems in Kenya. In : R. F. Hadley and T. Mizuyama (eds.) Sediment Problems, Strategies for Monitoring, Prediction and Control. IAHS Publ. No. 217 : 216-221.

Pilgrims, D.H., Chapman, T.C. and Doran, D.G. 1988. Problems of Rainfall-Runoff Modelling in arid and semiarid Regions. Hydrol. Sci. Journal 33: 379-400.

Rapp, D., Murray-Rust, H., Christiansson, C. and Berry, L. 1972. Soil Erosion and Sedimentation in Four Catchments near Dodoma, Tanzania. Bureau of Resource Assessment and Landuse Planning. Univ. of Dar-es-Salaam.

Rausch, D.L. and Heinemann, H.G. 1984. Measurement of Reservoir Sedimentation. In: R.F. Hadley D.E.Walling(eds.) Erosion and Sediment Yield: Some Methods of Measurement and Modelling. Cambridge Univ. Press. Lond. : 179-200.

Reeve, M. J. and Carter, A. D. 1991. Water Release Characteristics. In : K.A. Smith and

C.E. Mullins(eds.) Soil Analysis, Physical Methods. Marchel Dekker,Inc. New York, Basel, Hong Kong: 112-161

Renard, G.K., Foster, G.R., Weesies, G.A. and Porter, J.P. 1991. RUSLE. Revised Universal Soil Loss Equation. J. Soil and Water Conserv. Vol. 46: 30-33.

Roose, E.J. 1977. Use of the Universal Soil Loss Equation to Predict Erosion in West Africa. In : G.R. Foster(ed.) Soil Erosion: Prediction and Control. Soil Conserv. Soc. of Amer., Ankeny. Iowa: 60-74.

Schwab, G.O., Frevet, R.K., Edminster, T.W. and Barness, K.K. 1981. Soil and Water Conservation Engineering. 3 Edn. John Willey and Sons Inc.

SCS (Soil Conservaton Service). 1972. National Engineering Handbook. Sec. 4 Hydrology. USDA Washington D.C.

Shahin, M.M.A. 1993. An Overview of Reservoir Sedimentation in Some African River Basins. In : R.F. Hadley and T. Mizuyama(eds.) Sediment Problems: Strategies for Monitoring, Prediction and Control. IAHS Publ. No. 217: 93-100

Sharma, T.C. 1994. Sedimentation. M.Sc. Lecture Notes Handout. Dept. of Agric. Eng., Univ. of Nairobi.

Singer, M.J., Huntington, G.L. and Sketchley, H.R. 1977. Erosion Prediction on California Rangeland: Research Developments and Needs. In: G.R. Foster(ed.) Soil Erosion: Prediction and Control. Soil Conserv. Soc. of Amer. Ankeny, Iowa: 143-151.

Spraberry, J.A. and Bowie, A.J. 1969. Predicting Sediment Yields from Complex Watersheds. Trans. ASAE 12 (2) : 199-201.

Stall, J.B. 1961. Cooperative Research Studies of Reservior Sedimentation. Trans. ASAE 4 (1) : 85-89.

Storm, D.E., Barfield, B.J. and Altendorf, C.T. 1994. CREAMS/WEPP Sediment Deposition Equation: A Semitheoretical Evaluation. Trans. ASAE 37(4): 1105-1108

The Assistant Chief, 1977. Sipili Sub-location, Kenya. Personal contact.

Udo, E.J. and Ogunwale, J.A. 1978. Laboratory Manual for the Analysis of Soil, Plants and Water Samples. Soil Science Practicals Handout.

Waiganjo, 1997. Personal contact.

Ward, A.D., Haan, C.T. and Barfield, B.J. 1980. The Design of Sediment Basins. Trans. ASAE 23 (2) : 352-365.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses. A Guide to Conservation Planning. USDA Agricultural Handbook No. 537.

APPENDICES

Appendix 1: Questionnaire Used in Catchment Land use and Conservation Survey

DISTRICT ----------------------------DIVISION---
LOCATION-------------------SUB-LOCATION----------------------VILLAGE-----------------
FARMER'S NAME-----------------------------FARMER'S REFERENCE NUMBER ---------
FARMER'S AGE -----------------SEX ---

PART I : GENERAL

1. When were farmers settled on the catchment? ---------------------------------
2. What is the farmer's family size? --
3. What is the size of the farm? --
4. What are the other sources of income? ---------------------------------------

PART II : CROPLAND

5. What area is under crop? --
6. Is the farm owner staying on the farm? 1. Yes 2. No
7. If yes, what is the size of farmer's homestead? --------------------------------------
8. Which is the main common method of land preparation?
   a) Hand hoeing
   b) Tractor ploughing
   c) Oxen ploughing
   d) Zero tillage
   e) Other ---
9. Cost of method of land preparation per hectare --------------------------------
10. Depth of tillage --
11. What are the crops grown? ---
12. What is the farming system? ---
13. Which is the cropping pattern? ---------------------------
    1. Row cropping
    2. Clustered
    3. Others ---------------------
14. Crop interval --------------------Row interval------------------- (if any).
15. Number of crop seasons per year ----------------------------
    a) Main season: From ------------------- to -------------------------------
    b) Minor season : From -------------------to -----------------
    c) Other ---------------
16. How many weedings are done after planting? ---
17. How is weeding done?
    a) Hand hoeing
    b) Weedicide
    c) Others -------------------------------------
18. How is harvesting done?
    a) Cutting
    b) Slashing (combine harvester)

c) Hand picking
e) Others

19. If cutting, what is the cutting height? --

20. Are the crops grown on:
   a) ridges
   b) mounds
   c) flat land
   d) others --

21. If crops grown on ridges or mounds, what is the ridge or mound height?---------------

22. How do you improve soil fertility?
   a) By chemical fertilizer
   b) By Farm yard manure
   c) Other --

23. When is the soil improvement done?-------------------(Use crop stage as reference).

24. Yield from farm (tonnes/ha): Main season --
   Minor season --------------------------------------

25. Is the production per farmer (tonnes/ha) adequate for his/her family?
   a) Yes 2) No c) Not known -------------------

26. If No give reasons.
   a) The soils are infertile
   b) Tillage operation were not well done
   c) Weeding was not well done
   d) Area under crop was small
   e) The rains were inadequate
   f) Other reasons --

27. Do you have problems of soil erosion or runoff on the farm? 1) Yes 2) No

28. If yes, specify ---

PART III : GRAZING LAND

29. Size of grazing land per farm --

30. What is the number of the following on the farm?
   a) Goats --------------------------------------
   b) Sheep --------------------------------------
   c) Cattle -----------------------------
   d) Donkeys -----------------------------------

31. What is the main sources of livestock feed?
   a) Grass b) Shrubs c) Fodder d) Crop residue
   e) Others--

32. Do other farmers animals graze on your farm?
   a) Yes b) No c) Not certain

33. What is the estimated carrying capacity of the farm?

PART IV : RESERVOIR

34. When was the reservoir constructed? --

35. Who constructed it? ---

36. What was the intended use? --

a) Domestic water use
b) Livestock use
c) Irrigation
d) Flood control
e) Other --

37. When did the resevoir get filled up with sediments? ----------------------------

38. When was it desilted? ---

39. How was it desilted?

a) Community participation (manual)
b) Government
c) Non-governmental organisation
d) Contribution by community to hire scraper
e) Other --

40. What is the intended use of the reservoir?

a) Domestic use
b) Livestock use
c) Irrigation
d) Flood control
e) Others ---

41. Does the reservoir usually overflow its banks? 1) Yes 2) No

42. If yes, which period of the year? --

43. What measures have been taken to avoid water contamination in the reservoir?

Appendix 2 : Monthly and Annual Rainfall from 1976 to 1996(mm)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Ave.
Jan	1.4	48.8	104.3	75.3	2.2	0.0	43.0	0.0	7.1	0.0	0.0	20.4	12.7	40.2	15.0	11.7	1.5	139.8	0.0	0.0	0.00	24.9
Feb	35.6	20.8	85.4	70.0	0.0	0.0	2.9	59.1	0.0	51.2	0.0	44.4	4.2	3.8	152.1	7.5	0.6	70.6	6.7	37.1	4.90	32.7
Mar	0.0	13.1	60.4	76.0	19.1	255.0	0.3	2.6	6.4	68.2	36.3	1.9	44.4	71.4	100.5	50.5	10.7	4.4	42.9	42.2	76.50	46.8
Apr	80.1	166.5	74.6	249.6	42.9	102.9	146.8	91.8	66.6	110.1	196.3	78.8	254.1	128.7	206.4	36.5	92.2	35.1	103.7	23.7	22.10	110.0
May	39.1	148.5	7.4	141.6	223.0	30.2	70.8	22.9	1.0	20.7	52.3	79.1	30.0	35.1	19.3	17.0	110.2	24.4	49.3	47.0	70.40	59.0
Jun	51.0	64.8	86.7	16.3	19.7	76.9	8.2	35.1	42.8	1.2	172.3	170.7	55.6	39.3	68.1	70.3	87.0	81.9	79.8	52.4	194.6	70.2
Jul.	113.3	182.9	103.4	18.1	18.3	122.3	18.3	82.3	65.6	122.2	70.1	38.9	123.2	60.4	53.9	76.1	40.1	128.5	79.4	57.8	211.6	85.1
Aug.	124.9	44.7	27.9	70.1	24.1	108.8	83.0	227.5	5.8	52.8	87.6	27.4	68.6	105.2	89.1	128.8	107.1	34.2	93.3	50.4	156.3	81.8
Sept.	29.0	35.1	56.2	6.9	6.9	20.3	41.4	29.8	31.6	2.2	83.8	5.4	43.0	113.0	13.6	25.8	41.9	42.1	2.2	59.7	27.2	35.3
Oct.	6.2	113.6	50.5	24.7	22.3	26.2	105.9	48.8	26.8	51.6	53.4	6.9	19.1	42.6	131.7	42.8	122.5	13.2	76.4	79.2	7.0	51.0
Nov.	45.2	316.3	38.9	43.8	55.3	40.9	38.9	5.9	66.1	18.6	57.1	51.5	26.3	82.4	81.2	29.5	50.3	55.4	118.4	52.0	44.2	62.8
Dec.	60.7	26.5	13.9	2.3	0.50	13.6	51.0	95.0	90.8	4.20	43.30	9.80	13.70	45.50	88.30	53.5	66.7	71.9	34.4	48.1	8.1	40.1
Total	586.5	1181.6	709.6	794.7	434.3	797.1	610.5	7008	410.6	503.0	852.5	535.2	694.9	767.6	1019.2	550.0	730.8	701.9	686.5	549.6	822.9	699.0

Appendix 3 Some Physical and Chemical Properties of Soil Samples Collected from Ndaragwiti Catchment

Plot	Depth cm	Sand %	Silt %	Clay %	VFS %	Gravel Conc. g/100g	Bulk density g/cm^3	Hydraulic conductivity mm/hr	Organic matter %	CEC meq/100g
*B1P1	0-10	23.1	18.6	58.3	4.4	2.9	1.16	0.73	3.61	37.4
	10-20	25.5	17.6	56.9	4.0	6.8	1.31	0.78	3.44	36.6
	20-30	29.8	18.8	51.4	4.1	5.3	1.12	1.06	2.75	34.8
B1P2	0-10	24.3	23.8	51.9	3.9	0.5	1.08	1.03	3.76	40.1
	10-20	22.8	22.1	55.1	4.5	6.2	1.07	0.65	2.57	36.4
	20-30	30.3	17.8	51.9	3.9	4.0	1.04	1.03	2.09	34.2
B1P3	0-10	22.3	15.8	61.9	4.7	1.2	1.15	0.54	3.83	36.8
	10-20	25.4	12.6	62.0	3.8	1.3	1.21	0.54	3.44	34.8
	20-30	27.6	11.7	60.7	3.1	5.5	1.45	0.87	2.09	33.6
B1P4	0-10	20.2	17.8	62.0	3.5	0.3	1.29	0.64	3.97	42.4
	10-20	25.5	13.6	60.9	3.4	0.4	1.25	0.86	3.25	36.8
	20-30	18.8	13.1	68.1	2.9	0.5	1.31	0.51	2.35	32.2
B2P1	0-10	31.3	31.8	36.9	6.3	2.4	1.28	4.85	3.76	30.4
	10-20	37.1	25.6	37.3	5.3	7.7	1.42	3.40	2.12	28.6
	20-30	27.5	32.6	39.9	4.4	11.4	1.15	3.10	3.12	24.6
B2P2	0-10	30.6	38.0	31.4	5.0	9.7	1.15	4.80	2.90	25.2
	10-20	29.3	23.6	47.1	4.1	12.5	1.16	1.20	3.44	27.8
	20-30	29.1	18.9	52.1	3.4	13.6	1.30	0.71	2.67	24.8
B2P3	0-10	35.4	19.9	44.7	5.3	8.2	1.05	1.55	4.35	34.2
	10-20	31.4	18.7	49.9	4.5	3.9	1.52	0.88	2.64	32.0
	20-30	26.6	16.4	57.0	3.2	7.6	1.23	0.78	1.96	31.8
B2P4	0-10	23.4	30.2	46.4	4.6	1.4	1.61	1.27	3.54	38.6
	10-20	22.5	23.8	53.7	4.5	1.3	1.21	0.82	2.99	36.0
	20-30	23.8	20.8	55.4	3.5	2.5	1.30	0.54	2.57	34.2

