ESTIMATION OF WATER LOSSES IN NGACIUMA- KINYARITHA SUB-CATCHMENT, UPPER TANA BASIN, KENYA

BY

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A Thesis Submitted in partial Fulfillment of the Requirements of the Degree of Master of Science in Integrated Watershed Management in the School of Pure and Applied Sciences, Kenyatta University
DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other university.

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DEDICATION

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ABBREVIATIONS AND ACRONYMS

ASK: Agricultural Show of Kenya
CWM: Conjunctive Watershed Management
EMCA: Environmental Management and Co-ordination Authority
DAAD: Deutscher Academischer Austausch Dienst (German Academic Exchange Service).
DSS: Decision Support System
GIS: Geographical Information System
GOK: Government of Kenya
GWP: Global Water Partners
MU: Kenya Methodist University
LZ: Lower Zone
MZ1: Middle Zone 1
MZ2: Middle Zone
NGAKINYA: Ngaciuma-Kinyaritha
NGO: Non-Governmental Organization
NWRMS: National Water Resources Management Strategy
PAM: Polyacrylamide
RUSLE: Revised Universal Soil Erosion Equation
SDR: Sediment Delivery Ratio
SWOT: Strength, Weakness, Opportunities and Threats
Sv: Surface Velocity
USDA: United States Department of Agriculture
UZ1: Upper Zone 1
UZ2: Upper Zone 2
WELB: Water Edge Left Bank
WERB: Water Edge Right Bank
WRMA: Water Resources Management Authority
WRUAs: Water Resource Users Associations
XPAM: Cross-linked, Anionic Polyacrylamide Hydrogel
ABSTRACT

Soil is an important component of a watershed. It is important to understand how soils relate to management, planning and conservation of water resources in the watershed in order to make water availability a reality for both present and future generation. In this regard, there is need to understand soil physical properties together with other components such as biophysical and human environment in order to achieve comprehensive conservation of resources, management and planning of the watershed. Development of soil sampling and analysis programs are crucial for this purposes. It is important in a biologically mega-diverse country that is undergoing rapid human landscape transformation, to understand modes of the water patterns in the sub-catchment. This helps in developing conjunctive water management which controls geomorphology and hydromorphology of Ngaciuma-Kinyaritha sub-catchment. The main objectives of this study were: - (i) To determine selected soil physical properties of the sub-catchment. (ii) To investigate the losses of water due to poor water abstraction and hydro morphology threats of riparian land. (iii) To investigate the water losses in unlined furrow conveyance system in Ngaciuma-Kinyaritha sub-catchment. Soil sampling was done on any observed colour changes on the land surface and at the crest, at the middle of slopes and valleys which was used for soil texture and soil moisture content analysis. Soil texture analysis was done in the laboratory using mechanical machine and sieves as per United States Department of Agriculture (USDA) standards to determine the precise soil texture. Moisture content was determined in the laboratory using oven dry at 105°C for twenty-four hours. Soil profile was measured in situ using survey leveling staff and tape measure. Direct flow measurement was done using current meter and drop rod to ascertain progressive water losses in canals. Further, the overcrowding of water abstraction structures and their sizes relative to the width of river was determined using tape measure and tabulated estimate threat posed on riparian land. The data were analysed using Excel computer package and results tabulated in tables. Strength, weakness, opportunities and threats (SWOT) tool was used in the analysis of riparian land threats in the whole sub-catchment. Correlation was performed to examine relationship between soil texture and water losses in the furrow conveyance system and on soil particles distribution and water losses in the furrow conveyance system. The both test proved that correlation is statistically insignificant. The soil texture in the all zones was found to be loamy sand and sandy loam which have high infiltration rate but poor soil consolidation which are susceptible to erosion. Water losses in furrow conveyance system were very high in all zones which are the main source of emerging water conflicts in the watershed. Riparian land is threatened by high concentration of water abstraction structures which has resulted in over trenching of river banks. Also, riparian was further threatened by shamba system, encroachment of wetland and poor waste management among others. Therefore, there is need for holistic conjugative watershed planning, management and conservation in order to make water availability a reality for intergenerational equity in Ngaciuma-Kinyaritha sub-catchment.
CHAPTER ONE

INTRODUCTION

This chapter presents the background of the study, scope of the study, problem statement and objectives of the study. In addition, research questions, hypotheses, significant and anticipated output, limitations, justification of the study, and finally operations of terms and concepts are described.

1.1 Background to the Study

Soil is an important component of a watershed for perfect management and planning (Kiziltan et al., 2009). Understanding soil physical properties and its interactions with the other components is critical and essential for conservation of resources and management of the watershed. One of the most important soil physical properties is soil texture which is an indicator of the size ranges of sand, silt, and clay particles within a soil. It is used as a descriptor of other soil physical properties such as porosity, saturated hydraulic conductivity, soil metric potential at saturation and pore size distribution index. Analysis of soil texture of Ngaciuma-Kinyaritha sub-catchment assists in understanding the soil consolidation in the watershed for soil erosion conservation and artificial water infiltration management. According to Cosby et al., (1984) other important soil physical properties that are important in the planning and management of a sub-catchment are soil horizon or soil profile and structural size which influence the hydraulic parameters of soils. These properties have great influence on soil water movement and the energy state of water in the soils of a given sub-catchment. Thus, these physical properties will
influence the choice of soil conservation practices on the surface, subsurface and the general hydrological processes in a watershed.

Poor soil conservation practices within a watershed increases surface runoff that results in decreased in base flow of all rivers. This also affects soil erosion, flood magnitudes, channel morphology and sedimentation processes in a watershed. Good soil management of the sub-catchment contributes to groundwater recharge (Lerner et al., 1990). The water runoff in the watershed is determined mainly by soil infiltration rate and rain intensity. There are two main types of recharge; the direct vertical infiltration of precipitation when rain falls on the ground and indirect infiltration by interception of runoff by artificial designed structures. Understanding soil physical properties helps in overall sub-catchment management of soil conservation including artificial infiltration. The factors that influence the amount and type of recharge in any watershed include; precipitation, topography, vegetation, evapotranspiration, topsoil and subsoil types, flow mechanisms in the unsaturated zone and, bedrock geology (Knoop & Walker, 1985). Introducing artificial infiltration in a basin increases ground water recharge, important for conjunctive watershed management, which employs the principle of using surface water when it is plentiful and using groundwater in periods of scarcity (Republic of Kenya, 2005).

Irrigated agriculture is the backbone of Ngaciuma-Kinyarutha sub-catchment and contributes a bigger portion to the economy of majority of riparian users. Of the total available surface water, irrigated agriculture uses the highest amount of water (Oad &
Kullman, 2006). The main mode of water conveyance system in this sub-catchment is the use of furrows, which has resulted in hydro-solidarity conflicts among upstream and downstream users within the watershed (WRMA, 2007). Majority of downstream users has continuously raised alarm that the water scarcity in the watershed is associated with poor furrow conveyance dotted in the sub-catchment. High water infiltration rates in unlined canal, results in excessive seepage, which reduces furrow conveyance efficiency (Lentz et al., 2001). It is, therefore, very important to determine water losses in the main water conveyance furrows in the watershed. The riparian land is an important portion of Ngacima-Kinyaritha sub-catchment in order to retain the norm function of a natural filter of flooding surface water. The deterioration of this thin strip in a watershed is controlled by its soil physical properties and destruction of vegetation cover. According to Lizhu, et al., (2008), the thin strip has been ignored until recently when the structure, composition and functions received some consideration in ecosystem research. Destruction of riparian land in Ngaciuma-Kinyaritha due to land use change poses threats in terms of mass movement, water quality and quantity and also increases loss of water from main water profile (Magner & Brooks, 2008). It’s of great importance to study the extent at which the riparian land has suffered destruction due to various developments and other human activities within the sub-catchment.

1.1.1 Scope of the Study

The study dealt with analysis of soil physical properties within Ngaciuma-Kinyaritha sub-catchment and considers rain water as the only source of water. This helps to develop
a sub-catchment management strategy for planning and conservation of water resources
for inter generational equity. Thus, the study aims at making water available for both
present and future generations as well as ecological water. The study does not deal with
inter basin water into the sub-catchment but takes into considerations all water used from
the basin. The study does not deal with effects of non-bio-degradable materials, such as,
plastics or effects of any construction, such as, roads and buildings on water infiltration
but concentrates on natural movement of water in the soils of Ngaciuma-Kinyaritha sub-
catchment. Soil sampling was done on undisturbed sites in the basin.

1.2 Problem Statement

Data on soil physical properties is lacking for many Kenyan basins. This however, is very
key for the purpose of water conservation, planning and management under continuous
water scarcity conditions even in area of high rainfall like Ngaciuma-Kinyaritha sub-
catchment (DAAD, 2007). This study analysed the soil texture and soil profile in the
sub-catchment, which are the basic soil physical properties that make the basin to act as a
‘pot’ and ‘path’ for hydrological processes. This helps in sustainability of river regime
and groundwater recharge in order to make water availability a reality. According to
DAAD (2007), soil characteristics of a basin determine the infiltration rate and soil
consolidations which are important tools for watershed management, planning and
conservation.

Another area requiring immediate research in the sub-catchment is the Riparian land
which poses high threats due to developments taking place along this vital strip.
According to Magner & Brooks (2008), destruction of this strips results to river bank degradation which results in lowering both water quality and quantity in the sub-catchment. SWOT analysis was used to determine strengths, weakness, opportunities and threats in this vital strip for sustainable water planning and management in this sub-catchment.

The sub-catchment is dotted with many unlined furrows which are used for irrigation. DAAD (2007) and WRMA (2007) note that this mode of irrigation has contributed to high water wastage and has contributed to the growing of conflict among riparian users due to high water losses through seepage but no liable data is available. Therefore, there is a great need for research to be carried to develop a varied data of actual water loss within the furrows conveyance system to ascertain water losses. Water loss without intended purpose contradicts good principles of conjunctive watershed management and contributes to poor hydro-solidarity among upstream and downstream users. This means, downstream users are always in hydro-conflict with upstream users due to very low or no river flow at all, according to (Global Water Partnership (GWP), 2000).

1.2.1 Objectives of the Study

The study aimed at analyzing some physical soil properties that control water movement within the sub-surface deep percolation within the soil matrix. This is geared towards reduction of surface runoff which results in unnecessary water losses like flood flow and sub-catchment erosion.
Specific Objectives

(i) To analyze and examine soil texture, soil moisture content and soil profile physical properties for optimum conjunctive water management in the sub-catchment.

(ii) To investigate factors leading to water losses due to hydro-morphology threats of riparian land in Ngaciuma-Kinyaritha sub-catchment.

(iii) To investigate the water losses in unlined furrow conveyance system in Ngaciuma-Kinyaritha sub-catchment.

1.2.2 Research Questions

(i) How can soil texture and soil profile in Ngaciuma-Kinyaritha sub-catchment be used for optimum conjunctive watershed management, planning and conservation to ensure availability of water?

(ii) How does water abstraction structures and trenching of conveyance system affect riparian land in Ngaciuma–Kinyaritha sub-catchment?

(iii) What is the extent of water loss in the furrow conveyance system in the Ngaciuma–Kinyaritha sub-catchment?

1.2.3 Hypotheses

(i). \( H_0 \): There is no significant relationship between soil texture and water losses in the furrow conveyance system.
(ii). \( H_0: \) There is no significant relationship between soil particles distribution and water losses in furrow conveyance system.

1.3 Significance and Anticipated Output

The research was worth undertaking since it helped in ascertaining some soil physical properties which control the hydromorphologic and geomorphologic processes within the sub-catchment of Ngaciuma-Kinyaritha Rivers. Results emanating from the study will help in management, planning and conservation of the sub-catchment, thus reducing runoff while encouraging infiltration and subsequently deep percolation. This will also allow water temporarily held in the soil to finally replenish the river regime and groundwater storage. From furrow flow measurements results, the massive water losses can be reduced by lining the canals or shifting to alternative piped conveyance system. In addition the study results revealed great need to harmonize systems of water abstraction structures to encourage water containment within the river profile for sustainability flows and at the same time reducing riparian land threats. The data can also be integrated in wider basin database and analyse to derive sustainable management options of the later.

1.4 Limitations of the Study

Water availability in a watershed is governed by diverse soil physical properties which are either natural or artificial. The study was confined only on description of the soil profile, determination of soil texture and soil moisture content in Ngaciuma-Kinyaritha sub-catchment. It did not take into account physical properties such as plastics, road, and
buildings among others that affect water movement. These have been omitted owing partly to financial and time constraints. Despite very many furrows dotted in this sub-catchment, only handful was measurable due to their very low flow. The water flow in furrows was very heterogeneous to have consistent flow measurement for along distances which resulted to only very few points being gauged. But the data collected were sufficient for this study.