	0-10	23.4	20.7	55.9
B2P5	10-20	24.9	21.1	54.0
	20-30	23.6	15.6	60.8
	0-10	22.1	30.0	47.8
B3P1	10-20	19.4	25.6	55.0
	20-30	22.3	24.2	53.5
	0-10	26.3	24.6	49.2
B3P2	10-20	27.3	20.6	52.1
	20-30	28.4	21.6	50.0
	0-10	31.3	18.6	50.1
B3P3	10-20	31.6	11.6	56.8
	20-30	33.7	10.7	55.6
	0-10	26.5	33.0	40.5
	10-20	27.0	25.9	47.1
B3P4	20-30	21.7	21.2	57.1
	0-10	26.5	33.0	40.5
B3P4	10-20	27.0	25.9	47.1
	20-30	21.7	21.2	57.1
	0-10	28.1	22.0	49.9
BP	10-20	31.5	27.0	41.5
	20-30	27.9	15.0	57.1
	0-10	26.4	21.8	51.8
B4P1	10-20	25.3	23.2	51.5
	20-30	22.8	23.8	53.4
	0-10	25.2	17.6	57.2
B4P2	10-20	23.4	19.9	56.7
	20-30	21.4	17.3	61.3
	0-10	27.3	23.6	49.1
B4P3	10-20	21.3	25.6	53.1
	20-30	26.3	23.8	49.9

6.0	0.5	1.01	0.52	4.25	34.6
6.8	0.3	1.14	1.01	5.19	40.6
3.6	1.0	1.32	0.87	3.12	32.6
3.0	0.3	1.42	1.08	3.76	48.8
4.3	0.8	1.37	1.03	1.36	44.6
3.0	1.3	1.26	1.07	2.96	46.8
2.7	2.6	1.20	1.09	3.89	44.8
3.7	3.2	1.09	1.05	3.22	42.4
4.2	6.3	1.29	1.08	3.18	40.6
4.8	5.6	1.11	1.06	3.41	36.2
3.7	6.4	1.12	0.72	5.44	40.6
3.9	11.3	1.20	0.75	2.70	34.8
3.3	2.2	1.23	2.73	3.89	28.00
4.1	2.4	1.28	1.17	3.06	27.80
3.5	3.1	1.41	0.84	2.76	26.00

3.3	2.2	1.23	2.73	3.89	28.00
4.1	2.4	1.28	1.17	3.06	27.80
3.5	3.1	1.41	0.84	2.76	26.00
5.0	4.1	1.07	1.08	4.32	43.00
4.9	5.6	1.26	2.36	3.76	40.60
3.0	6.1	1.23	0.81	2.79	32.6
2.8	3.2	1.16	1.03	3.25	42.8
3.0	3.5	1.37	1.02	2.80	40.6
3.1	4.8	1.12	0.64	2.30	38.9
3.1	4.9	1.25	0.77	3.35	44.0
3.4	6.2	1.22	0.89	2.93	42.0
3.6	8.8	1.14	0.65	2.64	40.4
4.5	3.3	1.39	0.95	3.54	48.0
4.2	10.3	1.42	0.75	2.50	37.4
5.3	15.3	1.45	0.88	2.60	38.6

B4P4	0-10	21.1	21.6	57.3
	10-20	16.0	22.1	61.9
	20-30	42.8	32.7	24.5
B5P1	0-10	40.7	26.8	32.5
	10-20	21.1	25.7	53.2
	20-30	20.4	27.6	52.0
B5P2	0-10	28.7	28.7	42.6
	10-20	40.8	30.7	28.5
	20-30	30.9	26.1	43.0
B5P3	0-10	30.4	20.2	49.4
	10-20	30.4	16.9	52.7
	20-30	30.3	22.8	46.9
B5P4	0-10	21.0	34.8	44.2
	10-20	22.8	28.4	48.8
	20.30	25.7	27.2	47.1

*B means block and P means plot.

4.9	0.4	1.34	0.77	4.80	50.0
3.6	1.3	1.28	0.54	0.54	41.6
2.6	2.4	1.21	4.90	4.90	36.2
2.6	1.2	1.20	4.79	2.80	28.8
2.7	6.3	1.16	0.75	2.47	25.8
5.1	7.0	1.08	0.78	2.02	24.4
5.8	2.2	1.62	2.03	2.38	21.4
4.8	4.5	1.55	4.40	2.83	34.0
4.2	3.9	1.25	1.90	2.99	36.8
4.9	0.6	1.14	1.09	3.73	38.2
4.0	0.8	1.05	0.88	2.47	37.8
4.5	1.5	1.43	1.20	2.19	32.6
4.1	2.0	1.12	1.65	3.64	43.5
4.4	2.6	1.20	1.00	3.44	36.8
3.8	4.1	1.52	1.20	2.85	35.7

Appendix 4: Some Physical Properties of the Sediment Samples

Sediment Sample	Depths cm	Sand %	Silt %	Clay %	**VFS %	Gravel Conc. %	Bulk Density g/cm^3
*SRC1	0-10	33.2	18.3	48.5	3.3	0.9	1.28
	10-20	34.6	23.2	42.2	3.8	7.2	1.47
	20-30	28.5	25.7	45.8	2.1	2.3	1.21
SRC2	0-10	45.5	10.0	44.5	3.3	1.4	1.09
	10-20	30.7	22.3	47.5	5.1	8.6	1.14
	20-30	30.5	28.3	48.4	3.1	1.4	1.09
SRC3	0-10	21.5	26.0	52.5	4.1	0.1	1.20
	10-20	38.7	23.8	37.5	5.1	2.5	1.18
	20-30	33.4	23.1	43.5	4.5	3.2	1.23

* SRC means sediment sample taken at the mouth of channel that enters the reservoir.
**VFS means very fine sand.

Appendix 5: Channel Slope Characteristics

Channel	Aspect of Channel (degree from north)	Channel width (m)	No. of slope points for channel	Length of Channel (m)	Dist. from top of channel to point (m/m)	slope steepness point (m/m)
SUB-WATERSHED A:						
C1	90	1.5	2	1352	0 1	0.0 0.08
C2	180	1.5	2	190	0 1	0.0 0.01
SUB-WATERSHED B:						
C1	150	2.3	2	425	0 1	0.0 0.21
C 2	160	2.3	3	750	0 0.79 1	0.0 0.24 0.13
C3	180	1.8	2	170	0 1	0.0 0.14
C4	180	1.8	3	810	0 0.62 1	0.0 0.13 0.07
C5	180	1.8	2	330	0 1	0.0 0.11
C6	160	2.7	2	245	0 1	0.0 0.07
C7	220	1.2	2	160	0 1	0.0 0.6
SUB-WATERSHED C:						
C1	180	2.5	2	140	0 1	0.0 0.09
C2	180	2.5	2	495	0 1	0.0 0.1
C3	180	2.5	2	900	0 1	0.0 0.07

C4	180	2.5	3	500	0	0.0
					0.18	0.27
					1	0.09
C5	180	2.5	2	245	0	0.0
					1	0.12
C6	180	2.6	2	539	0	0.0
					1	0.15
C7	180	2.6	3	870	0	0.0
					0.06	0.19
					1	0.09
C8	180	2.6	2	450	0	0.0
					1	0.08
C9	270	1.2	3	190	0	0.0
					1	0.39
C10	180	2.1	2	235	0	0.0
					1	0.03
C11	265	2.0	2	50	0	0.0
					1	0.01

Appendix 6: Soil Water Retention of the Soils on the Catchment

Plots	Depth (cm)	Soil water retention (cm^3/cm^3) at suctions 0-1500 kPa									
		0	10	30	50	100	300	500	700	1000	1500
B1P1	0-10	0.498	0.436	0.356	0.337	0.322	0.304	0.287	0.269	0.262	0.259
	10-20	0.477	0.398	0.356	0.343	0.326	0.315	0.303	0.296	0.288	0.285
	20-30	0.518	0.351	0.320	0.314	0.310	0.303	0.299	0.283	0.278	0.274
B1P2	0-10	0.597	0.453	0.359	0.340	0.303	0.298	0.283	0.272	0.260	0.257
	10-20	0.486	0.434	0.374	0.365	0.342	0.326	0.307	0.301	0.282	0.273
	20-30	0.541	0.397	0.362	0.345	0.321	0.312	0.301	0.276	0.269	0.263
B1P3	0-10	0.529	0.451	0.381	0.359	0.349	0.321	0.306	0.291	0.280	0.272
	10-20	0.507	0.44	0.40	0.371	0.351	0.340	0.315	0.300	0.284	0.276
	20-30	0.536	0.462	0.344	0.354	0.344	0.308	0.298	0.263	0.261	0.260
B1P4	0-10	0.530	0.451	0.396	0.348	0.346	0.305	0.320	0.276	0.270	0.264
	10-20	0.536	0.456	0.376	0.361	0.341	0.323	0.307	0.295	0.282	0.274
	20-30	0.497	0.443	0.428	0.339	0.325	0.293	0.270	0.274	0.252	0.243
B2P1	0-10	0.530	0.351	0.313	0.296	0.285	0.233	0.217	0.196	0.193	0.188
	10-20	0.508	0.416	0.370	0.354	0.326	0.275	0.266	0.249	0.245	0.242
	20-30	0.483	0.401	0.384	0.357	0.321	0.270	0.261	0.247	0.243	0.240
B2P2	0-10	0.595	0.388	0.349	0.342	0.328	0.285	0.278	0.263	0.258	0.255
	10-20	0.575	0.438	0.363	0.357	0.348	0.318	0.314	0.286	0.274	0.265
	20-30	0.549	0.443	0.368	0.360	0.352	0.330	0.318	0.300	0.291	0.280
B2P3	0-10	0.538	0.439	0.351	0.345	0.338	0.321	0.319	0.307	0.298	0.267
	10-20	0.514	0.440	0.358	0.350	0.342	0.332	0.325	0.310	0.300	0.284
	20-30	0.503	0.450	0.362	0.356	0.349	0.341	0.336	0.327	0.316	0.296
B2P4	0-10	0.558	0.471	0.462	0.347	0.337	0.323	0.320	0.316	0.305	0.290
	10-20	0.498	0.489	0.478	0.362	0.351	0.334	0.321	0.319	312	0.298
	20-30	0.496	0.490	0.483	0.376	0.361	0.348	0.331	0.324	0.319	0.300
B2P5	0-10	0.539	0.411	0.365	0.335	0.322	0.293	0.286	0.273	0.266	0.255
	10-20	0.525	0.417	0.391	0.352	0.343	0.311	0.309	0.291	0.284	0.271
	20-30	0.509	0.476	0.403	0.364	0.347	0.321	0.314	0.302	0.291	0.284
B3P1	0-10	0.490	0.332	0.322	0.314	0.310	0.303	0.297	0.288	0.275	0.272
	10-20	0.451	0.400	0.358	0.346	0.338	0.324	0.305	0.290	0.278	0.273
	20-30	0.522	0.463	0.436	0.430	0.421	0.412	0.390	0.374	0.359	0.353
B3P2	0-10	0.562	0.339	0.304	0.294	0.280	0.271	0.258	0.246	0.233	0.228
	10-20	0.560	0.448	0.407	0.387	0.365	0.352	0.335	0.317	0.296	0.289
	20-30	0.533	0.491	0.437	0.412	0.391	0.379	0.136	0.339	0.318	0.315
B3P3	0-10	0.530	0.421	0.384	0.337	0.288	0.282	0.266	0.248	0.233	0.226
	10-20	0.561	0.450	0.413	0.367	0.347	0.333	0.290	0.269	0.251	0.246
	20-30	0.508	0.459	0.442	0.414	0.375	0.364	0.345	0.328	0.311	0.304
B3P4	0-10	0.604	0.463	0.362	0.353	0.336	0.326	0.309	0.293	0.277	0.273
	10-20	0.587	0.405	0.368	0.337	0.312	0.306	0.289	0.276	0.259	0.253
	20-30	0.529	0.404	0.366	0.339	0.318	0.310	0.300	0.285	0.271	0.266
BP	0-10	0.546	0.390	0.343	0.327	0.306	0.298	0.285	0.270	0.257	0.251
	10-20	0.531	0.427	0.384	0.358	0.343	0.330	0.306	0.288	0.271	0.264
	20-30	0.516	0.453	0.419	0.400	0.375	0.365	0.350	0.334	0.316	0.312

B4P1	0-10	0.556	0.416	0.334	0.316	0.296	0.289	0.276	0.262	0.253	0.238
	10-20	0.505	0.450	0.390	0.370	0.337	0.313	0.294	0.290	0.276	0.272
	20-30	0.514	0.440	0.362	0.343	0.322	0.293	0.289	0.264	0.248	0.245
B4P2	0-10	0.521	0.416	0.363	0.337	0.310	0.306	0.295	0.284	0.275	0.268
	10-20	0.506	0.412	0.321	0.307	0.291	0.280	0.270	0.260	0.248	0.240
	20-30	0.504	0.451	0.420	0.382	0.360	0.301	0.298	0.289	0.276	0.272
B4P3	0-10	0.510	0.429	0.321	0.303	0.279	0.270	0.256	0.248	0.235	0.231
	10-20	0.500	0.489	0.406	0.388	0.369	0.329	0.300	0.265	0.258	0.248
	20-30	0.508	0.538	0.354	0.343	0.306	0.305	0.298	0.282	0.271	0.269
B4P4	0-10	0.533	0.431	0.326	0.312	0.307	0.295	0.281	0.262	0.257	0.251
	10-20	0.501	0.453	0.447	0.419	0.351	0.346	0.320	0.285	0.278	0.268
	20-30	0.548	0.427	0.312	0.304	0.296	0.289	0.271	0.253	0.249	0.245
B5P1	0-10	0.538	0.435	0.381	0.343	0.328	0.311	0.301	0.287	0.264	0.254
	10-20	0.533	0.500	0.405	0.392	0.350	0.326	0.319	0.305	0.283	0.271
	20-30	0.509	0.501	0.408	0.386	0.360	0.338	0.323	0.320	0.303	0.286
B5P2	0-10	0.533	0.430	0.376	0.340	0.317	0.305	0.296	0.278	0.260	0.252
	10-20	0.530	0.490	0.400	0.359	0.340	0.328	0.317	0.306	0.286	0.275
	20-30	0.500	0.496	0.405	0.381	0.353	0.332	0.321	0.318	0.299	0.286
B5P3	0-10	0.510	0.429	0.321	0.303	0.279	0.270	0.256	0.248	0.235	0.231
	10-20	0.500	0.489	0.406	0.388	0.369	0.329	0.300	0.265	0.258	0.248
	20-30	0.508	0.438	0.354	0.343	0.306	0.305	0.298	0.282	0.271	0.269
B5P4	0-10	0.533	0.431	0.326	0.312	0.307	0.295	0.281	0.262	0.257	0.251
	10-20	0.501	0.453	0.447	0.419	0.351	0.346	0.320	0.285	0.278	0.268
	20-30	0.548	0.427	0.312	0.304	0.296	0.289	0.271	0.253	0.249	0.245

Appendix 7: Plant/ Management Input File Description

Information Section :
1) WEPP version (95.7) - real
2) Number of Overland Flow Elements for hillslopes - integer
3) Number of total years in simulation - real

Plant Growth Section :
1. number of unique plant types - integer
2. plant name - character
3. for use on land type - integer
    1) crop
    2) range
    3) forest
    4) roads

Cropland file was considered as the study catchment was a cultivated land.

4.0 harvest unit (t/a) - character
5.1 canopy cover coefficient - real
5.2 parameter value for canopy height equation - real
5.3 biomass energy ratio - real
5.4 base daily air temperature (°C) - real
5.5 parameter for flat residue cover equation (m^2/kg) - real
5.6 growing degree days to emergence (°C) - real
5.7 critical live biomass value below which grazing is not allowed(kg/m^2) -real
5.8 height of post-harvest standing; cutting height(m) - real
5.9 fraction canopy remaining after senescence (0-) - real
5.10 plant stem diameter at maturity (m) -real
6.1 heat unit index when leaf area index starts to decline - real
6.2 fraction of biomass remaining after senescence(0-1) -real
6.3 radiation extinction coeffient - real
6.4 standing to flat residue adjustment factor (wind, snow etc). - real
6.5 maximum Darcy Weisbach friction factor for living plant - real
6.6 growing degree days for growing section (°C) - real
6.7 harvest index - real
6.8 maximum canopy height (m) - real
7.1 use fragile or non-fragile operation values - integer
    1) fragile   2) non-fragile
8.1 decomposition constant to calculate mass change of above-ground biomass (surface or buried) - real
8.2 decomposition constant to calculate mass change of root-biomass - real
8.3 optimal temperature for plant growth (°C) - real
8.4 plant specific drought tolerance - real
8.5 in-row plant spacing (m) - real
8.6 maximum root depth (m) - real
8.7 root to shoot ratio - real
8.8 maximum root mass for a perennial crop (kg/m^2) - real
8.9 period over which senescence occurs (days) - real
8.10 maximum temperature that stops the growth of a perennial crop (°C) - real

9.1 critical freezing temperature for a perennial crop (°C) - real
9.2 maximum leaf area index - real
9.3 optimum yield under no stress conditions (kg/m^2) - real

Operation Section

1.1 number of unique operation types - integer
1.1 operation name - chracter
2.1 for use on land type - integer
    1) crop 2) range 3) forest 4) roads
3.1 interrill tillage intensity for fragile crops - real
3.2 interrill tillage intensity for non-fragile crops - real
3.3 number of rows of tillage implement - real
4.1 implement code - (pcode) - real
    1) planter 2) drill 3) cultivator 4) other
4.2 cultivator position - integer
    (read when pcode = 3)
    1) front mounted 2) rear mounted
5.1 ridge height value after tillage (m) - real
5.2 ridge intervall (m) - real
5.3 rill tillage intensity for fragile crops - real
5.4 rill tillage intensity for non-fragile crops - real
5.5 random roughness value after tillage (m) - real
5.6 fraction of surface are disturbed (0-1) - real
5.7 mean tillage depth (m) - real

Initial Condition Section

0.1 number of initial condition scenarios - real
1.1 scenario name - character
2.1 landuse - integer
    1) crop 2) range 3) forest 4) roads
3.1 bulk density after last tillage (g/cm^3) - real
3.2 initial canopy cover (0-1) - real
3.3 days since last tillage - real
3.4 days since last harvest - real
3.5 initial frost depth (m) - real
3.6 initial interrill cover (0-1) - real
4.1 Plant Growth Scenario index of initial type - real
5.1 initial residue cropping system - real
    1) annual 2) perennial 3) fallow
6.1 cumulative rainfall since last tillage (mm) - real
6.2 initial ridge height after last tillage (m) - real
6.3 initial rill cover (0-1) - real
6.4 initial ridge roughness after last tillage (m) - real
6.5 rill spacing (m) - real
7.1 rill width type - integer
    1) temporary 2) permanent
8.1 initial snow depth - real
8.2 initial depth of thaw (m) - real
8.3 depth of secondary tillage layer (m) - real

8.4 depth of primary tillage - real
8.5 initial rill width (m) - real
9.1 initial total dead root mass (kg/m^2) - real
9.2 initial total submerged residue mass (kg/m^2) - real

Surface Effects Section

0.1 Number of Surface Effect Scenarios - integer
1.1 Scenario name - character
2.1 For use of land type - integer
1) crop 2) range 3) forest 4) roads
3.1 number of operations for surface effect scenario - integer
4.1 day of tillage - integer
5.1 Operation Scenario Index - integer
6.1 tillage depth (m) - real
7.1 tillage type - integer
1) primary 2) secondary

Yearly Section

0.1 Number of Yearly Scenario - real
1.1 Scenario name - real
2.1 For use on land type - real
1) crop 2) range 3) forest 4) roads
3.1 Plant Growth Scenario Index - integer
4.1 Surface Scenario Index - integer
5.1 Contour Scenario Index - integer
6.1 Drainage Scenario Index - integer
7.1 Cropping system - integer
1) annual 2) perennial 3) fallow
8.1 harvesting date or end of fallow period - integer
9.1 planting date or start of fallow period - integer
10.1 row width (m) - integer
11.1 residue management option - integer
1) herbicide application 2) burning 3) silage
4) shredding or cutting 5) residue 6) none
12.1 standing residue shredding or cutting date - integer
13.1 fraction of standing residue shredding or cut (0-1) - real

Management Section

1.1 Scenario name - character
2.1 Number of OFE's in the rotation - integer
3.1 Initial Condition Scenario index used for the OFE - integer
4.1 Number of times the rotation is repeated - integer
5.1 Number of crops per year - integer
6.1 Yearly Scenario index used this year on this OFE with this crop - integer

NOTE: Some of the values for all the sections were obtained from tables and graphs docummented by Flanagan and Livingston(1995).

Appendix 8: Channel File Description

Line 1 : Version control number(95.7) - real
Line 2 : Number of channel elements - integer
Line 3 : Flag for the runoff peak calculation method - integer
  1 - use modified EPIC computation method
  2 - use CREAMS computation method
Line 4 : Length to width ratio - real
Line 5 : Flag to indicate the shape of the channel - integer
  1 - triangular
  2 - naturally eroded channel
Line 6 : Flag to indicate the type of conrol section at the channel outlet.
  0 - no control structure 1 - critical flow
  2 - normal flow 3 - normal flow with a different roughness
  4 - rating curve at the channel outlet
Line 7 : Flag to indicate friction slope calculation method - integer
  1 - CREAMS calculation method
  2 - the friction slope is equal to the bed slope
Line 8 : Flag to indicate the type of channel output - integer
  A value of 0 to be put here
Line 9 : a) inverse slope of channel banks (m/m) - real
  A value of 0 must be entered
  b) Manning roughness coefficient for bare soil in the channel- real
Line 10 : a) total Manning roughness coefficient in channel allowing for vegetation
  b) channel erodibility factor (s/m) - real
  c) channel shear stres (N/m²) - real
  d) depth to nonerodible layer in mid-channel (m) - real
  e) depth to nonerodible layer along the side of the channel (m) - real
*Line 11 : a) control structure slope (m/m) - real
  b) control structure average inverse side slope (m/m) - real
  c) control structure Manning coefficient - real

* This line must be present even though its values are not used.

Appendix 9: Impoundment Input File Description

Line 1 : Version number(95.7) - real
Line 2 : Number of impoundments in the watershed - real

Drop Spillway Section

Line 3 : Drop spillway index - integer
- 0 : no drop spillway is present, skip the drop spillway description
- 1 : drop spillway with circular riser and circular barrel
- 2 : drop spillway with rectangular box riser and circular barrel
- 3 : drop spillway with rectangular box riser and rectangular box barrel

(Drop spillway index = 0, therefore drop spillway description was skipped)

Culvert Section

Line 4 : Culvert index - integer
- 0 : no culvert is present, skip the culvert description
- 1 : culvert is present

(culvert index = 0 for the study)

Emergency Spillway Section

Line 5 : Emergency spillway index (ies) - integer
- 0 : no emergency spillway is present, skip the description section
- 1 : Emergency spillway or open channel outlet is present
- 2 : User specified stage - discharge relationship is present

(ies = 1 for the study)

Line 6 : a) Bottom width of the exit channel (m) - real
- b) Side slopes of the exit channel (m/m) - real
- c) Manning roughness coefficinet for the vegetation in the exit channel-real
- d) Stage of the exit channel (m) - real
- e) Maximum stage for flow through the exit channel (m) - real

Line 7: a) Slope of section # 1 of the exit channel (m/m) - real
- b) Length of section # 1 of the exit channel (m) - real
- c) Slope of section # 2 of the exit channel (m/m) -real
- d) Length of section # 2 of the exit channel (m) - real
- e) Slope of section # 3 of the exit channel (m/m) - real

Perforated Riser Section

Line 8 : Perforated riser index (ipr) - integer
- 0 : No perforated riser is present, skip the description section
- 1 : Perforated riser is present

(ipr = 0 for the study)

Miscellaneous and stage-area-Length data

Line 9 : a) Stage at which the overtop flag goes of (in) - real
- b) Stage at which the full of sediment flag goes off (m) - real
- c) Stage at the beginning of the simulation (m) - real
- d) Initial time step (hr) - real

e) Infiltration rate (m/d) - real
Line 10 : Structure size - integer
1 : Small structure with little to no permanent pool
2 : large structure (>0.4ha) with a permanent pool greater than 1 meter deep

Number of Particle Size Subclass Division
Line 11 : Number of stage-area-length-points utilized (nalpts) - real
Line 12 : Minimum stage (m) - real
Area at minimum stage (m^2) - real
Length at minimum stage (m) - real
Line 13 : Stage at point i (m) ($i > 0.0$) - ($l = 1$, nalpts)
Area at point i (m^2) - ($i = 1$, nalpts) - real
Length at point i (m) - ($i = 1$, nalpts) - real

Note : See WEPP manual prepared by Flanagan and Livingston (9195) for easy calculation or determination of some of the value.