1.5 Justification of the Study
Ngaciuma-Kinyaritha (Ngakinya) Water Resources Users Association (WRUAs) is one among other water organizations in Tana River basin. This is necessary because the Tana basin plays an important role in socio-economic activities of riparian users and to all Kenyans in general. Improvement of water resources in this sub-catchment forms an integral part of water availability in the whole Tana basin. This implies vital services such as provision of electricity; clean water and recreation opportunities are realized. In addition, increasing water availability in the basin will result to sustainable livelihood activities such as agriculture, fishing, irrigation, industries and institution developments. Ngakinya WRUAs was, therefore, formed as an avenue for implementation of integrated water resources management as defined by National Water Resources Management Strategy (NWRMS) after water reforms of 2002 (Water Act, 2005: 114). The Kenyan Water Sector Reforms were aimed at developing a sense of ownership of water resources by decentralizing management. The sub-catchment is also the study area of the DAAD Integrated Watershed Management Programme that the author was undertaking. Through
the sub-catchment studies, many avenues of research were opened that are geared towards the diverse holistic water resources management and development.

The study would contribute to other scientific findings on best methods of decentralized water resources management in accordance with Kenyan water reforms of 2002 and with the view of water requirement in vision 2030. Also, the area is located in diverse agro ecological and geographical zones with complex characteristics to study various watershed management, planning and conservation issues. The upper zone is an agricultural area, which receives water through natural rainfall, rainwater harvesting, groundwater abstraction or transboundary water abstraction from other sub-catchments. This comprises the head water region where upstream over abstraction and pollution directly affects water quality and quantity of the sub-catchment. Agricultural zone is followed by the forest area. This is the main source of major tributaries of the sub-catchments (Figure 1.1). This makes it critical to preserve the upper and lower “Imenti” forest for sub-catchment sustainability. The rivers flow in high potential agricultural area with high potential irrigation water demand and ever increasing land use change from rain fed agriculture. The sub-catchment has population density of 360 persons/km² plus municipal council and many upcoming urban centres. This results to high water demand for both domestic and urban purposes. Therefore, the sub-catchment forms an excellent area of study on sustainable watershed management and planning for competing uses and users (DAAD, 2007).
1.6 Operational Terms and Concepts

These are terms and concepts used in the context of this study.

Environmentally Sensitive Zones- Any area where there is a requirement of water for environmentally sensitive purposes.

Final Zone- Any area of the basin where there is no further opportunity for downstream reuse or the end of sub catchment to join bigger catchment.

Hydronomics - Systems of rules that define water management to retain good water quality and quantity in both surface and ground water sources.
Natural Recapture Zone- Area in the basin where surface and subsurface water is naturally captured by river systems networks.

Regulated Zone- Area of the basin where drainage can be regulated.

Stagnation Zone- Isolated area where the drainage capacity is insufficient for the removal of leached salts and excess water.

Source Zone- Area where excess precipitation provides runoff or ground water recharge for down stream.

Terranomics- Systems of rules that define land management and plan for water availability and high production (Onyango et al., 2005).

Conjunctive Watershed Management (CWM) - Use of surface water when it is plentiful and groundwater in times of scarcity (Republic of Kenya, 2005).

Intergeneration Equity- Present and future generation
CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Integrated watershed management is important in both irrigated and rain fed agriculture for reducing poverty through increased agriculture production, enhancing water availability and other resources efficiency (Hertfield et al., 2001). Water use efficiency in a sub-catchment means evapotranspiration is encouraged in all agricultural practices which is controlled by soil texture in the sub catchment (Beare et al., 1994). Soil is the upper layer of the earth crust regulating natural habitants and life sustaining resources such as nutrients which it releases to plants. Soil also filters toxic and non-hazardous compounds through surface adsorption and largely determines the quality of groundwater and terrestrial waters (Kukal et al., 2005). Soil characteristic depends largely on soil physical properties such soil texture, soil structure and soil profile which determines its capability and use in water storage. On contrast water losses in a sub-catchment depend on soil texture, soil profile and method of irrigation adopted (Kukal et al., 2008). In Ngaciuma-Kinyaritha sub-catchment, water consumption is increasing more rapidly than the human population and has raised the socioeconomic and strategic importance of water resources. In order to continuously meet the growing per-capita demand for water, it is important to estimate water losses in both agricultural and water abstraction practices in the sub-catchment (WRMA, 2007). Both land and water rights should encourage land and water conservation in order to maintain the utility, integrity and sustainability of water
quality and quantity. It is also important to analyze the soil texture, soil profile and soil moisture content with controls the hydrological processes in the sub-catchment.

Riparian land in Kenya covers about 3-6% of the land surface and provide many ecological and socio-economic goods and services. These include water supply, food production, construction materials, and products for the cottage industry, tourism and recreation. The ecological services comprise flood control, water recharge and discharge, water filtration, nutrient storage and re-cycling and wildlife habitats. But despite their valuable functions, they are often regarded as “wastelands” and are continually being degraded and lost through conversion for agricultural uses, settlement and industrial development (The ministry of environment, 2004). Sustainable management of riparian land need to takes into account the interaction of the people with the environment and causes of its degradation. Riparian conservation and management must be based on sound scientific principles. It is essential that Ngaciuma-Kinyaritha sub-catchment riparian land to have sound inventory and monitory strategy in order to have effective management. The sub-catchment has suffered degradation induced by pollution, overexploitation and catchment destruction. Degradation of Ngaciuma-Kinyaritha sub-catchment has resulted on the increase of diminishing water resource availability (DAAD 2007). In addition, lack of awareness and appreciation of the values of riparian land in the sub-catchment has contributed to its loss and mismanagement despite the fact that provision of water is a critical component in sustainable development as enshrine in Kenyan vision 2030. The major issues of concern relating to water resources are availability, quality, utilization, shared resources and strategies for harvesting, droughts and floods mitigation.

The design, operation, management and hydraulic evaluation of furrow conveyance irrigation methods depend on the water infiltration properties of the soil (Bali and Wallinder, 1987, Abdelwahab, 2000). This is because infiltration behavior of the soil directly determines the essential variables such as inflow rate, furrow length, application
time, depth of percolation and tail-water run-off in furrow irrigation. Furrow conveyance water system in unlined canal is briefed to be source of water losses and hydro-solidarity conflict in this sub-catchment (WRMA, 2007). Estimation of infiltration rate in the sub-catchment can be obtained by determining the soil texture and relating it to soil profile. Current meter measurement is the best method of estimating water losses in a sub-catchment with diverse soils due to: temporal and spatial variations caused by soil heterogeneity, difference in soil moisture content, compaction, surface crust and cracking depth. The method is also the most suitable technique to duplicate in field conditions while making accurate measurement (Liu, 2006).

Water abstraction has been controlled by the ministry of water development through the district water officer before enactment of water act 2002. Thus, up-bottom approach was used in water allocation and management with very little input of local and interested groups. This resulted to poor and overcrowding of abstraction structures and destruction of vital riparian land. Also illegal abstraction of water has been rampant and enforcement mechanisms poor in the sub-catchment. Water act 2002 allows bottom –up approach with involves riparian water users in decision making. It’s important to evaluate patterns of water abstraction structures in the sub-catchment and the effect of riparian land damage. This helps the community in making valuable decision in harmonization of water abstraction structures and developing of good and equitable water allocation strategies (Republic of Kenya, 2005).

2.2 Conceptual Framework

The study is anchored on hydronomics and terrenomics systems of rules that define holistic integrated watershed management, planning and conservation with linkages to sustainable environmental integrity in Ngaciuma–Kinyathira sub-catchment. This is achieved through development of hydronomics six zones with distinct characteristics which require specific water management to suit each zone based on similar hydrology,
geology and topography. The six zones include: - water sources zone, natural recapture zone, regulated zone, stagnation zone, final zone and environmentally sensitive zones (Molden et al., 2001). Terrenomics focus more on access to water resources by all stakeholders and also conservation and maintenance of riparian land (Malin, 2002). The study uses hydronomics and terrenomics modern integrated watershed management method.

Conceptual framework was developed from Http://waterknowledge.colostate.edu/hydr_img.htm Conceptual framework is used to show various water movements in hydrological cycle (Figure 2.1). The flow diagram figure (2.1) shows various stages of hydro movement within the soil surface and various interventions for sustainable water management. It is adopted and developed to fit various water management, planning and conservation measures within the watershed. The main objective is to minimize surface runoff and direct evaporation while encouraging evapotranspiration which increases food security (Onyango et al., 2005). It also aims at increasing both sub-surface and deep percolation for sustainable wetland and groundwater recharge. This is controlled by soil texture, soil moisture content and the characteristic of soil profile. Deep soils have high soil storage while loosely consolidated soils encourage high rates of infiltration. Soils with high humus clay have high moisture storage capacity which is the available water for plant growth. The various zones and related variable controlling or influencing water movements in a watershed are described below.
2.2.1 Precipitation, Runoff and Infiltration

Precipitation within the sub-catchment is noted as the only source of water that meets the demand of several uses of diverse users. When rain falls, it can either infiltrate into the soil matrix on flows on the land surface and to flood flow. Management of rainfall improves water infiltration but care must be taken to avoid soil saturation which hinders plant growth. Therefore, it is important to determine some soil physical properties that are important to enable development of sustainable conservation structures (Archer, 1996). On other hand, rain water infiltration rate in the sub-catchment needs to be
encouraged in order to have positive rag due to resultant subsurface flows which helps in flood mitigation. The infiltrated water results to higher moisture content which is the water available for plant and vegetation growth and constitutes the required evapotranspiration in water cycle. In addition, some water infiltrate into deep percolation to recharge both ground water storage and ground water flows (Archer, 1996). In addition, runoff water contributes to direct surface evaporation and flood water. Intervention for this water is required in order to reduce soil erosion and general river pollution. This can be achieved through proper water conservation measures including well-designed engineering structures with proper a forestation and re-forestation programme to increase canopy interception and soil cover (Lopes, 1996).

2.2.2 Sub-catchment Water Management Strategies

According to Molden et al., (2001) water issues are site specific hence management strategies should be tailored to suit each zone in a given sub-catchment. There are two basic conditions where the first is that outflow can be re-used and the second is where outflow cannot be re-used. These two conditions are determined by geographical conditions where water in the upper zone finds its way back into the river system in the direction of down stream. This water can be useful or becomes too polluted depending on the nature of land use or effectiveness of natural filtration in the sub-catchment which is governed by conservation measures including riparian land management. The water source is an area where excess precipitation provides runoff or ground water recharge for down stream processes.
In a sub-catchment, water tower is the upper zone that includes which acts as the main source of water bodies. The regulated recapture zone is the area in the sub-catchment where drainage can be regulated, typically regulated capture zones are irrigated areas in the middle zone. If the drainage and groundwater flows cannot be captured, the water will flow away from the sub-catchment contributing to low down stream flows hence water scarcity and hydro conflicts will result. Final use stage is any area of the basin where there is no further opportunity for down stream re-use. This is mainly the lower zone of the sub-catchment and all the water will be drained away and cannot be used. The stagnation zones include all wetlands where drainage is insufficient. They hold water for long time which contributes to both surface water and groundwater recharge. These zones require high level of preservation and conservation in order to maintain sub-catchment water availability and sustainability. The environmentally sensitive zones are the areas which require water for environmentally sensitive purposes including wetlands and the river regime. This means that total flows from the source to the mouth should take into consideration ecological water demand.

2.3 Review of Studies on Soil Physical Properties

Several studies have been carried out on soil physical properties varying in different geographical condition. The main focus in all studies is the use of soil physical properties on diverse scenarios on soil and water management.
2.3.1 Soil Physical Properties in Water Harvesting

Boer (1998) studied soil physical properties in desert micro-catchments of about 125m². The aim was to obtain water balance in terms of runoff, infiltration and crop water requirement. The results of water balance from the micro-catchment was that the soils had average runoff efficiency of 19% and average storage efficiency of 18%. Most of the water was lost on deep percolation due to high infiltration rate of soils. The purpose of the study was to create scenarios for surface water harvesting which needs to consider reduction of water due to infiltration.