Appendix 10: Climate Input Data File

4.00
1 0 0
Station: RUMURUTI CLIGEN VERSION 4.0

Latitude	Longitude	Elevation (m)	Obs. Years	Beginning year	Years simulated
0.38	36.65	1768	21	96	1

Observed monthly ave. max temperature (°C)
26.4 27.5 27.5 26.4 26.1 25.7 24.6 25.1 27.0 26.4 24.8 25.1
Observed monthly ave. min temperature (°C)
6.7 7.2 8.2 10.0 10.0 8.3 8.3 8.1 7.5 9.1 9.5 8.1
Observed monthly ave. solar radiation (Langleys/day)
560.0 589.0 575.0 539.0 558.0 531.0 507.0 540.0 576.0 540.0 515.0 547.0
Observed monthly ave. precipitation (mm)
24.9 32.7 46.8 110.0 59.0 70.2 85.1 81.8 35.3 51.0 62.8 40.1

da	mo	year	prcp (mm)	dur (h)	tp	ip	tmax (°C)	tmin (°C)	rad (l/d)	w-vl (m/s)	w-dir (Deg)	tdew (°C)
1	1	96	0.0	0.00	0.00	0.00	28.0	5.0	596.	1.7	304.	19.6
2	1	96	0.0	0.00	0.00	0.00	28.5	7.0	637.	2.5	285.	19.9
3	1	96	0.0	0.00	0.00	0.00	28.5	10.5	536.	2.4	141.	20.2
4	1	96	0.0	0.00	0.00	0.00	27.0	8.0	684.	2.4	311.	16.3
5	1	96	0.0	0.00	0.00	0.00	27.0	5.5	668.	2.6	269.	19.3
6	1	96	0.0	0.00	0.00	0.00	27.0	7.0	668.	2.6	277.	18.8
7	1	96	0.0	0.00	0.00	0.00	26.0	6.5	632.	2.7	50.	16.3
8	1	96	0.0	0.00	0.00	0.00	26.5	7.5	632.	3.1	181.	18.8
9	1	96	0.0	0.00	0.00	0.00	26.0	7.5	584.	2.4	1.	18.0
10	1	96	0.0	0.00	0.00	0.00	28.0	6.5	682.	2.5	330.	18.3
11	1	96	0.0	0.00	0.00	0.00	28.0	8.5	465.	3.2	0.	17.5
12	1	96	0.0	0.00	0.00	0.00	25.5	7.0	494.	3.0	0.	17.0
13	1	96	0.0	0.00	0.00	0.00	25.0	7.5	513.	2.9	320.	17.9
14	1	96	0.0	0.00	0.00	0.00	25.5	9.5	680.	2.7	242.	20.1
15	1	96	0.0	0.00	0.00	0.00	28.5	4.5	634.	3.0	347.	16.2
16	1	96	0.0	0.00	0.00	0.00	28.0	4.5	680.	3.5	87.	15.1
17	1	96	0.0	0.00	0.00	0.00	28.0	3.5	677.	3.4	284.	18.2
18	1	96	0.0	0.00	0.00	0.00	27.5	3.5	687.	2.7	317.	18.3
19	1	96	0.0	0.00	0.00	0.00	27.0	7.5	684.	2.6	186.	19.1
20	1	96	0.0	0.00	0.00	0.00	27.4	2.5	703.	2.3	299.	18.2
21	1	96	0.0	0.00	0.00	0.00	28.0	2.5	713.	2.3	83.	13.8
22	1	96	0.0	0.00	0.00	0.00	28.0	2.6	656.	2.6	0.	17.4
23	1	96	0.0	0.00	0.00	0.00	27.5	3.0	656.	2.6	187.	18.2
24	1	96	0.0	0.00	0.00	0.00	27.0	4.5	691.	3.0	201.	17.1
25	1	96	0.0	0.00	0.00	0.00	28.5	8.5	501.	2.5	63.	18.8
26	1	96	0.0	0.00	0.00	0.00	26.0	7.5	627.	2.9	305.	19.1
27	1	96	0.0	0.00	0.00	0.00	27.5	7.5	501.	4.7	207.	18.6
28	1	96	0.0	0.00	0.00	0.00	25.5	9.5	599.	4.6	254.	19.1
29	1	96	0.0	0.00	0.00	0.00	27.5	7.0	658.	3.0	215.	18.8
30	1	96	0.0	0.00	0.00	0.00	27.0	4.5	630.	2.9	177.	18.8
31	1	96	0.0	0.00	0.00	0.00	26.5	5.5	670.	3.3	223.	18.1
1	2	96	0.0	0.00	0.00	0.00	26.5	6.0	656.	3.2	17.	23.0
2	2	96	0.0	0.00	0.00	0.00	27.5	9.5	622.	3.4	255.	21.0
3	2	96	0.0	0.00	0.00	0.00	28.5	7.0	649.	3.4	60.	19.3
4	2	96	0.0	0.00	0.00	0.00	28.5	7.0	680.	3.6	113.	19.0
5	2	96	0.0	0.00	0.00	0.00	29.0	5.5	653.	3.6	27.	10.0

6	2	96	0.0	0.00	0.00	0.00	28.0	8.0	570.	3.8	84.	10.3
7	2	96	0.0	0.00	0.00	0.00	27.0	9.5	601.	3.5	184.	20.0
8	2	96	0.0	0.00	0.00	0.00	27.0	8.5	480.	5.2	260.	18.5
9	2	96	0.0	0.00	0.00	0.00	27.5	6.0	668.	3.9	36.	17.8
10	2	96	0.0	0.00	0.00	0.00	29.0	6.5	677.	3.5	303.	18.0
11	2	96	0.0	0.00	0.00	0.00	29.5	6.0	611.	3.2	307.	17.7
12	2	96	0.0	0.00	0.00	0.00	29.5	7.0	618.	3.3	269.	19.6
13	2	96	0.0	0.00	0.00	0.00	28.0	7.0	653.	5.0	272.	19.3
14	2	96	0.0	0.00	0.00	0.00	28.5	8.0	665.	3.4	359.	18.0
15	2	96	0.0	0.00	0.00	0.00	29.5	7.0	668.	3.2	342.	18.8
16	2	96	0.0	0.00	0.00	0.00	30.5	8.0	549.	2.8	153.	19.4
17	2	96	0.0	0.00	0.28	8.28	30.0	12.5	612.	3.1	249.	19.1
18	2	96	1.5	0.00	0.00	0.00	27.5	12.0	427.	3.8	289.	19.4
19	2	96	2.5	1.42	0.00	0.00	28.0	9.5	530.	3.2	347.	19.3
20	2	96	0.9	2.00	0.00	0.00	29.5	7.5	684.	2.5	320.	19.3
21	2	96	0.0	0.84	0.00	0.00	29.5	14.0	170.	3.4	287.	19.3
22	2	96	0.0	0.00	0.08	0.00	24.0	6.5	164.	3.0	265.	19.3
23	2	96	0.0	0.00	0.00	0.00	29.0	5.5	283.	3.4	119.	20.6
24	2	96	0.0	0.00	0.00	0.00	30.0	12.0	195.	3.6	249.	19.1
25	2	96	0.0	0.00	0.00	0.00	29.5	6.5	203.	4.0	122.	18.0
26	2	96	0.0	0.00	0.00	0.00	29.0	6.5	153.	4.6	21.	19.6
27	2	96	0.0	0.00	0.00	0.00	28.5	7.5	172.	4.7	351.	20.8
28	2	96	0.0	0.00	0.00	0.00	28.5	6.5	272.	4.8	150.	18.9
29	2	96	0.0	0.00	0.00	0.00	27.0	5.0	640.	4.6	240.	18.6
1	3	96	0.0	0.00	0.06	0.00	27.0	5.6	161.	2.1	320.	18.6
2	3	96	11.0	0.00	0.08	1.01	27.0	9.5	264.	7.8	148.	19.9
3	3	96	3.6	3.25	0.00	0.00	24.0	8.0	339.	3.2	44.	19.9
4	3	96	0.0	2.45	0.00	0.00	26.5	7.5	450.	4.2	303.	15.6
5	3	96	4.2	0.00	0.00	0.00	28.5	7.0	212.	3.8	266.	17.0
6	3	96	0.0	2.00	0.00	0.00	26.5	7.0	206.	4.0	289.	18.0
7	3	96	0.0	0.00	0.00	0.00	29.0	8.0	399.	0.9	188.	18.0
8	3	96	0.0	0.00	0.00	0.00	29.0	8.5	338.	2.6	284.	19.4
9	3	96	16.0	0.00	0.01	12.68	21.0	8.0	340.	3.2	210.	14.7
10	3	96	0.0	3.58	0.00	0.00	28.0	15.0	272.	3.2	143.	19.9
11	3	96	0.0	0.00	0.00	0.00	29.0	19.0	221.	3.3	132.	19.9
12	3	96	0.0	0.00	0.00	0.00	28.6	12.5	397.	3.1	335.	19.8
13	3	96	0.0	0.00	0.00	0.00	29.5	19.5	354.	4.6	283.	19.0
14	3	96	0.0	0.00	0.00	0.00	28.5	19.0	677.	4.8	111.	18.3
15	3	96	0.0	0.00	0.00	0.00	29.0	10.0	642.	2.9	324.	21.2
16	3	96	0.0	0.00	0.00	0.00	30.0	9.5	696.	3.3	332.	23.0
17	3	96	0.0	0.00	0.00	0.00	30.0	7.5	665.	3.4	189.	19.8
18	3	96	0.0	0.00	0.00	0.00	30.0	10.0	577.	4.7	216.	21.0
19	3	96	2.0	0.00	0.00	0.00	29.0	8.0	537.	2.5	43.	19.1
20	3	96	0.3	4.00	0.14	6.49	29.0	13.0	512.	4.2	355.	19.3
21	3	96	0.0	0.45	0.00	0.00	27.5	11.0	572.	5.4	331.	20.1
22	3	96	0.0	0.00	0.00	0.00	27.0	12.5	475.	3.8	111.	20.9
23	3	96	0.0	0.00	0.00	0.00	28.0	10.5	525.	4.4	198.	19.3
24	3	96	0.1	0.00	0.11	14.28	26.5	8.5	635.	3.7	186.	19.6
25	3	96	0.0	1.00	0.00	0.00	28.0	6.5	658.	2.6	153.	19.9
26	3	96	0.0	0.00	0.05	0.00	29.5	10.5	506.	3.1	31.	20.4
27	3	96	9.0	0.00	0.00	10.65	28.5	14.0	463.	3.0	219.	15.1
28	3	96	15.5	5.45	0.00	0.00	25.0	12.0	477.	2.3	144.	17.9
29	3	96	2.8	8.50	0.00	0.00	28.0	13.5	453.	2.3	10.	18.5
30	3	96	12.0	5.48	0.00	0.00	23.0	11.5	649.	2.3	188.	19.9
31	3	96	0.0	0.00	0.00	0.00	26.5	9.5	539.	2.7	37.	20.2