2.3.2 Soil Physical Properties for Soil Conservation in Pasture Management

Diego and Guertin (2007) studied soil physical properties to assist in buffer grass pasture management in North America. The buffer grass was used as a means of soil erosion control as well as providing forage for livestock. The soil erosion was estimated using the Revised Universal Soil Erosion equation (RUSLE) created by USDA soil conservation service. This was done at various geographical zones within the catchment (Brooks et al., 1997). According to Morgan (1995) and Renard et al., (1994), soil physical properties such as soil texture, soil permeability and soil structure help in determining factors in RUSLE equation. Soil physical properties are useful for pasture management in controlling overgrazing on lands. Statistical analyses demonstrated that buffer grass erosion rates are positively correlated with plant densities, soil micro relief and erosion features values, while relationships with soil crust development and pasture management index are negatives. The study only addressed erosion pattern under different vegetation
covers among different physical characteristics. The study in Ngaciuma - Kinyaritha sub-catchment dealt with analysis of soil texture, soil moisture content and soil profile to help in overall planning, management and conservation of the watershed to improve on water availability.

2.3.3 Soil Physical Properties in Water Sedimentation Analysis

Mutua and Andreas (2006) studied Masinga sub-catchment which covers an area of 6255 km² and located between latitudes 0°7’ and 1°15’ south and between longitudes 36°33’ and 37°46’. They used Sediment Delivery Ratio (SDR) based on length and relief to establish soil erosion and sediment yield from catchment. An accurate prediction of SDR is important in controlling sediments for sustainable natural resources which should be correlated to other soil physical properties. They used the existing data of average hydrological active soil profile depth, textual description of the soil, average water holding capacity, saturated soil hydraulic conductivity and rainfall distribution and intensity. The results were that sediment delivery ratio was affected by many highly variable physical characteristics of a catchment. They included the drainage area, slope, relief-length ratio, runoff-rainfall factors, land use/land cover and soil properties. The gap identified is that soil texture and soil moisture content were determined from first principles by sampling soils. Then soil samples were tested in the laboratory and by using USDA texture triangle, tables for soil physical analysis and soil texture classification tables, the overall sub-catchment soil texture was determined. Soil profile was done by direct field measurement along various sites.
2.3.4 Crop Production in Montimorillonite Clay

Asnakew (2003) analyzed soil physical properties on montimorillonite clay soils of Ethiopia. The montimorrillonite clay soil covers twenty-four percent of Ethiopia highlands that are important for crop growth. These soils contain more than forty-percent clay particles in the upper horizons and very low sand particle fraction in soil texture composition and they develops cracks when expanding and contracting with changes with moisture content. In the dry season, surface horizons are characterized by huge strongly developed prismatic structures separated from each other by deep vertical cracks. It was found that these soils have high water storage capacity in the root zones but very low permeability or infiltration rates as lower layer had very little water as compared to top layer. Poor drainage results to water logging which requires artificial drainage or water pans to store water for future use. These soils cannot be used in improving groundwater recharge due to poor infiltration rates. The study lacked management tools for catchments sustainability as it concentrated on poor crop performance in clay soils. This study is to fill the gap.

2.3.5 Canadian System of Soil Classification

Podwirny (2006) studied Canadian system of soil conservation based on soil profile characteristics. The study focused on O- horizon and B- horizon which are essential strata for agricultural purposes. He did not take into consideration the total horizons characteristics important for general water management. This study finds alternative secondary source of information to develop the overall characteristics of soil profile for
Ngaciuma- Kinyaritha sub-catchment. Thus, the study aims to establish the overall storage potential in the sub-catchment to increase water availability.

2.3.6 Seepage in Furrow Water System

Lentz (2007) studied the use of cross-linked, anionic, polyacrylamide hydrogel (XPAM), a water-absorbing which is a swell polymer solid, for reducing infiltration and seepage losses through soil in the Pacific Northwest USA. Abdel, (2007) and Mohamed, (2000) studied water losses in dry cracked clay soil to determine water loss in ‘Rahand’ irrigation project using Kostiakov equation. Infiltration rate was high at the start but decreases significantly with application of XPAM. The study in Ngaciuma-Kinyaritha sub-catchment used *in situ* measurement of flows using current meter to determine actual losses within the canal.

2.3.7 Effects on Riparian Land Destruction

Lizhu (2008) studied the relationships between land use in a watershed and habitat quality, and also relation between watershed land use and biotic integrity in 134 sites on 103 streams located throughout Wisconsin. Magner (2008), concentrated on the study of comparing of the catchments sizes of rivers, streams, ponds, ditches and lakes and effect of riparian land destruction to aquatic biodiversity in an agricultural landscape. This study used SWOT model to determine riparian land destruction and it effects on water availability in the sub-catchment (Appendix ix).
<table>
<thead>
<tr>
<th>No</th>
<th>Author and year</th>
<th>Summary of findings</th>
<th>Gaps identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boer (1998)</td>
<td>Studied soil physical properties in micro catchments of about 125 m² aiming at runoff water harvesting.</td>
<td>Determination of infiltration rate of soils in the sub-catchment for accurate planning and management of hydrological process.</td>
</tr>
<tr>
<td></td>
<td>Asnakew (2003)</td>
<td>Analysis soil physical properties on montmorillonitic clay soils of Ethiopia. The soils have very low permeability hence very low infiltration as lower layer had very little water as compared to top layer.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Renard, 1994; Morgan, 1998.</td>
<td>Soil physical properties is useful for pasture management in controlling overgrazing on lands under varying soil physical properties.</td>
<td>Direct analyses of soil texture to meet overall management of crop and water in the sub-catchment.</td>
</tr>
<tr>
<td>3</td>
<td>Saenyi (2002) and Mutua (2006).</td>
<td>Studied ‘Masinga’ sub-catchment using sediment delivery ratio based on length and relief to establish soil erosion and sediment yield from catchments with key limitations to achieving sustainable land use and maintaining water quality in the water body.</td>
<td>Evaluation of soil texture, soil moisture content which acts as descriptor of other vital soil physical properties to define susceptibility of sub-catchment erosion for holistic management of sustainable environment.</td>
</tr>
<tr>
<td>4</td>
<td>Podwirny (2006)</td>
<td>Studied Canadian System of Soil conservation using soil profile using O-horizon and B-horizon</td>
<td>Determination of the total depth in the sub-catchment horizons using both field measurements and secondary data available to estimate water storage potential.</td>
</tr>
<tr>
<td>5</td>
<td>Lentz (2007)</td>
<td>Used the cross-linked of anionic, polyacrylamide hydrogel (XPAM), and Water-absorbing, swell able polymer solid, for reducing infiltration and seepage losses through soil.</td>
<td>Direct determination of inflows and outflows to estimate in situ water losses in unlined furrow conveyance system.</td>
</tr>
</tbody>
</table>
CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This section introduces the study area, describes data collection methods, sources of information, sampling techniques, data computations and finally data analysis. There are various types of primary data collected which includes oven dry moisture content measurement, mechanical shaker soil texture measurement, soil profile measurement, current meter furrow flow measurement, and finally dimensions and concentrations of water abstraction structures. According Boorman et al., (1995), these soil physical properties control hydrological processes of a watershed. The secondary data was obtained from borehole geophysics to get total sub-catchment soil profile important for total ground water storage (Vrabra & Hirata, 2006). Data computations and analysis involve the following techniques; soil sampling, laboratory data analysis, SWOT analysis, direct flow gauging in furrow water conveyance, and finally use of excel computer packages to generate figures and tables.

3.2 Study Area

The study area (figure 3.1) is located in upper Tana basin. The sub-catchment has three zones: the upper zone, middle zone and lower zones following agro-ecological zones as shown in Appendix III. Ngaciuma-Kinyaritha has numerous wetlands and springs which are unevenly distributions in all zones. Understanding soil physical properties, furrow
water management and riparian land preservation and conservation is the core value in overall management of water among diverse conflicting uses and users.

Figure 3.1: Map of the Study Area of Ngaciuma–Kinyaritha Sub-Catchment
Source: Adapted from Survey Kenya Map, Sheet No. NA-37-14, (1996)
Ngaciuma-Kinyaritha is a small catchment of 167 km² in Upper Tana catchment in Eastern Province of Kenya. It has a population of about 36,000 people, representing a density of approximately 360 persons/km² (Republic of Kenya, 1999). The main part of the catchment is located within Meru Municipality, and is geographically bound by latitudes 37.5° E and 37.75° E and longitudes 0.04°N and 0.15° N (DAAD 2007). All the rivers originate from slopes of Mt Kenya Forest and flow eastwards to join Kathita, river. The major rivers that drain in the study area are Ngaciuma and Kinyaritha which is a tributary of the larger Ngaciuma-Kinyaritha River. Annual rainfall ranges from 1100mm to 1300mm and annual temperatures from 10°C to 30°C (DAAD 2007). The Upper and Lower Imenti forest covers about 50 km². The catchment can be divided into three zones for management purposes (Appendix III). Lower zone 30 km², Middle 47 km² and upper 90 km² (DAAD 2007).

3.3 Regional Background to the Study

3.3.1 Physiographic and Drainage Topography

The altitude of Ngaciuma – Kinyaritha ranges from 1120 to 2600m above the sea level and slopes eastwards. The upper zone has undulating terrain while the middle and lower zones are highly dissected by stream and there is a rugged structure. The main rivers in the sub-catchment are Kinyaritha River and Ngaciuma River. The watershed has several springs and wetlands concentrated in the middle and lower zones (Figure 1.1). The upper zone has a crater called Lake Nkunga which is fed by three springs and has subsurface outlets but has no significant permanent surface drainage (DAAD, 2007).
3.3.2 Climate

The climate condition of the sub-catchment ranges from humid to semi-humid with bimodal rainfall (DAAD, 2007). The long rain comes during the month of March to May and short rain starts from October to December.

3.3.3 Vegetations and Land use

Ngaciuma-Kinyaritha sub-catchment has diverse vegetation cover and land use from upper zone through middle zone and finally lower zone. There is a natural forest with indigenous trees which stretches from Upper Imenti to Lower Imenti. The forest is being deprived due to lumbering, shamba system, over exploiting for firewood and overgrazing by both domestic and wild animals. The sub-catchment has high potential for rain fed agriculture, as most areas receive over 1000 mm of rain annually. Surface water is not evenly distributed in space and time and has given rise to water use conflicts. However, most farmers’ abstract river water for commercial and subsistence irrigated agriculture (DAAD, 2007).

3.4 Geology and Soils

The geology of the catchment comprises of basaltic volcanic rocks with volcanic tuffs and pyroclasts of Nyambene eruption of the pleistocene age. The soils are young geologically created by eroding glacier while soils in the forested parts are millions of years old formed through fluvial erosion. Young soils are generally less than 10,000
years old and with more being created by the glaciers continuously (Baker, 1967). Therefore, these soils are dynamic in formation and as they age they become finer. The major soils are Nitisols with some Gleysols in the wetlands and Andosols on hill slopes (DAAD, 2007).

3.5 Data Collection Techniques

3.5.1 Primary Sampling Design

Ngaciuma-Kinyaritha sub-catchment was divided into three main zones, namely; the upper zone, the middle zone and the lower zone as per agro ecological zones as shown in Appendix III. To take care of two main steep slopes that drain to Ngaciuma River and Kinyaritha River, the upper zone and middle zone was further sub-divided into two zones. This helped to increase on accuracy and precision of soil sampling in the watershed. This gave five sampling zones which were: upper zone 1 (UZ1), upper zone 2 (UZ2), middle zone 1 (MZ1), middle zone 2 (MZ2) and lower zone as shown in Figure 3.2. Transverse soil sampling method was adapted in all randomly predetermined sites (Figure 3.2) in accordance to Soil Survey Staff (1999).
Figure 3.2: Sampling Zones and Sites in Ngaciuma-Kinyaritha Sub-catchment
3.5.2 Soil Sampling

The sampling was transversely in each sampling zone on predetermined points marked in the sub-catchments (Soil Survey Staff, 1999). This was done using visual observations on any colour changes of the soil, top of hill, at the middle of slopes and valley bottom with accordance to International Organization for Standardization (ISO) 11277. In areas with homogenous soils, six samples per 40 acres were collected at 0.6m soil deep. According to Ferguson et al., (2007), 0.6 m soil deep is the depth important for crop root growth. It is the zone which controls infiltration and flood flow. This was done in all zones in areas that were not disturbed. The Plate 3.1 below shows the start of soil sampling at the mouth of Kinyartha River as it joins Kathita River. There were 50 sites sampled in the lower zone as shown in appendix IV.

Plate 3.1: Start of Soil sampling at the Mouth of Kinyartha River Lower Zone  
(Position: 00° 03"N, 37°45"E, Author 5-4-2010)
Sampling in middle zone 1 started in Chiru market and transverse through Kinyaritha River up to point where it meets Ngaciuma River. Plate 3.2 shows soil sampling at Njuri Ncheke headquarters, which is a historical uncultivated land within the watershed. In total, 54 sites were sampled in this zone as shown in Appendix IV.