1	4	96	0.0	0.06	0.00	0.00	26.5	13.5	572.	3.8	260.	22.2
2	4	96	0.0	0.00	0.00	0.00	27.0	10.5	620.	3.6	88.	20.6
3	4	96	0.0	0.00	0.00	0.00	30.5	9.0	682.	3.5	310.	20.3
4	4	96	0.0	0.00	0.00	0.00	27.5	6.6	606.	3.7	98.	19.2
5	4	96	0.0	0.00	0.00	0.00	28.0	9.0	625.	3.6	276.	18.8
6	4	96	0.0	0.00	0.00	0.00	29.0	11.0	601.	3.0	198.	19.8
7	4	96	0.0	0.00	0.00	0.00	28.0	7.8	492.	3.9	96.	21.4
8	4	96	6.0	1.20	0.04	10.94	28.0	8.5	539.	3.2	284.	17.2
9	4	96	5.6	1.16	0.02	9.10	27.0	7.5	672.	3.7	244.	17.5
10	4	96	0.0	0.00	0.00	0.00	26.0	7.5	630.	3.5	350.	18.7
11	4	96	0.0	0.00	0.00	0.00	27.5	10.0	642.	3.3	353.	18.7
12	4	96	0.0	0.00	0.00	0.00	28.0	6.5	651.	3.3	3.	20.5
13	4	96	0.0	0.00	0.84	0.00	27.0	11.0	508.	5.9	37.	17.0
14	4	96	3.6	2.00	0.07	8.60	28.0	12.6	749.	1.5	152.	16.5
15	4	96	0.6	0.40	0.98	7.22	26.5	9.5	503.	3.5	7.	17.2
16	4	96	4.8	1.00	0.32	3.35	27.0	7.5	574.	3.5	115.	18.3
17	4	96	0.0	0.00	0.00	0.00	26.0	7.5	639.	3.6	57.	17.1
18	4	96	0.0	0.00	0.00	0.00	27.5	9.0	627.	4.4	212.	17.8
19	4	96	0.0	0.00	0.00	0.00	27.0	8.5	565.	3.0	357.	17.5
20	4	96	0.0	0.00	0.00	0.00	27.0	7.5	561.	5.1	35.	17.0
21	4	96	1.5	1.05	0.97	2.26	27.5	10.0	587.	4.1	179.	16.7
22	4	96	0.0	0.00	0.00	0.00	27.0	14.5	668.	4.8	227.	15.8
23	4	96	0.0	0.00	0.00	0.00	27.5	6.5	596.	4.5	321.	0.0
24	4	96	0.0	0.00	0.00	0.00	27.5	6.5	661.	4.6	268.	0.0
25	4	96	0.0	0.00	0.00	0.00	28.0	7.0	684.	3.4	201.	0.0
26	4	96	0.0	0.00	0.00	0.00	29.0	7.5	622.	3.9	194.	21.1
27	4	96	0.0	0.00	0.00	0.00	28.5	8.5	558.	4.7	132.	0.0
28	4	96	0.0	0.00	0.00	0.00	28.5	8.5	596.	4.3	163.	0.0
29	4	96	0.0	0.00	0.00	0.00	28.0	8.0	608.	3.6	204.	18.3
30	4	96	0.0	0.00	0.00	0.00	28.5	10.0	561.	3.8	344.	20.6
1	5	96	0.0	0.00	0.00	0.00	27.6	12.5	453.	4.1	307.	22.3
2	5	96	0.0	0.00	0.00	0.00	26.0	20.0	656.	4.4	229.	19.1
3	5	96	0.0	0.00	0.00	0.00	28.0	15.5	584.	5.2	132.	18.0
4	5	96	0.0	0.00	0.00	0.00	28.0	13.0	615.	1.3	29.	0.0
5	5	96	0.0	0.00	0.00	0.00	28.5	19.5	546.	7.0	330.	20.8
6	5	96	0.0	0.00	0.00	0.00	29.0	20.5	630.	7.7	190.	20.6
7	5	96	0.0	0.00	0.00	0.00	28.0	12.0	544.	1.6	311.	18.6
8	5	96	0.0	0.00	0.00	0.00	28.0	8.5	582.	5.7	324.	16.0
9	5	96	0.0	0.00	0.00	0.00	27.5	12.5	608.	4.0	232.	18.8
10	5	96	0.0	0.00	0.00	0.00	27.5	14.5	523.	4.0	358.	20.2
11	5	96	0.0	0.00	0.00	0.00	28.5	14.5	439.	5.6	153.	19.1
12	5	96	3.5	1.70	0.00	0.00	25.5	14.0	358.	3.8	306.	18.0
13	5	96	22.0	5.33	0.08	11.00	26.5	12.5	477.	3.1	0.	16.5
14	5	96	18.7	6.40	0.37	8.92	26.0	11.5	358.	2.6	33.	17.5
15	5	96	22.2	8.50	0.21	10.30	25.0	12.0	649.	2.5	107.	18.8
16	5	96	0.0	0.00	0.00	0.00	25.5	10.5	665.	3.6	222.	19.6
17	5	96	0.0	0.00	0.00	0.00	26.5	10.5	615.	4.2	164.	19.6
18	5	96	0.0	0.00	0.00	0.00	25.5	10.0	523.	3.9	260.	19.3
19	5	96	1.0	2.00	0.00	0.00	25.5	10.0	477.	3.4	64.	19.3
20	5	96	0.0	0.00	0.00	0.00	25.0	10.0	558.	3.2	176.	20.4
21	5	96	0.0	0.00	0.00	0.00	26.5	10.5	577.	4.6	334.	17.9
22	5	96	0.0	0.00	0.00	0.00	25.5	9.5	470.	4.9	261.	19.1
23	5	96	0.5	1.00	0.00	0.00	26.0	9.0	513.	4.8	177.	18.3
24	5	96	0.0	0.00	0.00	0.00	25.5	14.0	493.	5.0	293.	19.3
25	5	96	0.0	0.00	0.00	0.00	26.0	9.5	437.	3.6	76.	16.5

26	5	96	2.5	2.00	0.06	0.00	25.0	12.5	661.	2.6	326.	19.3
27	5	96	0.0	0.00	0.00	0.00	26.5	10.5	599.	3.5	210.	19.3
28	5	96	0.0	0.00	0.00	0.00	26.5	8.5	642.	4.7	180.	19.8
29	5	96	0.0	0.00	0.00	0.00	26.5	7.0	570.	4.2	216.	17.0
30	5	96	0.0	0.00	0.00	0.00	26.5	8.5	570.	4.9	241.	17.2
31	5	96	0.0	0.00	0.00	0.00	26.5	7.5	594.	2.2	320.	16.7
1	6	96	0.0	0.00	0.00	0.00	26.0	9.5	582.	3.0	19.	17.9
2	6	96	36.7	17.00	0.08	0.00	27.5	11.0	525.	2.4	233.	17.5
3	6	96	1.0	0.90	0.60	4.00	24.5	14.0	323.	2.1	132.	17.0
4	6	96	1.4	1.00	0.55	8.40	21.5	14.0	577.	1.8	269.	17.0
5	6	96	47.5	17.00	0.00	0.00	25.0	13.0	434.	2.5	106.	16.5
6	6	96	21.5	9.95	0.00	0.00	23.0	13.0	468.	2.2	211.	16.5
7	6	96	20.0	7.00	0.00	0.00	22.5	12.0	396.	1.7	96.	17.5
8	6	96	2.0	1.33	0.00	0.00	21.5	13.5	563.	2.4	202.	17.5
9	6	96	1.3	1.00	0.00	0.00	25.0	13.5	268.	2.4	36.	15.7
10	6	96	0.7	0.90	0.00	0.00	19.0	13.5	277.	1.5	107.	16.5
11	6	96	9.2	3.00	0.00	0.00	21.0	13.0	420.	1.6	196.	15.7
12	6	96	0.0	0.00	0.00	0.00	24.5	13.0	663.	2.0	268.	18.5
13	6	96	7.7	1.42	0.28	5.81	25.0	13.0	539.	2.5	191.	19.5
14	6	96	3.4	1.25	0.00	0.00	21.0	7.0	401.	3.4	304.	17.5
15	6	96	21.0	8.00	0.03	17.81	24.0	12.5	411.	2.9	7.	16.3
16	6	96	1.6	1.00	0.00	0.00	22.0	13.0	468.	2.1	0.	17.6
17	6	96	4.2	1.42	0.00	0.00	25.5	13.5	586.	2.1	91.	17.1
18	6	96	9.3	3.40	0.00	0.00	26.0	11.5	596.	2.7	277.	15.7
19	6	96	6.1	2.10	0.00	0.00	24.0	13.0	487.	2.5	0.	16.5
20	6	96	0.0	0.00	0.00	0.00	23.0	12.5	508.	3.2	209.	16.7
21	6	96	0.0	0.00	0.00	0.00	22.0	13.8	573.	1.1	0.	14.9
22	6	96	0.0	0.00	0.00	0.00	23.0	10.0	601.	1.1	265.	17.0
23	6	96	0.0	0.00	0.00	0.00	23.0	13.5	622.	1.5	178.	15.9
24	6	96	0.0	0.00	0.00	0.00	23.5	7.5	568.	3.0	212.	17.9
25	6	96	0.0	0.00	0.00	0.00	23.0	13.0	611.	2.2	328.	17.5
26	6	96	0.0	0.00	0.00	0.00	23.5	13.0	558.	3.0	178.	16.5
27	6	96	0.0	0.00	0.00	0.00	23.5	7.0	589.	5.6	205.	16.0
28	6	96	0.0	0.00	0.00	0.00	23.5	7.5	625.	2.9	246.	17.5
29	6	96	0.0	0.00	0.00	0.00	24.0	7.5	511.	3.6	235.	17.5
30	6	96	0.0	0.00	0.00	0.00	23.5	5.0	642.	2.6	260.	17.2
1	6	96	0.0	0.00	0.00	0.00	24.5	6.5	595.	4.0	219.	15.7
2	6	96	0.0	0.00	0.00	0.00	25.5	5.5	634.	3.2	227.	14.8
3	6	96	0.0	0.00	0.00	0.00	25.0	6.5	596.	2.7	251.	16.7
4	7	96	0.0	0.00	0.00	0.00	23.5	4.3	668.	2.8	0.	18.6
5	7	96	0.6	0.80	0.00	0.00	25.8	8.8	568.	2.4	179.	17.9
6	7	96	19.7	3.00	0.00	0.00	26.0	13.5	584.	2.0	63.	17.9
7	7	96	0.0	0.00	0.00	0.00	25.0	7.0	594.	2.5	272.	17.0
8	7	96	0.5	1.00	0.00	0.00	25.8	8.5	534.	2.4	347.	18.8
9	7	96	1.8	0.21	0.00	0.00	24.5	7.0	534.	2.0	234.	15.5
10	7	96	0.0	0.00	0.00	0.00	25.0	9.5	470.	1.8	0.	16.0
11	7	96	14.9	2.45	0.08	4.00	24.5	12.2	363.	2.1	126.	16.0
12	7	96	21.3	8.00	0.00	0.00	22.8	12.5	306.	1.3	2.	16.4
13	7	96	53.8	10.00	0.02	29.49	20.5	12.0	458.	1.4	346.	14.7
14	7	96	20.3	6.33	0.05	8.11	21.7	11.5	408.	1.8	321.	15.2
15	7	96	6.7	2.12	0.00	0.00	22.5	13.0	572.	1.4	88.	16.5
16	7	96	0.0	0.00	0.00	0.00	24.0	12.5	430.	1.5	0.	16.7
17	7	96	16.7	4.00	0.00	15.45	24.0	12.5	339.	3.1	314.	17.0
18	7	96	1.4	0.65	0.15	6.07	22.0	12.5	432.	2.1	158.	14.3
19	7	96	0.0	0.00	0.00	0.00	21.0	11.5	294.	2.4	253.	12.1