Plate 3.2: Soil Sampling at Chiru Middle Zone 1

(Position: 00° 07'N, 37° 42'E, Author, 7-4-2010)

Sampling in MZ2 started where the two rivers, Ngaciuma and Kinyaritha meets, across the opposite bank of Ngaciuma River and ends at Makutano shopping centre in Meru town. The area was characterized by many hills which necessitated 60 sampling sites in order to capture all soil details as shown in Appendix IV.
Soil sampling in UZ1 started at Chiru market, through Meru college of Agriculture and Technology compound opposite Njuri Ncheke headquarters (Plate 3.3). The sampling continued upward within Kinyaritha River, Kioru River, Gieto River, passed KEMU University, through Upper Imenti forest and finally finished at Kirua mission hospital passing Lake Nkunga wetland (Plate 3.2). The zone was very homogenous and gently sloping which resulted to only 50 sites sampled as shown in Appendix IV.

Plate 3.3: Soil Sampling at Meru College (Upper Zone 1)
(Position: 00° 07"N, 37° 4"E, Author, 6-4-2010)
UZ 2 soil sampling started at KEMU University and continued within Ngaciuma basin and transverse through the source of Ngaciuma River, Kagwakuguru River, Meru ASK show ground, across Upper Imenti forest and finally ending at Kirua market. Due to varying soil colour and topographical conditions, 55 sites were sampled. All the soil sampled in each zone was thoroughly mixed using sacks as shown in Plates 3.4 and 5 kg of soil in each zone sampled in sampling bags for analysis.

Plate 3.4: Field Soil mixing in the sub-Catchment
(10-4-2010)

A composite soil sample of 4 kg was obtained from each zone and taken to the laboratory for particle size distribution. Particle size distribution was determined using the
mechanical shaker machine (Marshall, 1947). In addition soil sample of 1kg was obtained from each zone was taken to the laboratory for soil moisture content determination. Soils were immediately taken in the laboratory and analysed. In the laboratory moisture content was determined using oven dry method. Using the soil texture in the sub-catchment, the strength, weakness, opportunities and threats for water use sustainability were determined.

3.5.3 Soil Profile Description

Soil profile on the roadside cuttings was described according to standard procedures (FAO, 1990). Parameter observed in each horizon was depths due to colour variation. Visible depths were measured using 6m survey leveling staff which was placed vertical to the roadside cutting. The stepladder was also placed parallel to the survey staff and the depth of horizons measured. This was repeated in various parts within the sub-catchment as shown in Appendix I. Plate 3.5 shows a road cut section along newly constructed Meru – Mikinduri tarmac road. The height of road cut section at this point was 7.67m and has three distinct horizons namely; O –Horizon, A-Horizon and B-Horizon. Generally, all road cuttings in the area have shown distinctively two or three horizons.
Plate 3.5: Soil Profile Cutting on Meru - Mikinduri Road.
(Position: 00° 03'N, 37° 44'E, 5-4-2010)

Along Meru – Kieru – Maua road, the scenario was the same. Plate 3.6 shows the road cut section at KEMU University. Here, the section which measured 4.2m and revealed the first-three horizons. The same arrangement of horizons was visible in many other parts along the road.
Plate 3.6: Soil Profile at KEMU University in Meru Kieru Road.

Position: 00°04"N, 37°39"E, (6-4-2010)

Measurements of soil profile along Meru – Naari-Nanyuki road revealed that the three horizons were distinctively visible. The upper horizon was covered with dense vegetation. Plate 3.7 was taken Near Meru Technical Institute where a cross section
cutting of three visible horizons was 5.4m. In many parts of the road, soil profile depth was between 2m to 3.5m.

Plate 3.7: Soil Profile at Gitoro on Meru- Naari Nanyuki Road.

Position: 00°04'N, 37°37'E, (7-4-2010)

3.5.4 Water Flow Measurements in Furrows

The stream flow measurements in all furrows was done using current meter and applying wadding method as shown in Plate 3.8 for Ngaciuma furrow, in the lower zone. The tape measure was anchored across furrow banks and the width divided into equal intervals where measurements were taken. The drop rod was used to measure the depth of water each point and the propeller fixed at 0.6 of the depth from the surface of water. The propeller was then fixed in the current meter and switched on. The number of propeller revolution for 50 seconds was recorded. The cross sectional area, velocity and
discharge at each point was determined and tabulated. The summation of each gave the total cross section area, mean velocity and total discharge at each point.

Plate 3.8: Furrow Gauging at Lower Zone Women Furrow

Position: 00°04’’N, 37°42’’E, (3-4-2010)

The following equations were used for computations:

\[ Q = A \cdot V \]  \quad \text{whereas,} \\

\[ A = (0.5 \left( f_1 + f_2 \right) + f_3 + \ldots + f_{n-1}) \cdot d; \quad \text{Equation 1} \]

\[ V = \frac{v_1 + v_2 + \ldots + v_n}{n}; \quad \text{Equation 2} \]

\[ Q = \text{discharge, } A = \text{cross section area, } f = \text{depth of the canal, } d = \text{distance between two successive depth,} \]

(Hansen, 1979).
This was repeated at intervals of 50m and where 0.6 of depth was not achievable, surface velocities was measured as illustrated in Plate 3.9 for Kinyartha furrow in the middle zone 1.

Plate 3.9: Furrow Gauging at Kinyartha Furrow in Middle Zone
Position: 00° 05"N, 37° 41"E, (3-4-2010)

The study noted that most of the furrows were in upper zone 1, middle zone 1 and lower zone but there were no furrows in upper zone 2 and middle zone 2 due to steep slopes these two zones.
3.5.5 Riparian Land Threats

The diversions of surface abstraction from main river profile were measured using linear tape measure at various abstraction points. The dimensions of abstraction structures and the difference in length of successive structures was measured and tabulated to estimate their effect on riparian land. Plate 3.10 illustrates a typical abstraction method used near the source of Ngaciuma River. The effect of land tenure system which is individual ownership has major setback on the riparian land since land ownership is up to the middle of river channel. The farming activities have resulted into massive destruction of riparian land for agricultural purposes. In all areas, the distances between the river profile and the spread of riparian land and finally the start of agricultural land was determined.

Plate 3.10: Water Abstraction through Diversion Furrow

(Position: 00°06'N, 37°40'E, 6-4-2010)
3.5.6 SWOT- Analysis on Riparian Land Threats

SWOT analysis was used in the study to evaluate the challenges and opportunities in the planning, management and conservation of Ngaciuma-Kinyaritha riparian land. SWOT is the acronym for Strengths, Weakness, Opportunities and Threats that a community faces towards realizing its goals (Boseman & Phatok 1989; Khayesi, 1998). Strengths are the internal capacities of an organization’s objectives in a reactive and competitive environment. Weaknesses are internal disadvantages that restrict the attainment of community objectives. Opportunities are external factors that enable communities to achieve its objective. Threats are external factors that might cause harm to the community. Strengths and weakness can be monitored and evaluated by the community while opportunities and threats cannot be controlled by the community. The latter endangers the capacity of the community to achieve its objectives.

SWOT analysis is very useful in the study of endangered riparian land of Ngaciuma-Kinyaritha sub-catchment. It uses systems approach whereby the riparian land in a watershed institution structures are considered as endogenous factors and are the source of strength or weakness for sustainable planning, management and conservation of water resource. Political and socio-economic institutions along with physical environment components are considered as exogenous factors to basin management. Thus, they are sources of opportunities and treats. Therefore, SWOT analysis was important to be adopted in this study. Decision-making was based on the SWOT analytical matrix in Table 3.1.
Table 3.1 Strengths, Weakness, Opportunities and Treats (SWOT) Analytical

<table>
<thead>
<tr>
<th>Exogenous Factors</th>
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<th>Treats (T)</th>
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<tr>
<td>Strength (S)</td>
<td>(SO)</td>
<td>(ST)</td>
</tr>
<tr>
<td>Weakness (W)</td>
<td>(WO)</td>
<td>(WT)</td>
</tr>
</tbody>
</table>

Source: Boseman and Phatok (1989)

3.6 Secondary Data

To obtain overall geology of the sub-catchment, borehole completion geophysics or geological records was sought from the Ministry of Water and Irrigation, (WRMA) regional office (Appendix V). Plate 3.11 shows one of the boreholes in the upper zone 2.

The soil profile is very deep with parent rock at 38m.

Plate 3.11: Completed Borehole in Upper Zone 2

(Position: 00° 06”N, 37°36”E, (6-4-2010)
3.7 Laboratory Data Collection

3.7.1 Soil Moisture Content

Twenty cans, four for each of the five zones were weighed when empty labelled and then weight recorded. The cans were filled with moist soil sample from each zone, then weighed and recorded. The cans were oven dried at 105°C for twenty-four hours and final weight recorded. This was to ensure all moisture within the soil pore spaces is completely evaporated from each soil sample without change of soil physical properties. The percentage moisture content for each zone was computed and tabulated.

3.7.2 Soil Texture

Soil texture was analysed using mechanical shaker machine as shown in Plate 3.12. The six sieves, lid, and the bottom were weighed recorded and arranged as per USDA standards to determine the precise soil type (Marshall 1947). The machine was switched on until all soil passed through the required sieve. The soil in each sieve was weighed and recorded for three trails. The results were analysed using excel computer package and the results tabulated for the five zones. According to Marshall (1947) the over all soil texture for each zone was analysed using USDA soil triangle plus soil size distribution tables (Appendix II).
Plate 3.12: Mechanical Shaker Machine

(Courtesy of Geography Department of Kenyatta University, (2010)
4.1 Overview

This chapter outlines the results obtained from field observations and measurements, laboratory analysis and the statistical analysis of the data. The chapter deals with results of the measurements and analysis of soil texture, soil moisture content, soil profile, furrow water gauging and SWOT analysis of riparian land. The chapter discusses some geomorphologic aspects like soil texture, soil moisture content and soil profile, which controls the hydro-morphologic process through artificial interventions or natural water mobility. In addition, geomorphologic effects on furrow method of irrigation within Ngaciuma–Kinyaritha Sub-catchment are also explained. Riparian land degradation by water abstracting structures and agricultural practices is also outlined in this chapter. The chapter finally concludes by explaining the purpose and goals achieved through excellent planning, management, and conservation of the sub-catchment for sustainable development through collaborative and participatory approach of all riparian users and other interested groups.

4.2 Results of Soil Texture, Soil Moisture Content and Soil Profile Analysis

4.2.1 Soil Texture and Particle Distribution Analysis

This section gives results of laboratory analysis of soil texture and particle distribution for the three zones within the sub-catchment. Table 4.1 shows results of soil texture of
all the zones in the sub-catchment. Three trials of sieve analysis were done and average percentage particle size distribution computed (appendix VI).

Table 4.1: Soil Texture in the Sub-catchment

<table>
<thead>
<tr>
<th>Percentage Soil Particles Type</th>
<th>Soil particle type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Zone Zone 2 Zone 1 Zone 2 Zone 1</td>
<td></td>
</tr>
<tr>
<td>29.44 28.53 30.32 32.74 23.08 Very coarse sand</td>
<td></td>
</tr>
<tr>
<td>29.70 31.30 23.83 28.62 20.42 Coarse sand</td>
<td></td>
</tr>
<tr>
<td>15.57 14.88 12.31 13.45 21.85 Medium sand</td>
<td></td>
</tr>
<tr>
<td>10.91 10.17 10.94 9.05 14.43 Fine/very fine sand</td>
<td></td>
</tr>
<tr>
<td>3.95 4.67 7.14 5.69 7.07 Silt</td>
<td></td>
</tr>
<tr>
<td>10.42 10.45 15.45 10.46 13.25 Clay</td>
<td></td>
</tr>
<tr>
<td>100.00 100.00 100.00 100.00 100.00 Total</td>
<td></td>
</tr>
</tbody>
</table>

a) Comparison of Soil Texture Distribution within the Sub-catchment

The soil texture which is the ratio of sand, silt and clay of the five zones is illustrated in table 4.2. In all zones, sand particles are dominant and silt is very low, the clay soil increases depending on closeness of the zone from the forest and its general terrain.

Table 4.2: Soil Particle Distribution in the Sub-catchment

<table>
<thead>
<tr>
<th>Soil Particle Type</th>
<th>Lower Zone Zone 2 Zone 1 Zone 2 Zone 1</th>
<th>Upper Zone Zone 2 Zone 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>85.63 84.88 77.41</td>
<td>83.86 79.68</td>
</tr>
<tr>
<td>Silt</td>
<td>3.95 4.67 7.14</td>
<td>5.69 7.07</td>
</tr>
<tr>
<td>Clay</td>
<td>10.42 10.45 15.45</td>
<td>10.46 13.25</td>
</tr>
<tr>
<td>Total</td>
<td>100.00 100.00 100.00</td>
<td>100.00 100.00</td>
</tr>
</tbody>
</table>

The USDA soil triangle in Figure 4.1 is used to determine the textual class of soil samples in the five zones. This is obtained by first determining the percentage distribution of sand, silt and clay, and then you move from each percentage point parallel to light or dotted lines. Where the three lines meet, you read soil type enclosed by dark lines.
c) Comparison of Soil Texture Characteristics within the Sub-catchment

From the result, the soil texture of Ngaciuma-Kinyaritha sub-catchment is loamy sand and sandy loam with other soil physical properties summarized in Table 4.3.

Table 4.3: Overall sub-Catchment Soil Texture

<table>
<thead>
<tr>
<th>Class</th>
<th>Silt %</th>
<th>Sand %</th>
<th>Clay%</th>
<th>n%</th>
<th>Log Ks inches h⁻¹</th>
<th>log ψ cm</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loamy sand</td>
<td>12</td>
<td>82</td>
<td>6</td>
<td>38.6</td>
<td>0.371</td>
<td>0.806</td>
<td>3.864</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>32</td>
<td>58</td>
<td>10</td>
<td>41.6</td>
<td>0.003</td>
<td>1.120</td>
<td>3.864</td>
</tr>
</tbody>
</table>

N, porosity, pore size distribution index, Ks saturated hydraulic conductivity and ψ soil matrix potential at saturation. Values are obtained through univariate regression equations of Cosby et al., (1984). Note that 1 inch h⁻¹=0.30cm h⁻¹
e) Sub-catchment Soil Texture

Although the general soil texture in this basin is the same, it has different soil characteristics depending on clay content, silt content and distribution of various sand particles in each zone (Appendix IV). The lower zone has clay content above 10.42% but silt content very low. In sand distribution, the very coarse sand is high and significantly decreases to very fine sand. The middle zone 2 has clay content of about 10.45% and silt of about 4.67%. The coarse sand is high followed by very coarse sand, medium sand and finally fine /very fine sand. The middle zone 1 has clay content of 15.45% and silt of 7.14%. On the other hand it has high very coarse sand and coarse sand. The medium sand and fine/ very fine sand are 12.31% and 10.96% respectively. The soil texture in upper zone 2 has clay content of 10.46% and silt of about 5.69%. The sand distribution shows high very coarse sand followed by coarse sand and low medium sand and fine/very fine sand. Upper zone 1 has clay content of about 13.25% and very little silt of about 7.07%. The zone has average very coarse sand, coarse sand, medium sand and fine /very fine sand (Table 4.1).

4.2.2 Results of Moisture Content within the Various Zones

The moisture content of all five zones is almost equal and the difference arises due to different soil texture in various zones of the sub-catchment. Tables 4.4 illustrate soil moisture content in all zones. Lower zone passes through the lower Imenti forest shown in figure 1.1. The zone is characterized by very few flat areas. Other areas are moderately sloping. The zone receives eroded humus clay deposit from the forest which makes it have high moisture content (Appendix IV). The zone has the average moisture content of 28.70%. MZ2 is within Ngaciuma river basin and characterized by hilly ground. The
zone is highly eroded with very low moisture content. MZ1 is along Kinyaritha River basin. The zone is gently sloping near upper Imanti forest and flat along lower imenti forest (figure 1.1). The area receives eroded deposits from UZ1, UZ2 and MZ2 with are rich with humus from the forest making it to have high moisture content. The average moisture content is 33.84%. UZ2 is on the upper part of Kinyaritha basin. The zone has few hills and characterized by moderate soil erosion. The zone transverse along upper Imenti forest hence has high potential of receiving eroded humus. The zone has relatively high moisture content of 30.4%.

Table 4.4: Sub-catchment Water Moisture Content

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Weight of empty moisture can (g)</th>
<th>Weight of moisture can plus wet soil (g)</th>
<th>Weight of moisture can plus dry soil (g)</th>
<th>Percentage moisture content (%)</th>
<th>Average percentage moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Zone</td>
<td>52.20</td>
<td>143.50</td>
<td>122.70</td>
<td>29.50</td>
<td>28.90</td>
</tr>
<tr>
<td></td>
<td>36.20</td>
<td>135.40</td>
<td>113.00</td>
<td>29.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>46.30</td>
<td>142.50</td>
<td>120.60</td>
<td>29.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>49.20</td>
<td>146.70</td>
<td>125.70</td>
<td>27.45</td>
<td></td>
</tr>
<tr>
<td>Middle Zone 2</td>
<td>40.10</td>
<td>149.10</td>
<td>128.40</td>
<td>23.44</td>
<td>23.87</td>
</tr>
<tr>
<td></td>
<td>49.70</td>
<td>160.20</td>
<td>139.40</td>
<td>23.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>54.70</td>
<td>155.30</td>
<td>134.70</td>
<td>25.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60.40</td>
<td>153.10</td>
<td>135.70</td>
<td>23.11</td>
<td></td>
</tr>
<tr>
<td>Middle Zone 1</td>
<td>51.60</td>
<td>143.10</td>
<td>120.90</td>
<td>32.03</td>
<td>33.84</td>
</tr>
<tr>
<td></td>
<td>51.50</td>
<td>146.00</td>
<td>121.50</td>
<td>35.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40.40</td>
<td>138.80</td>
<td>113.30</td>
<td>35.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>63.80</td>
<td>161.90</td>
<td>137.50</td>
<td>33.11</td>
<td></td>
</tr>
<tr>
<td>Upper Zone 2</td>
<td>39.60</td>
<td>152.30</td>
<td>126.00</td>
<td>30.44</td>
<td>30.40</td>
</tr>
<tr>
<td></td>
<td>44.80</td>
<td>147.80</td>
<td>125.60</td>
<td>27.48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>54.00</td>
<td>161.00</td>
<td>135.30</td>
<td>31.61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34.50</td>
<td>152.20</td>
<td>123.50</td>
<td>32.25</td>
<td></td>
</tr>
<tr>
<td>Upper Zone 1</td>
<td>44.20</td>
<td>148.80</td>
<td>123.70</td>
<td>31.07</td>
<td>33.13</td>
</tr>
<tr>
<td></td>
<td>53.20</td>
<td>157.80</td>
<td>130.40</td>
<td>35.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51.60</td>
<td>158.90</td>
<td>132.10</td>
<td>33.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45.70</td>
<td>160.60</td>
<td>132.30</td>
<td>32.68</td>
<td></td>
</tr>
</tbody>
</table>
4.2.3 Results of Soil Profile in the Sub-catchment

Soil profile characteristics within the sub-catchment are outlined in table 4.5. The plate 3.5, plate 3.6 and plate 3.7 shows the visible horizons from road cutting. From these plates, O-horizon, A-horizon and B-horizon were visible. The O-horizon had two distinct \( O_1 \) and \( O_2 \) horizons. \( O_1 \)-horizon was composed of undecomposed litter from weed and agricultural residue. \( O_2 \)-horizon was composed partly with decomposed debris. The depth of O-horizon was 0.1m. Below O-horizon followed A-horizon which depth of between 0.1m to 3m deep. Below A-horizon was B-horizon with span depth of between 3m to 9m deep. The C-horizon and R-horizon were not visible from road side cutting. The depth of these two horizons was obtained from secondary data of complete boreholes records in the sub-catchment. The depth of C-horizon was between 9m and 38m while the R-horizon was below 38m deep.

From roadside cutting measurements and boreholes completion records, the sub-catchment has very deep soils which are 38 m deep and the water table is at 82 m (Appendix V). The soil profile in the sub-catchment shows homogeneous connection between successive horizons which is important for hydromorphology process. According to Buol et al., (2003) and FAO (1998) the O-horizon contains undecomposed litter and partly decomposed debris which acts as permeable sponge to receive rain water. This zone is connected to A-horizon or zone of eluviations which is rich in humus accumulation. This is the zone of strongest leaching of mineral through transitional zone to B-horizon. The B-horizon or illuviation zone is then connected to C-horizon which is
made up of unconsolidated rock. The C-horizon is connected to R–horizon or consolidated rock which is 38.8m deep in Ngaciuma-Kinyaritha sub-catchment according to geophysics report, the water table is about is at 82m (Appendix V). Therefore the sub-catchment has very high water storage capacity.

Table 4.5 Sub-Catchment Soil Profile

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Type</th>
<th>Description</th>
<th>Layer thickness (m)</th>
<th>Geophysics/geological formation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-Horizon</td>
<td>O₁</td>
<td>Undecomposed litter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone of plant residues</td>
<td>O₂</td>
<td>Party decomposed debris</td>
<td>0-0.1</td>
<td>top soil</td>
<td>In situ field measurement</td>
</tr>
<tr>
<td>A-Horizon</td>
<td>A</td>
<td>Zone of humus accumulation and strong leaching</td>
<td>0.1-3</td>
<td>Top soil and sub-soil</td>
<td>In situ field measurement</td>
</tr>
<tr>
<td>Zone of illumination</td>
<td>B</td>
<td>Zone of maximum illuviation</td>
<td>3-9</td>
<td>-Sub soil</td>
<td>-Field measurement -Borehole completion records</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Fresh volcanic</td>
<td></td>
</tr>
<tr>
<td>C-horizon</td>
<td>C</td>
<td>Unconsolidated rock</td>
<td>9-38</td>
<td>Fresh volcanic/highly weathered volcanic</td>
<td>-Field measurement -Borehole completion records</td>
</tr>
<tr>
<td>Zone of parent material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-horizon</td>
<td>R</td>
<td>Consolidated rock</td>
<td>Below 38</td>
<td>Weathered volcanic</td>
<td>Borehole completion records</td>
</tr>
<tr>
<td>layer of bed rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Field Survey 2010
4.3 Results of Riparian Land Abstraction Structures Effects.

Table 4.6 shows various intake structure dimensions in comparison to width of main river channel in different points in the basin. In various zones the intakes are concentrated in one place. This has resulted to massive destruction of riparian land and high water conflict due to water losses in infiltration and evaporation. The water is lost because all intakes are comparative more wide than river profile and soils have high infiltration rate.

Table 4.6 Riparian Land Abstraction Effects

<table>
<thead>
<tr>
<th>RIVER</th>
<th>River Width At Intake (M)</th>
<th>Intake Dimensions</th>
<th>Distance Between Intakes</th>
<th>Furrow Diversion Length From Main River (m)</th>
<th>Geographical Location (G.P.S Reading)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinyaritha River (At Source)</td>
<td>3.0</td>
<td>6 6 1.5 15</td>
<td>4 0° 06&quot; 37° 43&quot;</td>
<td>Land use up to the river</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kioru (Ngaciuma tributary)</td>
<td>2.0</td>
<td>6 6 1.5 30</td>
<td>6 0° 06&quot; 37° 41&quot;</td>
<td>Source at wet land which is damaged</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gieto (Ngaciuma tributary)</td>
<td>2.5</td>
<td>2 3.5 1.7 10</td>
<td>5 0° 06&quot; 37° 40&quot;</td>
<td>Multi-intakes at one point. Land use up to the River.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ngaciuma River (At Source)</td>
<td>3.0</td>
<td>2.7 3.5 1.7 8</td>
<td>10 0° 04&quot; 37° 38&quot;</td>
<td>Very close intakes and wide diversion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kagwakugeru River (Ngaciuma tributary)</td>
<td>1.5</td>
<td>1.5 2 1.3 10</td>
<td>2 0° 04&quot; 37° 37&quot;</td>
<td>Meru technical source near show ground.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ngaciuma river (Kienderu)</td>
<td>3.5</td>
<td>5 3.5 1.6 10</td>
<td>8 0° 05° 37° 40&quot;</td>
<td>Multi-Intake, more than 30 abstractions.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Field Survey 2010
4.3.1 Results of Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

The section presents the strengths, weaknesses, opportunities and threats on the riparian land in the sub-catchment. Various strengths, weaknesses, opportunities and threats in the sub-catchment were highlighted by evaluating the challenges and opportunities of riparian land for sustainable water resources conservation and management. This was done through identification of the internal structure and external context of a watershed in terms of endogenous and exogenous influences and recorded as in table 4.7.