20	7	96	0.0	0.00	0.00	0.00	21.0	11.0	430.	1.7	101.	14.4
21	7	96	1.3	1.00	0.03	3.97	21.5	9.5	549.	1.8	173.	16.5
22	7	96	0.0	0.00	0.00	0.00	23.0	9.0	523.	1.6	354.	15.4
23	7	96	2.0	1.15	0.00	0.00	22.5	9.0	629.	2.2	0.	16.7
24	7	96	0.0	0.00	0.00	0.00	24.0	9.5	556.	3.3	331.	16.2
25	7	96	0.0	0.00	0.00	0.00	23.0	7.5	644.	3.2	18.	15.4
26	7	96	0.0	0.00	0.00	0.00	24.0	11.5	530.	1.8	0.	17.5
27	7	96	3.5	1.00	0.01	7.23	24.0	9.5	627.	1.7	43.	16.0
28	7	96	0.0	0.00	0.00	0.00	23.0	12.5	589.	2.4	45.	17.5
29	7	96	0.0	0.00	0.00	0.00	24.0	9.5	503.	2.0	255.	15.4
30	7	96	26.6	5.05	0.27	8.17	23.0	9.0	501.	2.1	0.	15.0
31	7	96	20.5	3.67	0.41	4.32	23.0	8.0	613.	1.6	200.	14.7
1	8	96	0.0	0.00	0.00	0.00	23.0	7.5	587.	2.1	178.	15.0
2	8	96	0.0	0.00	0.00	0.00	24.0	8.5	565.	1.9	162.	15.4
3	8	96	0.0	0.00	0.00	0.00	25.0	5.5	680.	2.3	219.	14.8
4	8	96	0.0	0.00	0.00	0.00	25.5	11.0	506.	2.1	26.	15.3
5	8	96	3.5	1.50	0.11	6.03	25.5	9.5	608.	1.7	322.	15.7
6	8	96	3.1	0.98	0.08	8.15	26.0	7.5	670.	1.7	283.	15.4
7	8	96	1.2	1.05	0.12	8.86	25.5	9.0	506.	2.3	64.	18.0
8	8	96	13.2	3.45	0.34	4.50	23.5	8.5	615.	3.2	273.	14.9
9	8	96	0.0	0.00	0.00	0.00	23.5	5.5	651.	3.4	173.	15.7
10	8	96	0.0	0.00	0.00	0.00	23.5	5.0	665.	3.2	0.	15.2
11	8	96	0.0	0.00	0.00	0.00	25.0	5.5	599.	1.7	45.	15.2
12	8	96	0.0	0.00	0.00	0.00	24.0	9.5	613.	2.7	241.	16.0
13	8	96	0.0	0.00	0.00	0.00	23.5	7.5	630.	2.9	142.	16.5
14	8	96	0.0	0.00	0.00	0.00	24.0	5.5	630.	2.1	79.	16.5
15	8	96	0.0	0.00	0.00	0.00	26.0	8.5	465.	2.4	213.	18.2
16	8	96	2.3	1.00	0.16	10.45	24.5	7.5	539.	1.9	1.	15.4
17	8	96	0.0	0.00	0.00	0.00	23.5	7.0	567.	2.0	227.	16.0
18	8	96	12.2	4.87	0.09	7.38	24.0	7.0	649.	1.9	16.	15.4
19	8	96	0.3	0.75	0.07	3.95	25.0	7.5	632.	1.8	143.	16.0
20	8	96	0.0	0.00	0.00	0.00	24.0	7.5	634.	1.8	25.	16.8
21	8	96	0.3	1.05	0.05	4.28	25.5	9.0	577.	2.3	322.	17.5
22	8	96	0.0	0.00	0.00	0.00	26.0	13.0	437.	2.3	304.	18.6
23	8	96	0.0	0.00	0.00	0.00	23.5	9.5	394.	1.8	179.	17.9
24	8	96	9.5	4.00	0.12	6.54	22.5	12.0	472.	2.2	229.	14.7
25	8	96	20.5	6.50	0.11	5.55	23.5	11.0	527.	1.3	0.	17.5
26	8	96	2.1	0.90	0.08	3.80	23.5	13.5	577.	2.2	152.	15.9
27	8	96	37.2	8.45	0.07	8.43	24.0	12.0	613.	2.4	220.	16.7
28	8	96	0.0	0.00	0.00	0.00	24.0	10.0	458.	2.3	111.	17.5
29	8	96	50.3	10.65	0.07	8.96	24.5	10.0	603.	1.9	293.	14.7
30	8	96	0.6	0.95	0.01	6.86	24.5	10.0	701.	1.9	0.	18.3
31	8	96	0.0	0.00	0.00	0.00	24.0	8.5	701.	2.2	354.	16.5
1	9	96	0.0	0.00	0.00	0.00	24.5	7.5	622.	1.8	213.	16.7
2	9	96	0.0	0.00	0.00	0.00	25.5	8.5	461.	2.7	136.	16.2
3	9	96	0.0	0.00	0.00	0.00	25.0	5.5	694.	2.2	293.	14.1
4	9	96	0.0	0.00	0.00	0.00	25.0	6.0	608.	2.0	219.	16.2
5	9	96	0.0	0.00	0.00	0.00	24.5	6.5	606.	6.8	264.	16.0
6	9	96	0.0	0.00	0.00	0.00	25.5	4.5	620.	0.2	0.	14.0
7	9	96	0.0	0.00	0.00	0.00	25.5	4.5	632.	2.0	338.	14.8
8	9	96	0.0	0.00	0.00	0.00	25.5	5.0	651.	2.3	44.	15.4
9	9	96	0.0	0.00	0.00	0.00	26.8	6.5	568.	1.8	99.	18.0
10	9	96	0.0	0.00	0.00	0.00	26.0	5.0	646.	2.5	100.	16.5.
11	9	96	0.0	0.00	0.00	0.00	26.5	7.0	584.	1.1	64.	17.0
12	9	96	0.0	0.00	0.00	0.00	25.0	6.5	606.	4.1	293.	17.9

13	9	96	0.0	0.00	0.00	0.00	26.0	7.5	670.	2.4	310.	17.5
14	9	96	0.0	0.00	0.00	0.00	26.0	7.5	439.	2.0	0.	20.9
15	9	96	0.0	0.00	0.00	0.00	26.0	7.0	649.	1.4	35.	15.2
16	9	96	20.6	6.45	0.20	3.95	22.0	7.7	546.	2.0	326.	15.2
17	9	96	2.0	0.75	0.06	2.40	21.5	6.6	696.	2.2	348.	15.0
18	9	96	0.0	0.00	0.00	0.00	25.6	6.3	556.	1.8	283.	17.9
19	9	96	0.0	0.00	0.00	0.00	21.2	8.0	622.	2.5	259.	15.4
20	9	96	4.6	1.56	0.03	5.30	26.0	6.0	625.	1.7	190.	17.0
21	9	96	0.0	0.00	0.00	0.00	26.0	6.5	596.	2.8	216.	16.7
22	9	96	0.0	0.00	0.00	0.00	26.0	5.5	622.	2.7	35.	16.0
23	9	96	0.0	0.00	0.00	0.00	26.5	5.3	649.	1.4	175.	14.0
24	9	96	0.0	0.00	0.00	0.00	27.0	6.5	577.	2.7	183.	0.0
25	9	96	0.0	0.00	0.00	0.00	27.0	5.5	599.	3.4	0.	16.2
26	9	96	0.0	0.00	0.00	0.00	26.0	5.0	658.	2.4	159.	15.2
27	9	96	0.0	0.00	0.00	0.00	26.5	6.0	611.	2.4	0.	16.9
28	9	96	0.0	0.00	0.00	0.00	26.8	6.5	542.	3.6	201.	18.4
29	9	96	0.0	0.00	0.00	0.00	26.7	6.5	608.	4.2	114.	17.9
30	9	96	0.0	0.00	0.00	0.00	26.0	6.5	658.	2.2	0.	15.2
1	10	96	0.0	0.00	0.00	0.00	26.5	5.5	544.	0.9	8.	16.2
2	10	96	0.0	0.00	0.00	0.00	26.0	5.5	639.	1.7	286.	18.9
3	10	96	0.0	0.00	0.00	0.00	27.0	4.8	625.	2.9	10.	17.7
4	10	96	0.0	0.00	0.00	0.00	27.8	5.6	580.	3.6	223.	19.4
5	10	96	0.0	0.00	0.00	0.00	27.7	7.0	599.	2.9	359.	18.8
6	10	96	0.0	0.00	0.00	0.00	27.0	6.5	596.	4.2	332.	16.7
7	10	96	0.0	0.00	0.00	0.00	18.0	14.0	530.	3.9	0.	15.1
8	10	96	0.0	0.00	0.00	0.00	24.9	16.0	513.	3.9	274.	20.2
9	10	96	0.0	0.00	0.00	0.00	25.8	6.8	523.	3.7	59.	13.4
10	10	96	0.0	0.00	0.00	0.00	26.0	6.5	592.	3.1	184.	16.0
11	10	96	0.0	0.00	0.00	0.00	26.5	5.8	639.	3.0	70.	18.1
12	10	96	0.0	0.00	0.00	0.00	26.5	6.1	651.	4.9	105.	14.4
13	10	96	0.0	0.00	0.00	0.00	27.0	6.5	606.	3.4	311.	17.5
14	10	96	1.4	1.00	0.04	9.00	26.5	6.0	653.	4.1	342.	19.3
15	10	96	0.0	0.00	0.00	0.00	26.2	5.5	639.	2.8	0.	20.2
16	10	96	0.0	0.00	0.00	0.00	27.0	6.5	565.	3.2	33.	18.8
17	10	96	0.0	0.00	0.00	0.00	27.0	6.8	484.	3.0	226.	18.2
18	10	96	0.0	0.00	0.00	0.00	27.0	7.5	444.	3.3	274.	17.6
19	10	96	0.0	0.00	0.00	0.00	25.0	6.3	534.	3.3	0.	17.5
20	10	96	0.0	0.00	0.00	0.00	25.5	7.5	513.	3.6	2.	17.0
21	10	96	0.0	0.00	0.00	0.00	26.0	6.4	534.	2.8	0.	20.0
22	10	96	0.0	0.00	0.00	0.00	27.0	10.5	558.	3.4	81.	19.2
23	10	96	0.0	0.00	0.00	0.00	27.0	9.5	513.	4.0	335.	18.3
24	10	96	1.4	3.00	0.21	3.94	27.5	8.5	570.	4.1	208.	19.4
25	10	96	0.0	0.00	0.00	0.00	27.0	7.5	534.	2.4	185.	17.0
26	10	96	0.0	0.00	0.00	0.00	27.5	6.5	544.	2.9	297.	17.4
27	10	96	0.0	0.00	0.00	0.00	28.0	7.5	456.	1.2	309.	17.1
28	10	96	1.2	1.20	0.00	0.00	27.0	8.5	515.	2.5	327.	19.6
29	10	96	2.1	0.98	0.01	5.53	27.5	5.7	537.	4.8	336.	19.8
30	10	96	0.0	0.00	0.00	0.00	27.5	6.0	568.	2.5	216.	19.3
31	10	96	0.9	1.05	0.05	4.68	28.0	9.5	584.	2.6	221.	18.8
1	11	96	0.0	0.00	0.00	0.00	28.0	8.0	456.	3.1	204.	20.0
2	11	96	0.9	1.00	0.06	0.00	27.0	12.0	611.	3.5	185.	18.6
3	11	96	0.0	0.00	0.00	0.00	28.0	8.5	492.	3.6	121.	19.3
4	11	96	0.7	0.84	0.00	0.00	27.5	12.0	349.	1.9	320.	19.1
5	11	96	4.0	1.56	0.00	0.00	24.5	9.5	527.	2.8	287.	17.5
6	11	96	0.0	0.00	0.00	0.00	25.5	8.5	582.	2.7	303.	19.1

7	11	96	0.0	0.00	0.00	0.00	27.5	8.5	534.	3.1	41.	18.0
8	11	96	0.0	0.00	0.00	0.00	27.5	10.5	434.	2.9	168.	19.1
9	11	96	4.2	2.00	0.01	8.94	26.0	13.0	530.	2.1	305.	19.1
10	11	96	0.0	0.00	0.00	0.00	25.5	11.5	453.	4.3	261.	19.9
11	11	96	0.0	0.00	0.00	0.00	25.0	9.5	442.	3.8	251.	18.3
12	11	96	0.3	0.85	0.04	3.22	24.0	11.0	396.	3.1	322.	17.5
13	11	96	0.0	0.00	0.00	0.00	24.5	7.0	513.	3.3	260.	16.8
14	11	96	0.0	0.00	0.00	0.00	25.0	8.5	563.	3.6	108.	18.8
15	11	96	0.0	0.00	0.00	0.00	26.0	10.0	442.	3.8	4.	19.1
16	11	96	1.0	0.67	0.06	4.10	25.5	12.5	620.	3.1	346.	18.8
17	11	96	0.0	0.00	0.00	0.00	26.0	5.0	530.	5.3	152.	19.1
18	11	96	0.0	0.00	0.00	0.00	25.5	4.5	499.	4.5	46.	19.1
19	11	96	0.8	1.00	0.02	2.35	25.5	9.5	530.	3.9	246.	17.2
20	11	96	2.4	1.25	0.00	0.00	26.0	14.0	420.	5.3	325.	17.0
21	11	96	5.8	2.05	0.00	0.00	24.0	12.5	382.	4.0	320.	15.7
22	11	96	1.4	0.50	0.04	1.87	23.0	6.0	430.	2.1	178.	16.1
23	11	96	1.5	1.20	0.00	0.00	24.0	10.5	442.	2.1	78.	17.2
24	11	96	2.8	1.48	0.00	0.00	23.5	10.5	404.	2.4	0.	16.5
25	11	96	6.7	2.00	0.06	2.39	23.5	11.0	499.	2.2	278.	15.9
26	11	96	0.0	0.00	0.00	0.00	23.5	12.5	430.	2.6	288.	17.5
27	11	96	0.4	0.56	0.00	0.00	24.0	13.0	418.	3.6	43.	17.0
28	11	96	0.0	0.00	0.00	0.00	23.5	12.0	553.	2.6	279.	19.1
29	11	96	0.0	0.00	0.00	0.00	26.0	12.0	499.	3.0	257.	18.5
30	11	96	11.3	2.43	0.06	5.65	25.0	8.5	680.	3.0	183.	19.1
1	12	96	0.0	0.00	0.00	0.00	24.5	8.0	646.	3.4	171.	18.6
2	12	96	0.0	0.00	0.00	0.00	25.0	7.0	656.	3.7	311.	17.5
3	12	96	0.0	0.00	0.00	0.00	24.5	3.5	715.	3.1	179.	17.7
4	12	96	0.0	0.00	0.00	0.00	25.5	5.5	515.	2.5	193.	19.9
5	12	96	0.0	0.00	0.00	0.00	26.0	9.5	601.	2.3	186.	19.1
6	12	96	0.0	0.00	0.00	0.00	26.0	13.5	634.	3.4	223.	19.1
7	12	96	0.0	0.00	0.00	0.00	26.0	8.5	646.	3.1	281.	18.8
8	12	96	0.0	0.00	0.00	0.00	27.0	9.5	572.	3.0	252.	19.3
9	12	96	0.0	0.00	0.00	0.00	25.0	7.5	608.	3.0	64.	19.3
10	12	96	0.0	0.00	0.00	0.00	25.7	2.0	689.	2.8	299.	19.5
11	12	96	0.0	0.00	0.00	0.00	26.5	2.5	613.	3.9	313.	18.8
12	12	96	0.0	0.00	0.00	0.00	26.5	5.0	513.	4.0	294.	15.3
13	12	96	4.4	4.48	0.06	1.01	26.0	5.5	611.	2.9	41.	18.8
14	12	96	0.0	0.00	0.00	0.00	26.0	7.0	668.	2.6	170.	19.3
15	12	96	0.0	0.00	0.00	0.00	27.0	6.0	706.	2.6	25.	18.9
16	12	96	0.0	0.00	0.00	0.00	17.0	6.5	627.	2.9	251.	19.6
17	12	96	0.0	0.00	0.00	0.00	17.0	7.0	658.	2.9	176.	18.8
18	12	96	0.0	0.00	0.00	0.00	18.5	4.6	696.	2.8	98.	17.2
19	12	96	0.0	0.00	0.00	0.00	27.0	4.7	663.	2.9	0.	19.2
20	12	96	0.0	0.00	0.00	0.00	27.0	4.5	637.	2.8	171.	19.3
21	12	96	0.0	0.00	0.00	0.00	27.5	7.2	694.	2.4	154.	18.3
22	12	96	0.0	0.00	0.00	0.00	28.0	6.0	672.	2.6	297.	19.1
23	12	96	0.0	0.00	0.00	0.00	28.0	6.0	637.	2.7	222.	19.1
24	12	96	0.0	0.00	0.00	0.00	28.0	7.0	692.	4.0	0.	19.4
25	12	96	3.7	2.00	0.05	2.34	26.5	6.0	613.	6.8	0.	13.2
26	12	96	0.0	0.00	0.00	0.00	25.5	6.5	534.	2.0	0.	18.4
27	12	96	0.0	0.00	0.00	0.00	27.0	6.0	592.	4.8	175.	17.5
28	12	96	0.0	0.00	0.00	0.00	25.5	3.6	632.	3.5	48.	16.5
29	12	96	0.0	0.00	0.00	0.00	26.0	7.0	525.	3.5	248.	18.0
30	12	96	0.0	0.00	0.00	0.00	26.0	7.8	606.	4.0	0.	18.9
31	12	96	0.0	0.00	0.00	0.00	26.0	9.7	537.	4.0	46.	17.5