<table>
<thead>
<tr>
<th>Exogenous factors</th>
<th>Opportunities (O)</th>
<th>Threats (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endogenous Factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength (S)</td>
<td>O₁, O₂, O₃, O₄, O₅, O₆</td>
<td>T₁, T₂, T₃, T₄, T₅, T₆</td>
</tr>
<tr>
<td>S₁, S₂, S₃, S₄, S₅, S₆, S₇, S₈</td>
<td>For effective planning, management and conservation of riparian land strengths (S₁, S₂, S₃, S₄, S₅, S₆, S₇, S₈) needs to be maximized to take advantages of the opportunities (O₁, O₂, O₃, O₄, O₅, O₆).</td>
<td>There is need to maximize on strengths (S₁, S₂, S₃, S₄, S₅, S₆, S₇, S₈) in the watershed and reduce impacts of threats (T₁, T₂, T₃, T₄, T₅, T₆).</td>
</tr>
<tr>
<td>Weakness (W)</td>
<td>W₁, W₂, W₃, W₄, W₅, W₆, W₇</td>
<td>For sustainable watershed and functionable riparian land in this sub-catchment, there is need to minimize weakness and mitigate threats.</td>
</tr>
</tbody>
</table>

Source: Field Survey 2010

The following are key strengths, weaknesses, opportunities and threats (SWOT) matrix on riparian land.
a) Strength

S₁: Adequate rainfall which is well distributed throughout the year.

S₂: Soils with high infiltration rates.

S₃: Deep soil profile giving rise to high storage.

S₄: Fertile soil for excellent vegetation growth.

S₅: Local involved in water allocation through WRUA.

S₆: The sub-catchment has established proactive Ngaciuma-Kinyaritha Water Resources Users Association (WRUAs).

S₇: Existence of WRMA in Meru town for technical advice.

S₈: Existence of active management committee.

b) O: Opportunities

O₁: Presence of Imenti forest, which acts as water tower and recharges all rivers.

O₂: Many springs, which run throughout the year.

O₃: Constructed electrical fence around the forest.

O₄: Availability of diverse sector technical officers in the sub-catchment.

O₅: Good rural electrification programme.

O₆: The sub-catchment is a pilot area for European Union Water Facility Project.

c) Weaknesses

W₁: Poor soil consolidation.

W₂: Land use/cover change.
W₃: Poor design of water abstraction structures.
W₄: Illegal water abstraction.
W₅: Over crowding of abstraction structures.
W₆: Poor water allocation and water use control.
W₇: Over trenching of riparian land for water conveyance systems.

d) Threats
T₁: Poor waste disposal from urban centres.
T₂: Soil erosion in the area.
T₃: Wetland encroachment for both agriculture and building construction purposes.
T₄: Illegal logging of trees from the riparian land strip.
T₅: Chemical pollution.
T₆: Lack of support from local community

4.4 Results of Furrow Flow Current Meter Gauging

a) Lower Zone Furrow Gauging
Tables 4.8-4.9-4.10, 4.11 and 4.12 show results from furrow gauging stations. Table 4.8 shows the first gauging station results which had average discharge $Q₁$ of 0.1028 m³/s or 8881.9 m³/day.

This was the first gauging point in the furrow. The furrow was wide and deep which allowed for more gauging points.
Table 4.8: Lower Zone Women Group Furrow Point I Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth M</th>
<th>Width M</th>
<th>Area M²</th>
<th>Discharge m³/s</th>
<th>Velocity</th>
<th>Time(s)</th>
<th>Revs</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean in vertical</td>
<td>At point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.0033</td>
<td>0.163</td>
<td>0.163</td>
<td>50</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.80</td>
<td>0.20</td>
<td>0.10</td>
<td>0.020</td>
<td>0.0087</td>
<td>0.378</td>
<td>0.378</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>0.90</td>
<td>0.23</td>
<td>0.10</td>
<td>0.023</td>
<td>0.0183</td>
<td>0.703</td>
<td>0.703</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.00</td>
<td>0.26</td>
<td>0.10</td>
<td>0.026</td>
<td>0.0228</td>
<td>0.816</td>
<td>0.816</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.10</td>
<td>0.28</td>
<td>0.10</td>
<td>0.028</td>
<td>0.0214</td>
<td>0.713</td>
<td>0.713</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.20</td>
<td>0.30</td>
<td>0.10</td>
<td>0.030</td>
<td>0.0154</td>
<td>0.551</td>
<td>0.551</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.30</td>
<td>0.28</td>
<td>0.10</td>
<td>0.028</td>
<td>0.0129</td>
<td>0.476</td>
<td>0.476</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.40</td>
<td>0.15</td>
<td>0.15</td>
<td>0.027</td>
<td>0.0194</td>
<td>0.476</td>
<td>0.476</td>
<td>50</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.60</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.182</td>
<td></td>
<td>0.1028</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Discharge Q₁ = 0.1028 m³/s OR 8881.9 m³/d

River: Ngaciuma  Zone: Lower  Date: 3 April 2010
Method Used: WADDING POINT I
Meter Make: BRAYSTOKER  W.D.D No: BMF001  Prop No: 375
Time of Starting: 11.50 HRS  Time of Finishing: 12.16 HRS  Initial point: W.E.R.B
G.P.S Position 00° 04”N, 37° 42”E
Area: 0.182 m². Mean Velocity: 0.565 m/s. Discharge 0.1028 m³/s

Table 4.9 shows third point results of gauging which is 50m from point 1. It was gauged after

Table 4.9: Lower Zone Women Group Furrow Point III Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth m</th>
<th>Width m</th>
<th>Area m²</th>
<th>Discharge m³/s</th>
<th>Velocity</th>
<th>Time(s)</th>
<th>Revs</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean in vertical</td>
<td>At point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.0023</td>
<td>0.233</td>
<td>0.233</td>
<td>50</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.80</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0063</td>
<td>0.487</td>
<td>0.487</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>0.90</td>
<td>0.13</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0051</td>
<td>0.362</td>
<td>0.362</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.00</td>
<td>0.14</td>
<td>0.10</td>
<td>0.014</td>
<td>0.0058</td>
<td>0.416</td>
<td>0.416</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.10</td>
<td>0.14</td>
<td>0.10</td>
<td>0.014</td>
<td>0.0044</td>
<td>0.311</td>
<td>0.311</td>
<td>50</td>
<td>0.6</td>
</tr>
<tr>
<td>1.20</td>
<td>0.05</td>
<td>0.065</td>
<td>0.024</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.30</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Discharge Q₂ = 0.024 m³/s OR 2073.6 m³/d
River: Ngaciuma. Zone: Lower Date: 3 April 2010
Method Used: WADDING POINT III (MIDDLE Main branch)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
G.P.S Position 00° 04” N, 37° 42”E
Area: 0.065 m2. Mean Velocity: 0.369 m/s. Discharge 0.024 m³/s

Table 4.10 shows second gauging point results 100m from first gauging with average discharge Q3 of 0.017 m³/s or 1468.8 m³/day in the main furrow. The discharge decline even more.

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth</th>
<th>Width</th>
<th>Area</th>
<th>Discharge</th>
<th>Velocity</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.0013</td>
<td>0.217</td>
<td>0.217</td>
<td>50</td>
<td>39</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.90</td>
<td>0.06</td>
<td>0.10</td>
<td>0.06</td>
<td>0.0013</td>
<td>0.217</td>
<td>0.217</td>
<td>50</td>
<td>59</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.00</td>
<td>0.07</td>
<td>0.10</td>
<td>0.07</td>
<td>0.0027</td>
<td>0.379</td>
<td>0.379</td>
<td>50</td>
<td>69</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.10</td>
<td>0.08</td>
<td>0.10</td>
<td>0.08</td>
<td>0.0033</td>
<td>0.411</td>
<td>0.411</td>
<td>50</td>
<td>75</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.20</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.0024</td>
<td>0.244</td>
<td>0.244</td>
<td>50</td>
<td>44</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.30</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.0045</td>
<td>0.454</td>
<td>0.454</td>
<td>50</td>
<td>83</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.40</td>
<td>0.06</td>
<td>0.10</td>
<td>0.06</td>
<td>0.0024</td>
<td>0.395</td>
<td>0.395</td>
<td>72</td>
<td>0.6</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.50</td>
<td>0</td>
<td>0.05</td>
<td></td>
<td>0</td>
<td>0.217</td>
<td>0.217</td>
<td>50</td>
<td></td>
<td>W.E.R.B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average Discharge Q3</td>
<td>0.017 m³/s OR 1468.8 m³/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

River: Ngaciuma. Zone: Lower Date: 3 April 2010
Method Used: WADDING POINT II (LOWER)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
G.P.S Position 00° 04” N, 37° 42”E
Area: 0.05 m². Mean Velocity: 0.369 m/s. Discharge 0.017 m³/s

The furrow has two branches and Table 4.11 shows fourth gauging point 50 m from point I. The average discharge Q4 was 0.0467 m³/s or 4034.88 m³/day.
Table 4.11: Lower Zone Women Group Furrow Point IV Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth</th>
<th>Width</th>
<th>Area</th>
<th>Discharge</th>
<th>Velocity (Mean in vertical)</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.05</td>
<td></td>
<td>0.010</td>
<td>0.0023</td>
<td>0.233</td>
<td>50</td>
<td>42</td>
<td>0.6</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.80</td>
<td>0.10</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0063</td>
<td>0.487</td>
<td>50</td>
<td>89</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td>0.13</td>
<td>0.10</td>
<td>0.026</td>
<td>0.0183</td>
<td>0.703</td>
<td>50</td>
<td>129</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.26</td>
<td>0.10</td>
<td>0.028</td>
<td>0.0154</td>
<td>0.551</td>
<td>50</td>
<td>101</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>0.28</td>
<td>0.10</td>
<td>0.014</td>
<td>0.0044</td>
<td>0.311</td>
<td>50</td>
<td>57</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.20</td>
<td>0.14</td>
<td>0.10</td>
<td>0.008</td>
<td>0.0012</td>
<td>0.225</td>
<td>50</td>
<td></td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.30</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>W.E.L.B</td>
</tr>
</tbody>
</table>

Average Discharge $Q_4$ = 0.0467 m$^3$/s OR 4034.88 m$^3$/d

River: Ngaciuma. Zone: Lower Date: 3 April 2010
Method Used: WADDING POINT IV (MIDDLE Second branch)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
G.P.S Position 00° 04"N, 37° 42"E
Area: 0.063 m$^2$. Mean Velocity: 0.513 m/s. Discharge 0.031 m$^3$/s.

Table 4.12 shows the fifth gauged point results and the last point that could be gauged. The average discharge $Q_5$ was 0.0334 m$^3$/s or 28885.76 m$^3$/day.

Table 4.12: Lower Zone Women Group Furrow Point V Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth</th>
<th>Width</th>
<th>Area</th>
<th>Discharge</th>
<th>Velocity (Mean in vertical)</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0023</td>
<td>0.233</td>
<td>50</td>
<td>42</td>
<td>0.6</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.90</td>
<td>0.23</td>
<td>0.10</td>
<td>0.023</td>
<td>0.0087</td>
<td>0.378</td>
<td>50</td>
<td>69</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.28</td>
<td>0.10</td>
<td>0.028</td>
<td>0.0154</td>
<td>0.551</td>
<td>50</td>
<td>101</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>0.14</td>
<td>0.10</td>
<td>0.014</td>
<td>0.0058</td>
<td>0.416</td>
<td>50</td>
<td>76</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.20</td>
<td>0.08</td>
<td>0.10</td>
<td>0.008</td>
<td>0.0012</td>
<td>0.225</td>
<td>50</td>
<td>42</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1.30</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>W.E.L.B</td>
</tr>
</tbody>
</table>

Average Discharge $Q_5$ = 0.0334 m$^3$/s OR 2885.76 m$^3$/d

River: Ngaciuma. Zone: Lower Date: 3 April 2010
Method Used: WADDING POINT V (MIDDLE Second branch)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
G.P.S Position: 00° 04"N, 37° 42"E
Area: 0.065 m². Mean Velocity: 0.369 m/s. Discharge 0.024 m³/s

1. First Discharge Drop = \((Q_1 - (Q_2 + Q_4))/Q_1\)*100
\[ = ((8881.90 - (2073.60 + 4034.88))/8881.9) * 100 \]
\[ = 31.23\% \]

2. Mainline Drop = \((Q_2 - Q_3)/Q_2\)*100
\[ = ((2073.6 - 1468.8)/2073.6)*100 \]
\[ = 29.17\% \]

3. Branch line Drop = \((Q_4 - Q_5)/Q_4\)*100
\[ = ((4034.88 - 2885.76)/4034.88)*100 \]
\[ = 28.48\% \]
Average = 29.63

b) Middle Zone 1 Furrow Gauging

Kinyaritha furrow is the largest furrow in middle zone where current meter can be used. Tables 4.14 - 4.15, 4.16 and 4.17 gives results of total furrow discharge at various points in the middle zone 1.

Table 4.13 shows the first gauged results at Kinyaritha furrow with average discharge \(Q_1\) of 0.087 m³/s or 7516.8 m³/day.

Table 4.13: Middle Zone 1 Kinyaritha Furrow Point I Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth</th>
<th>Width</th>
<th>Area</th>
<th>Discharge</th>
<th>Velocity</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.R.B</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.16</td>
<td>0.20</td>
<td>0.032</td>
<td>0.0099</td>
<td>0.308</td>
<td>0.308</td>
<td>50</td>
<td>56</td>
<td>0.6</td>
</tr>
<tr>
<td>1.20</td>
<td>0.23</td>
<td>0.20</td>
<td>0.046</td>
<td>0.0240</td>
<td>0.514</td>
<td>0.514</td>
<td>50</td>
<td>94</td>
<td>0.6</td>
</tr>
<tr>
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<td>0.20</td>
<td>0.048</td>
<td>0.0250</td>
<td>0.541</td>
<td>0.541</td>
<td>50</td>
<td>99</td>
<td>0.6</td>
</tr>
<tr>
<td>1.60</td>
<td>0.24</td>
<td>0.20</td>
<td>0.048</td>
<td>0.0214</td>
<td>0.465</td>
<td>0.465</td>
<td>50</td>
<td>85</td>
<td>0.6</td>
</tr>
<tr>
<td>1.80</td>
<td>0.16</td>
<td>0.20</td>
<td>0.024</td>
<td>0.0070</td>
<td>0.290</td>
<td>0.290</td>
<td>50</td>
<td>62 sv</td>
<td></td>
</tr>
<tr>
<td>1.90</td>
<td>0.16</td>
<td>0.20</td>
<td>0.024</td>
<td>0.0070</td>
<td>0.290</td>
<td>0.290</td>
<td>50</td>
<td>62 sv</td>
<td>W.E.I.B</td>
</tr>
</tbody>
</table>

Average Discharge \(Q_1\) 0.087 M³/s OR 7516.8 M³/day

River: Kinyaritha Furrow. Zone: Middle 1 Date: 3 April 2010
Method Used: WADDING POINT I (Upstream)
Table 4.14 shows second gauged point which was water flowing back to the river due to poor flow controls. The average discharge $Q_2$ was 0.0458 m$^3$/s or 3957.1 m$^3$/day.

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth</th>
<th>Width</th>
<th>Area</th>
<th>Discharge</th>
<th>Velocity</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.0023</td>
<td>0.233</td>
<td>0.233</td>
<td>50</td>
<td>42</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.80</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0063</td>
<td>0.487</td>
<td>0.487</td>
<td>50</td>
<td>89</td>
<td>0.6</td>
</tr>
<tr>
<td>0.90</td>
<td>0.13</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0087</td>
<td>0.378</td>
<td>0.378</td>
<td>50</td>
<td>69</td>
<td>0.6</td>
</tr>
<tr>
<td>1.00</td>
<td>0.23</td>
<td>0.10</td>
<td>0.023</td>
<td>0.0154</td>
<td>0.551</td>
<td>0.551</td>
<td>50</td>
<td>101</td>
<td>0.6</td>
</tr>
<tr>
<td>1.20</td>
<td>0.28</td>
<td>0.10</td>
<td>0.028</td>
<td>0.0087</td>
<td>0.378</td>
<td>0.378</td>
<td>50</td>
<td>69</td>
<td>0.6</td>
</tr>
<tr>
<td>1.30</td>
<td>0.23</td>
<td>0.10</td>
<td>0.023</td>
<td>0.0044</td>
<td>0.311</td>
<td>0.311</td>
<td>50</td>
<td>57</td>
<td>0.6</td>
</tr>
<tr>
<td>1.50</td>
<td>0.14</td>
<td>0.10</td>
<td>0.014</td>
<td>0.0087</td>
<td>0.378</td>
<td>0.378</td>
<td>50</td>
<td>69</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Average Discharge $Q_2$ = 0.0458 m$^3$/s OR 3957.1 m$^3$/day

Table 4.15 shows a third gauging result which was 50 m from gauging point I. The average discharge $Q_3$ was 0.0143 m$^3$/s or 1235.5 m$^3$/day.
### Table 4.15: Middle Zone I Kinyaritha Furrow Point III Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Discharge (m³/s)</th>
<th>Velocity Mean in vertical</th>
<th>Velocity At point</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.00</td>
<td>0.17</td>
<td>0.20</td>
<td>0.034</td>
<td>0.0038</td>
<td>0.111</td>
<td>0.130</td>
<td>50</td>
<td>23</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.20</td>
<td>0.19</td>
<td>0.20</td>
<td>0.038</td>
<td>0.0053</td>
<td>0.139</td>
<td>0.163</td>
<td>50</td>
<td>29</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.40</td>
<td>0.20</td>
<td>0.20</td>
<td>0.040</td>
<td>0.0044</td>
<td>0.111</td>
<td>0.130</td>
<td>50</td>
<td>23</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.60</td>
<td>0.10</td>
<td>0.15</td>
<td>0.015</td>
<td>0.0008</td>
<td>0.056</td>
<td></td>
<td></td>
<td></td>
<td>sv</td>
<td>½ of above</td>
</tr>
<tr>
<td>1.70</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.127</td>
<td>0.0143</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Discharge Q₃ = 0.0143 m³/s or 1235.5 m³/d

River: Kinyaritha Furrow. Zone: Middle Date: 3 April 2010
Method Used: WADDING POINT III (Midstream)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
G.P.S Position: 00° 05"N, 37° 42"E
Area: 0.127 m². Mean Velocity: 0.113 m/s. Discharge 0.0143 m³/s

Table 4.6 shows gauging results at 100m from point I which had average discharge Q₄ of 0.010 m³/s or 864.0 m³/day.

### Table 4.16 Middle Zone I Kinyaritha Furrow Point IV Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Discharge (m³/s)</th>
<th>Velocity Mean in vertical</th>
<th>Velocity At point</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
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<tbody>
<tr>
<td>1.00</td>
<td>0.13</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0035</td>
<td>0.271</td>
<td>0.319</td>
<td>50</td>
<td>58</td>
<td>sv</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.10</td>
<td>0.14</td>
<td>0.10</td>
<td>0.014</td>
<td>0.0028</td>
<td>0.198</td>
<td>0.233</td>
<td>50</td>
<td>42</td>
<td>sv</td>
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<td>0.13</td>
<td>0.10</td>
<td>0.013</td>
<td>0.0026</td>
<td>0.198</td>
<td>0.233</td>
<td>50</td>
<td>42</td>
<td>sv</td>
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</tr>
<tr>
<td>1.40</td>
<td>0.13</td>
<td>0.15</td>
<td>0.020</td>
<td>0.0012</td>
<td>0.060</td>
<td>0.071</td>
<td>50</td>
<td>12</td>
<td>sv</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.60</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Discharge Q₄ = 0.010 m³/s or 864.0 m³/d

River: Kinyaritha. Zone: Middle Date: 3 April 2010
Method Used: WADDING POINT IV (Downstream)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
Time of Starting: 14.56 HRS. Time of Finishing: 15.03 HRS. Initial point: W.E.L.B
G.P.S Position: 00° 05"N, 37° 42"E
1. Flight drop
   \[ ((Q_1 - (Q_2 + Q_3)) / Q_1) \times 100 \]
   \[ = ((7516.8 - (3957.1 + 1235.5)) / 7516.8) \times 100 \]
   \[ = 30.92\% \]

2. Second drop
   \[ = ((Q_3 - Q_4) / Q_3) \times 100 \]
   \[ = ((1235.5 - 864.0) / 1235.5) \times 100 \]
   \[ = 30.06\% \]

3. Average Drop
   \[ = 30.49\% \]

c) Upper Zone 1 Furrow Gauging

Tables 4.18 and 4.19 show results from two furrow gauging stations. Table 4.60 shows gauging result at point I at muthomi furrow UZ2 which had average discharge \( Q_1 \) of 0.006 m\(^3\)/s or 518.4 m\(^3\)/d.

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth</th>
<th>Width</th>
<th>Area</th>
<th>Discharge</th>
<th>Velocity Mean in vertical</th>
<th>Velocity at point</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.0006</td>
<td>0.074</td>
<td>0.087</td>
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<td>15</td>
<td>sv</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.10</td>
<td>0.08</td>
<td>0.10</td>
<td>0.008</td>
<td>0.0012</td>
<td>0.129</td>
<td>0.152</td>
<td>50</td>
<td>27</td>
<td>sv</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.20</td>
<td>0.09</td>
<td>0.10</td>
<td>0.009</td>
<td>0.0013</td>
<td>0.133</td>
<td>0.157</td>
<td>50</td>
<td>28</td>
<td>sv</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.30</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0020</td>
<td>0.184</td>
<td>0.217</td>
<td>50</td>
<td>39</td>
<td>sv</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.40</td>
<td>0.11</td>
<td>0.10</td>
<td>0.011</td>
<td>0.0009</td>
<td>0.074</td>
<td>0.087</td>
<td>50</td>
<td>15</td>
<td>sv</td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.50</td>
<td>0.12</td>
<td>0.10</td>
<td>0.012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.60</td>
<td>0.17</td>
<td></td>
<td></td>
<td>0.005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.R.B</td>
</tr>
</tbody>
</table>

Average Discharge \( Q_1 \): 0.006 m\(^3\)/s OR 518.4 m\(^3\)/d

River: Kinyaritha (Muthomi Furrow). Zone: Upper Date: 4 April 2010
Method Used: WADDING POINT 1 (Upper)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
Time of Starting: 10.30HRS Time of Finishing: 10.50 HRS. Initial point: W.E.R.B
G.P.S Position 00°07'00" N37°41'41"E
Area: 0.005 m\(^2\). Mean Velocity: 0.12 m/s. Discharge 0.006 m\(^3\)/s

Table 4.18 shows gauging results at point II 50 m from point I which had average discharge \( Q_2 \) of 0.0038 m\(^3\)/s or 328.2 m\(^3\)/day showing major drop.
### Table 4.18: Upper Zone I Muthomi Furrow Point II Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Discharge (m³/s)</th>
<th>Velocity Mean in vertical (m/s)</th>
<th>Velocity At point (m/s)</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface (cm)</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>0.90</td>
<td>0.08</td>
<td>0.10</td>
<td>0.008</td>
<td>0.0020</td>
<td>0.248</td>
<td>0.292</td>
<td>50</td>
<td>53</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.08</td>
<td>0.10</td>
<td>0.008</td>
<td>0.0012</td>
<td>0.225</td>
<td>0.265</td>
<td>50</td>
<td>48</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.L.B</td>
</tr>
</tbody>
</table>

Average Discharge $Q_2 = 0.0038$ m³/s or 328.2 m³/d

River: Kinyaritha (Muthomi Furrow). Zone: Upper Date: 4 April 2010
Method Used: WADDING POINT II (LOWER)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
Time of Starting: 10.30HRS Time of Finishing: 10.50 HRS. Initial point: W.E.R.B
G.P.S Position 00° 07′N, 37° 41′E
Area: 0.016 m². Mean Velocity: 0.238 m/s. Discharge 0.0038 m³/s

Drop of flow = \( \frac{(Q_1 - Q_2)}{Q_1} \times 100 \)

\[ = \frac{(518.4 - 328.2)}{518.4} \times 100 \]

\[ = 36.69\% \]

#### d) Upper Zone 1 Gleysols Furrow Gauging

Tables 4.19 and 4.20 show results from furrow gauging stations in Gieto wetland.

Table 4.62 shows gauging result at Gieto furrow within Gieto wetland. The average discharge $Q_1$ at point I was 0.0026 m³/s or 224.66 m³/day.

### Table 4.19: Upper Zone I Gleysols Furrow Point I Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Discharge (m³/s)</th>
<th>Velocity Mean in vertical (m/s)</th>
<th>Velocity At point (m/s)</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface (cm)</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.90</td>
<td>0.05</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.L.B</td>
</tr>
<tr>
<td>1.00</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0012</td>
<td>0.120</td>
<td>0.141</td>
<td>50</td>
<td>25</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0014</td>
<td>0.139</td>
<td>0.163</td>
<td>50</td>
<td>29</td>
<td>sv</td>
<td></td>
</tr>
<tr>
<td>1.20</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W.E.R.B</td>
</tr>
</tbody>
</table>

TOTAL 0.020 0.0026

Average Discharge $Q_1 = 0.0026$ m³/s or 224.66 m³/day

River: Gieto. Zone: Upper Date: 4 April 2010
Method Used: WADDING POINT I (Upstream)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
Time of Starting: 13.00HRS. Time of Finishing: 1307 HRS. Initial point: W.E.R.B
G.P.S Position 00° 06"N, 37° 42"E
Area: 0.020 m². Mean Velocity: 0.130m/s. Discharge 0.026m³

Table 4.20 shows gauging result at point II 50m from point II which had average discharge $Q_2$ of 0.0026m³/s or 181.44m³/day.