Appendix 11: Sample of Soil and Slope Input Data Files

```
95.7

#      B3P3 Soil Input Data
#
#      Created on 24Jul97 by 'WSOL', (Ver. 15Apr95)
#
xxx

1      1
'sipilib33'     'clay'  3      0.15    0.42    3.65008e+006  0.00348
4.99    0.845
100     31.3    50.1    3.41    36.2    5.6
200     31.6    56.8    5.44    40.6    6.4
300     33.7    55.6    2.7     34.8    11.
```

```
95.7
#      B3P3 Slope Input Data
#
#      Created on 07Jul97 by 'WSLP', (Ver. 15Apr95)
#
1
270     890
3       193
0,0.02  0.88,0.202  1,0.288
```

```
95.7

#      B1P1 Slope Data File
#
#      Created on 24Jul97 by 'WSLP', (Ver. 15Apr95)
#
1
267     450
3       165
0,0.01  0.565,0.162  1,0.197
```

Appendix 12: Plant/Management Input Data File

```
95.7
#     Ndaragwiti Catchment
#     Created 2Aug.97 by 'WMAN'(Ver.15 Aug 95)
#     Source: Sipili Area
#
1     # number of OFEs
3     # (total) years in simulation
#################
# Plant Section #
#################
1        # looper; number of Plant scenarios
#        Plant scenario 1 of 1
corn & beans_001
Intercropping of corn and beans
1        # 'landuse' - <Cropland>
WeppWillSet
3.6    3   35    10    4    60    9999   0.608    0.9    0.0508
0.8    0.9  0.65  0.99  0    1700  0.5    2.6
2       # 'mfo' - <Non-fragile>
0.01    0.01  25    0.25   0.15    1.52  0.25   1       30     0
0       5     0
#####################
# Operation Section #
#####################
3      # looper; number of operation scenarios
#      Operation scenario 1 of 3
#
THOE001
Toothed Hoe
1      # 'landuse' - <Cropland>
0.15   0.15    0
4      # 'pcode' - <Other>
0.025  1    0.15   0.15   0.012    1    0
#
#      Operation scenario 2 of 3
Row P102
Row Planting & fert. application with hoe
1      # 'landuse' - <Cropland>
0.16   0.16    0
4      # 'pcode' - <Other>
0.025  1    0.16   0.16    0.012     0.3     0
#
#      Operation scenario 3 of 3
Row CU03
Row Cultivator hoe
#     # 'landuse' - <Cropland>
```

```
0.15  0.15      0
4       # 'pcode'- <Other>
0.025  1     0.15    0.15    0.012   0.6    0
######################
# Initial Condition #
######################
1        # looper; number of Initial Condition Scenarios
#        Initial Condition scenario 1 of 1
INTCOBEA
Intercropping-Tilled Corn&Beans
1          # landuse - <Cropland>
1.3       0.7        200     150        0    0.1
1          # 'iresd' - <corn&Beans>
1          # 'mgmt' -<Annual>
822.9    0.025     0.9    0.034    0
1          # 'rtyp' - <Temporary>
0          0            0.1    0.15     0
############################
# Surface Effects Section #
############################
1         # looper; number of Surface Effects Scenarios
#
#         Surface Effects scenario 1 of 1
INTCOBEA
Intercropping-Tilled Corn&Beans
Initial Cultivation and Twice Hoeing
1         # 'landuse' -<Cropland.
5         # 'ntill' - <number of operations>
          135      # 'mdate' - <3/20>
          1        # 'op' - <THOE001>
          0.15
          1        # 'typtil' - <Primary>
          160      # 'mdate' -<4/15>
          2        # 'op' - <ROW P102>
          0.1
          2        # 'typtil' - <Secondary>
          220      # 'mdate'- <6/15>
          3        # 'op' - <RowCU03>
          0.15
          2        # 'typtil' - <Secondary>
          280      # 'mdate' - <8/15>
          3        # 'op' - <RowCU03>
          0.15
          2        # 'typtil' - <Secondary>
          330      # 'mdate' - <10/5>
          3        # 'op' - <RowCU03>
          0.15
          2        # 'typtil' - <Secondary>
```

```
######################
# Contouring Section #
######################
0       # looper; number of Contouring scenarios
####################
# Drainage Section #
####################
0       # looper; number of Drainage scenarios
##################
# Yearly Section #
##################
1       # looper; number of Yearly scenarios
#       Yearly scenario 1 of 1
#
INTCOBEA
Intercropping-Tilled Corn&Beans
1       # 'landuse' - <Cropland>
1       # 'itype' - <Corn&Beans>
1       # 'tilseq' - <INTCOBEA>
0       # 'conset' - <NotUsed>
0       # 'drset' - <NotUsed>
1       # 'mgmt' - <Annual>
        200     # 'jdharv' - <10/25>
        150     # 'jplt' - <4/15>
        0.6
        6       # 'resmgmt' - <None>
######################
# Management Section #
######################
INTCOBEA
Intercropping of Corn&Beans
Hoeing in March
Hoe Twice after Initial Preparation May-Oct and Apr.
1       # 'nofe' - <number of Overland Flow Elements>
        1       # 'Initial Conditions indx' - <INTCOBEA>
3       # 'nrots' - <rotation repeats..>
1       # 'nyears - <years in rotation>
#
#       Rotation 1 : year 1 to 1
        1       # 'nycrop' - <plants/yr; Year of Rotation : 1 - OFE : 1>
                1       # 'YEAR indx' - <INTCOBEA>
#
#       Rotation 2 : year 2 to 2
        1       # 'nycrop' - <plants/yr; Year of Rotation : 1 - OFE : 1>
                1       # 'YEAR indx' - <INTCOBEA>
#       Rotation 3 : year 3 to 3
        1       # 'nycrop' - <plants/yr; Year of Rotation : 1 - OFE : 1>
        1       # 'YEAR indx' - <INTCOBEA>
```

Appendix 13: Channel Input Data File

```
95.7
#       Ndaragwiti Catchment
#
#       Created on 17Apr95 by 'WCHN', (Ver. 15Apr95)
#
20      # number of Channel components
1       # Peak-Volume Calculations: EPIC
2       # Length : Width Ratio

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculations: CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.3     0.0069  3.50    0.25    0.3
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069  3.50    0.35    0.3
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated;annual
5       0.035
0.03    0.0034  4.90    0.35    0.3
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0029  4.6     0.35    0.3
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: NOT Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
```

```
0.03    0.0069  3.5     0.25     0.3
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069  3.5     0.30     0.3
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5   0.25       0.25
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5   0.25     0.25
0       0       0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation:CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5   0.25       0.25
0       0       0


2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation: CREAMS
1       # Output: Abbreviated; annual
0       0.035
0.03    0.0069  3.5     0.25     0.25
0       0       0

2       # Channel Shape: Erodile Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation: CREAMS
1       # Output: Abbreviated; annual
```

```
5      0.035
0.03    0.0069  3.5     0.25     0.25
0       0       0

2      # Channel Shape: Erodible Natural Channel
0      # Control Section:Not Present
1      # Friction Slope Calculation: CREAMS
1      # Output: Abbreviated; annual
5      0.035
0.03    0.0069  3.5     0.25     0.25
0       0       0


2      # Channel Shape: Erodible Natural Channel
0      # Control Section: Not Present
1      # Friction Slope Calculation: CREAMS
1      # Output: Abbreviated;  annual
5      0.035
0.03    0.0069   3.5    0.25     0.25
0       0        0

2      # Channel Shape: Erodible Natural Channel
0      # Control Section: Not Present
1      # Friction Slope Calculation: CREAMS
1      # Output: Abbreviated; annual
5      0.035
0.03    0.0069    3.5     0.25    0.25
0       0         0

2      # Channel Shape: Erodible Natural Channel
0      # Control Section: Not Present
1      # Friction Slope Calculation: CREAMS
1      # Output: Abbreviated; annual
5      0.035
0.03    0.0069    3.5     0.25     0.25
0       0         0

2      # Channel Shape: Erodible Natural Channel
0      # Control Section: Not Present
1      # Friction Slope Calculation: CREAMS
1      # Output: Abbreviated; annual
5      0.035
0.03    0.0069    3.5    0.25      0.25
0       0         0

2      # Channel Shape: Erodible Natural Channel
0      # Control Section: Not Present
1      # Friction Slope Calculation: CREAMS
```

```
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5    0.25    0.25
0       0         0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation: CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5    0.15    0.25
0       0         0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation: CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5    0.35    0.35
0       0         0

2       # Channel Shape: Erodible Natural Channel
0       # Control Section: Not Present
1       # Friction Slope Calculation: CREAMS
1       # Output: Abbreviated; annual
5       0.035
0.03    0.0069    3.5    0.35    0.35
0       0         0
```

Appendix 14: Sample of Channel Scenario

```
95.7
#       H1 of Sub- Watershed(A)
#       This is a WEPP Channel scenario file.
#
comments                        # Comments
NotUsed                         # Management
CSLB1P1                         # Slope
SOB5P2                          # Soil
NotUsed                         # Depletion-Level
NotUsed                         # Fixed-Date
P1                              # Channel

95.7
#       Created on 04Aug97 by 'WSHED', (Ver. 15Apr95)
#       This is a WEPP Channel scenario file.
#
comments                          # Comments
NotUsed                           # Management
CSLB1P2                           # Slope
SOB5P1                            # Soil
NotUsed                           # Depletion-Level
NotUsed                           # Fixed-Date
P1                                # Channel
```

Appendix 15: Impoundment Input Data File for Ndaragwiti Reservoir

```
95.7
#      NDARAGWITI  RESERVOIR
#      Created on 27Jun95 by 'WIMP', (Ver. 1Mar95)
#
1      # number of Impoundment components
Test Impoundment With Emergency Spillway Only
0      # Drop Spillway: Not Present
0      0      # Culvert: Not Present
0      0      # Culvert: Not Present
0      # Rockfill Checkdam: Not Present
1      # Emergency Spillway: Open Channel
Impoundment With Open Channel Outflow Structure
       5.05    1      0.35    0.87    2.1
       0.0     12.191 0       3.048   0.135
0      # Filter Fence: Not Present
0      # Perforated Riser: Not Present
2.12   0.876   2.0    0.1     0.00086
2      2
7      # Number of stage-area-length points
0      500     10
#      Stage data
       0.4     0.8    1.2     1.6     2.0
       2.4     2.8
#      Area data
       1370.55 2015.7  2596.48 3139    3654.79
       4150.19 4629.26
#      Length data
       20.5    37     50.5    65.5    68.5
       85      112
```

Appendix 16: Hillslope WEPP (95.7) Summary Output of some Plots.

Summary for WEPP Run 'B1P1 ' Annual; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 268.78mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00mm
**Soil loss (Avg. of Net Detachment Areas) = 93.819 kg/m^2 **
A AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 15480.134 kg/m
Average annual SSA enrichment ratio leaving profile = 1.00

Summary for WEPP Run 'B1P4': Annual; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 271.20mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00mm
Soil loss (Avg. of Net Detachement Areas) = 64.710 kg/m^2
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 13543.314kg/m
Average annual SSA enrichment ratio leaving profile = 1.02

Summary for WEPP Run 'B2P1': Annual ; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 121.69mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00mm
** Soil Loss (Avg. of Net Detachment Areas) = 125.440 Kg/m^2 **
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 23168.723kg/m
Average annual SSA enrichment ratio leaving profile = 1.00

Summary for WEPP Run 'B2P5': Annual; abbreivated
Mean annual precipation 822.90mm
Mean annual runoff from rainfall 41.71mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00 mm
Soil Loss (Avg. of Net Detachment Areas) = 17.962 kg/m^2
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 7903.156 kg/m
Average annual SSA enrichment ratio leaving profile = 1.00

Summary for WEPP Run 'B3P4': Annual; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 171.41mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00mm
Soil Loss (Avg. of Net Detachment Areas) = 56.718 kg/m^2
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 6487.551 kg/m
Average annual SSA enrichment ratio leaving profile = 1.14

Summary for WEPP Run 'BP': Annual; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 170.59mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00 mm
Soil Loss (Avg. of Net Detachment Areas) = 30.341 kg/m^2
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 5907.470 kg/m

Aveage annual SSA enrichment ratio leaving profile = 1.01

Summary for WEPP Run 'B4P1': Annual; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 186.71mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00 mm
Soil Loss (Avg. of Net Detachment Areas) = 42.658 kg/m^2
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 3677.109 kg/m
Average annual SSA enrichment ratio leaving profile= 1.00

Summary for WEPP Run 'B5P4': Annual; abbreviated
Mean annual precipitation 822.90mm
Mean annual runoff from rainfall 168.20mm
Mean annual runoff from snow melt and/or rain storm during winter 0.00 mm
Soil loss (Avg. of Net Detachment Areas) = 45.777 kg/m^2
A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 10871.982kg/m
Average annual SSA enrichment ratio leaving profile = 1.00

Appendix 17: Hillslope WEPP(95.7) Detailed Output of B5P1

I. RAINFALL AND RUNOFF SUMMARY

TOTAL SUMMARY: YEARS 1 - 1

99 storms produced 822.90 mm of precipitation
17 rain storm runoff events produced 159.71mm of runoff
0 snow melt and/or events during winter produced 0.00 mm of runoff

Annual averages

Number of years	1
Mean annual precipitation	822.90 mm
Mean annual runoff from rainfall	159.71 mm
Mean annual runoff from snow melt and/or rain storm during winter	0.00 mm

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of net Detachment Areas) = 49.238 kg/m^2**
** Maximum Soil Loss = 97.324 kg/m^2 at 178.30 meters**

B.

Area of Net Loss (m)	Soil Loss MEAN (kg/m^2)	Soil Loss STDEV (kg/m^2)	MAX Loss (kg/m^2)	MAX Loss Point (m)	MIN Loss (kg/m^2)	MIN Loss Point (m)
0.00-178.30	49.238	32.144	97.324	178.30	1.233	7.13

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

dist. (m)	soil loss (kg/m^2)	flow elem.	dist. (m)	soil loss (kg/m^2)	flow elem.	dist. (m)	soil loss (kg/m^2)	flow elem.
1.78	1.233	1	62.41	33.529	1	123.03	72.606	1
3.57	1.233	1	64.19	35.071	1	124.81	73.457	1
5.35	1.233	1	65.97	36.545	1	126.59	74.298	1
7.13	1.233	1	67.75	37.954	1	128.38	75.130	1
8.91	1.233	1	69.54	39.301	1	130.16	75.954	1
10.70	1.233	1	71.32	40.589	1	131.94	76.770	1
12.48	1.233	1	73.10	41.902	1	133.73	77.580	1

14.26	1.233	1	74.89	43.228	1	135.51	78.384	1
16.05	1.402	1	76.67	44.504	1	137.29	79.183	1
17.83	1.801	1	78.45	45.733	1	139.07	79.978	1
19.61	2.190	1	80.24	46.919	1	140.86	80.769	1
21.40	2.563	1	82.02	48.079	1	142.64	81.557	1
23.18	2.919	1	83.80	49.278	1	144.42	82.343	1
24.96	3.258	1	85.58	50.574	1	146.21	83.126	1
26.75	3.641	1	87.37	51.908	1	147.99	83.908	1
28.53	4.515	1	89.15	53.206	1	149.77	84.689	1
30.31	5.509	1	90.93	54.469	1	151.56	85.468	1
32.09	6.706	1	92.72	55.697	1	153.34	86.248	1
33.88	8.239	1	94.50	56.892	1	155.12	87.027	1
35.66	9.813	1	96.28	58.054	1	156.90	87.808	1
37.44	11.345	1	98.07	59.184	1	158.69	88.595	1
39.23	12.805	1	99.85	60.284	1	160.47	89.383	1
41.01	14.198	1	101.63	61.355	1	162.25	90.172	1
42.79	15.573	1	103.41	62.398	1	164.04	90.961	1
44.58	16.995	1	105.20	63.414	1	165.82	91.752	1
46.36	18.424	1	106.98	64.406	1	167.60	92.544	1
48.14	20.018	1	108.76	65.375	1	169.39	93.337	1
49.92	21.603	1	110.55	66.321	1	171.17	94.131	1
51.71	23.237	1	112.33	67.248	1	172.95	94.927	1
53.49	24.966	1	114.11	68.162	1	174.73	95.725	1
55.27	26.677	1	115.90	69.079	1	176.52	96.524	1
57.06	28.484	1	117.68	69.981	1	178.30	97.324	1
58.84	30.236	1	119.46	70.869	1			
60.62	31.918	1	121.24	71.744	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE 8779.132 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diam. (mm)	Specific Gravity	Particle Composition Sand %	Silt %	Clay %	O.M %	Detached Sediment Fraction	Fraction In Flow Existing
1	0.002	2.60	0.0	0.0	100.0	7.6	0.121	0.122
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.073	1.80	0.0	40.5	59.5	4.5	0.316	0.318
4	0.930	1.60	37.8	34.0	28.2	2.1	0.554	0.551
5	0.200	2.65	100.0	0.0	0.0	0.0	0.010	0.010

Average annual SSA enrichment ratio leaving profile = 1.00

ppendix 18: Watershed WEPP(95.7) Output for the Three Sub-Watersheds of the Ndaragwiti Catchment

```
     95.7

                    SUB-WATERSHED(A)  STRUCTURE INPUT FILE
Iillslope Elements: 1-2
                          (CONTRIBUTING ELEMENTS MATRIX)
                         HILLSLOPE        CHANNEL       IMPOUNDMENT
     ELEM.  ELEMENT

#  FED.    NUM          L    R    T      L    R    T      L    R    T
3  CHANNEL  1           H1
4  CHANNEL  2                H2                C1
5  IMPOUND  1                     C2


                  AVERAGE  ANNUAL  SUMMARY  FOR  WATERSHED

                    Soil              Sediment           Sediment
                    Loss              Deposition          Yield
 Hillslope          (kg)                (kg)               (kg)

   1             1312687.4               0.0           1312687.4
   2               32101.2               0.0             32101.2

 Channels                   Sediment
  and                        Yield
 Impoundments               (tonne)

 Channel         1           927.1
 Channel         2           950.8
 Impoundment     1            89.5

 99  storms produced  822.90 mm. of rainfall
 19  events produced  184.99 mm. of runoff passing through the watershed outlet


       Delivery From Channel and Impoundment Outlets :

  Total sediment discharge from channel outlet          =  950.8 tonnes
  Total sediment discharge from impoundment outlet =   89.5 tonnes
  Total sediment trapped in the impoundment              =  861.3 tonnes
```

95.7

SUB-WATERSHED(B) STRUCTURE INPUT FILE

Hillslope Elements: 1-10

(CONTRIBUTING ELEMENTS MATRIX)

ELEM.	ELEMENT		HILLSLOPE			CHANNEL			IMPOUNDMENT		
#	FED.	NUM.	L	R	T	L	R	T	L	R	T
11	CHANNEL	1	H1								
12	CHANNEL	2	H2					C1			
13	CHANNEL	3	H3	H4	H5						
14	CHANNEL	4	H6	H7				C3			
15	CHANNEL	5	H8	H9				C4			
16	CHANNEL	6		H10		C2		C5			
17	CHANNEL	7					C6				
18	IMPOUND	1					C7				

AVERAGE ANNUAL SUMMARY FOR WATERSHED(B)

Hillslope	Soil Loss (kg)	Sediment Deposition (kg)	Sediment Yield (kg)
1	2264.2	0.0	2264.2
2	213244.5	39540.5	173704.0
3	886045.9	0.0	886045.9
4	10362.1	0.0	10362.1
5	48889.7	0.0	48889.7
6	329451.1	0.0	329451.1
7	588656.1	0.0	588656.1
8	88289.1	0.0	88289.1
9	107076.8	0.0	107076.8
10	109584.3	37304.3	72280.0

Channels and Impoundments	Sediment Yield (tonne)
Channel 1	13.8
Channel 2	211.8
Channel 3	891.8
Channel 4	296.8
Channel 5	224.4
Channel 6	290.9
Channel 7	372.9
Impoundment 1	35.1

```
99  storms produced  822.90mm. of rainfall
18  events produced  182.92mm. of runoff passing through the watershed outlet

        Delivery From Channel and Impoundment Outlets :
Total sediment discharge from channel outlet       = 372.9
Total sediment discharge from impoundment outlet  =  35.1
Total sediment trapped in the impoundment          = 337.8


95.7
       SUB-WATERSHED(C)  STRUCTURE  INPUT  FILE

Hillslope  Elements : 1-9
                (CONTRIBUTING  ELEMENTS  MATRIX)
                                HILLSLOPE        CHANNEL       IMPOUNDMENT

ELEM.    ELEMENT
 #     FED.    NUM.       L      R     T      L    R    T       L    R    T

 10   CHANNEL    1        H1
 11   CHANNEL    2        H2                  C1
 12   CHANNEL    3        H3                  C2
 13   CHANNEL    4        H4                  C3
 14   CHANNEL    5        H5
 15   CHANNEL    6        H6                  C5
 16   CHANNEL    7        H7                  C6
 17   CHANNEL    8        H8                  C7
 18   CHANNEL    9               C8
 19   CHANNEL    10       H9     C4            C9
 20   CHANNEL    11              C10
 21   IMPOUND    1                    C11

                AVERAGE  ANNUAL  SUMMARY  FOR  WATERSHED(C)

                  Soil           Sediment          Sediment
                  Loss           Deposition        Yield
 Hillslope        (kg)            (kg)              (kg)
 1                4044.9           0.0              4044.9
 2               22713.3           0.0             22713.3
 3               18338.8           0.0             18338.8
 4               39858.6           0.0             39858.6
 5               28587.4           0.0             28587.4
 6               98803.8           0.0             98803.8
 7               20834.5           0.0             20834.5
 8                8990.7           0.0              8990.7
 9               76990.8           0.0             76990.8
```

Channels and Impoundments	Sediment Yield (tonne)
Channel 1	8.6
Channel 2	105.2
Channel 3	233.1
Channel 4	193.1
Channel 5	33.8
Channel 6	267.5
Channel 7	729.3
Channel 8	2717.8
Channel 9	6469.4
hannel 10	904.9
Channel 11	764.0
Impoundment 1	71.9

99 storms produced 822.90mm. of rainfall
18 events produced 181.82mm. of runoff passing through the watershed outlet

Delivery From Channel and Impoundment Outlet :

Total sediment discharge from channel outlet = 764.0 tonnes
Total sediment discharge from impoundment outlet = 71.9 tonnes
Total sediment trapped in the impoundment = 692.1 tonnes

Channels and Impoundments		Sediment Yield (tonne)
Channel	1	8.6
Channel	2	105.2
Channel	3	233.1
Channel	4	193.1
Channel	5	33.8
Channel	6	267.5
Channel	7	729.3
Channel	8	2717.8
Channel	9	6469.4
hannel	10	904.9
Channel	11	764.0
Impoundment	1	71.9

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