Table 4.20: Upper Zone I Gleysols Furrow Point II Gauging

<table>
<thead>
<tr>
<th>Distance from initial point</th>
<th>Depth (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Discharge (m³/s)</th>
<th>Velocity Mean in vertical</th>
<th>Velocity At point</th>
<th>Time (s)</th>
<th>Revs</th>
<th>Depth of observation from surface</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.90</td>
<td>0.05</td>
<td></td>
<td>0.010</td>
<td>0.0014</td>
<td>0.143</td>
<td>0.168</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>W.E.R.B</td>
</tr>
<tr>
<td>1.00</td>
<td>0.10</td>
<td>0.10</td>
<td>0.010</td>
<td>0.0007</td>
<td>0.139</td>
<td>0.093</td>
<td>50</td>
<td>16</td>
<td>50</td>
<td>sv</td>
</tr>
<tr>
<td>1.10</td>
<td>0.09</td>
<td>0.10</td>
<td>0.009</td>
<td>0.0007</td>
<td>0.139</td>
<td>0.093</td>
<td>50</td>
<td>16</td>
<td>50</td>
<td>No Flow</td>
</tr>
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<td>0.10</td>
<td>0.009</td>
<td>0.0007</td>
<td>0.139</td>
<td>0.093</td>
<td>50</td>
<td>16</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>1.30</td>
<td>0.05</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Average Discharge $Q_2$ = 0.0026 m³/s OR 181.44 m³/d

River: Gieto. Zone: Upper Date: 4 April 2010
Method Used: WADDING POINT II (Downstream)
Meter Make: BRAYSTOKE W.D.D No: BMF 001 Prop No: 375
Time of Starting: 15.07HRS. Time of Finishing: 15.13HRS. Initial point: W.E.R.B
G.P.S Position 00° 06”N, 37° 42”E
Area: 0.020 m². Mean Velocity: 0.130 m/s. Discharge 0.026 m³/s

Discharge Drop = $\frac{(Q1-Q2)}{Q1} \times 100$

$= \frac{(224.66 - 181.44)}{224.66} \times 100$

$= 19.34\%$

e) Sub-catchment Annual Rainfall

The sub-catchment receives high rainfall throughout the year. Table 4.21 and Figure 4.2 show average annual rainfall for Meru forest station. It represents rainfall during short rains and long rains and the total annual rainfall.
Table 4.21: Annual Rainfall for Meru Forest Station

<table>
<thead>
<tr>
<th>Year</th>
<th>March (mm)</th>
<th>April (mm)</th>
<th>May (mm)</th>
<th>Total (mm)</th>
<th>October (mm)</th>
<th>November (mm)</th>
<th>December (mm)</th>
<th>Total (mm)</th>
<th>Total Annual Rainfall (mm)</th>
</tr>
</thead>
<tbody>
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<td>87.6</td>
<td>417.2</td>
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<td>610.4</td>
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<td>237.8</td>
<td>132.3</td>
<td>463.6</td>
<td>1074.0</td>
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<tr>
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<td>64.0</td>
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<td>93.3</td>
<td>367.1</td>
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<td>187.1</td>
<td>29.4</td>
<td>218.7</td>
<td>585.8</td>
</tr>
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<td>399.4</td>
<td>103.6</td>
<td>572.4</td>
<td>250.2</td>
<td>288.4</td>
<td>283.5</td>
<td>822.1</td>
<td>1394.5</td>
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<td>47.1</td>
<td>308.2</td>
<td>272.5</td>
<td>399.2</td>
<td>307.6</td>
<td>979.3</td>
<td>1287.5</td>
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<td>393.9</td>
<td>250.4</td>
<td>376.9</td>
<td>300.4</td>
<td>627.3</td>
<td>1021.2</td>
</tr>
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<td>129.3</td>
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<td>154.2</td>
<td>200.6</td>
<td>234.5</td>
<td>589.3</td>
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<td>223.3</td>
<td>423.6</td>
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<td>494.4</td>
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<td>135.1</td>
<td>561.0</td>
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<td>271.6</td>
<td>810.1</td>
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</tr>
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<td>36.5</td>
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<td>388.4</td>
<td>90.6</td>
<td>304.3</td>
<td>48.2</td>
<td>443.1</td>
<td>831.5</td>
</tr>
<tr>
<td>1997</td>
<td>97.8</td>
<td>414.0</td>
<td>70.2</td>
<td>582.0</td>
<td>50.6</td>
<td>232.5</td>
<td>23.0</td>
<td>306.1</td>
<td>888.1</td>
</tr>
<tr>
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<td>115.5</td>
<td>121.8</td>
<td>67.6</td>
<td>304.9</td>
<td>61.7</td>
<td>378.8</td>
<td>225.9</td>
<td>666.4</td>
<td>971.3</td>
</tr>
<tr>
<td>2000</td>
<td>7.2</td>
<td>90.2</td>
<td>23.4</td>
<td>120.8</td>
<td>49.0</td>
<td>241.6</td>
<td>142.4</td>
<td>433.0</td>
<td>553.8</td>
</tr>
<tr>
<td>2001</td>
<td>154.4</td>
<td>228.8</td>
<td>25.5</td>
<td>408.7</td>
<td>30.9</td>
<td>524.7</td>
<td>65.2</td>
<td>620.8</td>
<td>1029.5</td>
</tr>
<tr>
<td>2002</td>
<td>206.4</td>
<td>540.9</td>
<td>103.6</td>
<td>859.9</td>
<td>434.9</td>
<td>226.1</td>
<td>208.6</td>
<td>869.6</td>
<td>1720.5</td>
</tr>
<tr>
<td>2003</td>
<td>58.1</td>
<td>481.3</td>
<td>65.4</td>
<td>604.8</td>
<td>389.3</td>
<td>337.5</td>
<td>123.1</td>
<td>849.9</td>
<td>1454.7</td>
</tr>
<tr>
<td>2004</td>
<td>44.3</td>
<td>242.6</td>
<td>97.7</td>
<td>384.6</td>
<td>317.0</td>
<td>338.2</td>
<td>177.2</td>
<td>832.4</td>
<td>1217.0</td>
</tr>
<tr>
<td>2005</td>
<td>22.4</td>
<td>155.8</td>
<td>182.1</td>
<td>360.3</td>
<td>139.0</td>
<td>232.8</td>
<td>38.2</td>
<td>410.0</td>
<td>770.3</td>
</tr>
<tr>
<td>2006</td>
<td>33.8</td>
<td>292.9</td>
<td>125.9</td>
<td>452.6</td>
<td>298.5</td>
<td>477.1</td>
<td>273.3</td>
<td>1048.9</td>
<td>1501.5</td>
</tr>
<tr>
<td>2007</td>
<td>111.0</td>
<td>190.8</td>
<td>197.3</td>
<td>469.1</td>
<td>304.1</td>
<td>205.8</td>
<td>110.7</td>
<td>620.5</td>
<td>1089.6</td>
</tr>
<tr>
<td>2008</td>
<td>62.5</td>
<td>201.2</td>
<td>8.7</td>
<td>272.4</td>
<td>289.9</td>
<td>91.6</td>
<td>40.0</td>
<td>421.5</td>
<td>693.9</td>
</tr>
</tbody>
</table>
Figure 4.2: Annual Rainfall in Meru Forest Station (1986-2008)

4.5 Results on Hypotheses testing

4.5.1 Correlation of Soil Texture and Furrow Conveyance Water Losses

From the five zones, only three zones; UZ1, MZ1 and L in the sub-catchment have furrow conveyance systems. Soil texture of lower zone is loamy sand while the soil texture of both upper zone 1 and middle zone 1 is sandy loam as illustrated in Table 4.3. From this Table 4.3, any of either sand, silt or clay particles percentage can be used to evaluate correlation of soil texture with percentage furrow conveyance water losses. The formula below was used to calculate correlation.
Correlation analysis of soil texture

Let \( X \) = Percentage score of Clay

\( Y \) = Percentage water losses

The Table 4.22 illustrates correlation of soil texture and water losses in furrows using clay particles. The correlation values were between negative one (-1) to positive one (+1).

**Table 4.22: Correlation of Soil Texture and Furrow Water Losses**

<table>
<thead>
<tr>
<th>Zones</th>
<th>( X )</th>
<th>( Y )</th>
<th>( XY )</th>
<th>( X^2 )</th>
<th>( Y^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>6</td>
<td>29.63</td>
<td>177.78</td>
<td>36</td>
<td>877.937</td>
</tr>
<tr>
<td>MZ1</td>
<td>10</td>
<td>30.49</td>
<td>304.90</td>
<td>100</td>
<td>929.640</td>
</tr>
<tr>
<td>UZ1</td>
<td>10</td>
<td>36.69</td>
<td>366.90</td>
<td>100</td>
<td>1346.156</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>96.81</td>
<td>849.58</td>
<td>236</td>
<td>3153.733</td>
</tr>
</tbody>
</table>

\[
r = \frac{(3\times849.58-(26\times96.81)}{\sqrt{(3\times236-26^2)\times (3\times3153.733-96.81^2)}}
\]

\[
= 0.592 \text{ say, 0.6}
\]

The coefficient of correlation is strong and positive. This shows that water is lost depending on soil texture.
4.5.2 Correlation of Soil Particles Distribution and Water Losses

The sub-catchment had different soil particles distribution in the three zones. The hypothesis test was calculated using correlation analysis. The correlation values were between negative one (-1) to positive one (+1).

Let \( X \) or \( Y \) = score of either Clay or silt or sand

i) Correlation of Clay and Water Loss in Furrows

Let \( X = \) Clay scores and \( Y = \) Moisture content scores

Table 4.23: Correlation of Clay and Water Loss in Furrows

<table>
<thead>
<tr>
<th>Zones</th>
<th>X</th>
<th>Y</th>
<th>XY</th>
<th>( X^2 )</th>
<th>( Y^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>10.42</td>
<td>29.63</td>
<td>308.745</td>
<td>108.58</td>
<td>877.937</td>
</tr>
<tr>
<td>MZ1</td>
<td>15.45</td>
<td>30.49</td>
<td>471.071</td>
<td>238.70</td>
<td>929.640</td>
</tr>
<tr>
<td>UZ1</td>
<td>13.25</td>
<td>36.69</td>
<td>486.143</td>
<td>175.56</td>
<td>1346.156</td>
</tr>
<tr>
<td>Total</td>
<td>39.12</td>
<td>96.81</td>
<td>1265.958</td>
<td>522.84</td>
<td>3153.733</td>
</tr>
</tbody>
</table>

\[
r = \frac{(3 \times 1265.958 - (39.12 \times 96.81))}{\sqrt{(3 \times 19358.99 - 39.12^2) \times (3 \times 3153.733 - 96.81^2)}}
\]

\[= 0.18\]

From Table: 4.23, the coefficient of correlation is 0.18 which is very low approaching zero but on the positive. This shows there is insufficient correlation between the water losses in conveyance system and clay particles.

ii) Correlation of Sand and Water Loss in Furrows

Let \( X = \) Sand scores and \( Y = \) Water losses in the zones

Table 4.24: Correlation of Sand and Water Loss in Furrows

<table>
<thead>
<tr>
<th>Zones</th>
<th>X</th>
<th>Y</th>
<th>XY</th>
<th>( X^2 )</th>
<th>( Y^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>85.63</td>
<td>29.63</td>
<td>2537.217</td>
<td>7332.497</td>
<td>877.937</td>
</tr>
<tr>
<td>MZ1</td>
<td>77.41</td>
<td>30.49</td>
<td>2360.231</td>
<td>5992.308</td>
<td>929.640</td>
</tr>
<tr>
<td>UZ1</td>
<td>77.68</td>
<td>36.69</td>
<td>2850.079</td>
<td>6034.182</td>
<td>1346.156</td>
</tr>
<tr>
<td>Total</td>
<td>240.42</td>
<td>96.81</td>
<td>7747.530</td>
<td>19358.990</td>
<td>3253.733</td>
</tr>
</tbody>
</table>
\[ r = \frac{3\cdot7747.53-(240.72\cdot96.81)}{\sqrt{(3\cdot19358.99-240.72^2)(3\cdot3153.733-96.81)}} \]

= -0.57, say -0.6

From Table 4.24, the coefficient of correlation is strong and negative. This shows lower zones have high percentage of sand particles but low water losses in furrows.

### iii) Correlation of Silt and Water Loss in Furrows

Let \( X = \text{silt scores} \) and \( Y = \text{Water losses in the zones} \)

<table>
<thead>
<tr>
<th>Zones</th>
<th>X</th>
<th>Y</th>
<th>XY</th>
<th>X^2</th>
<th>Y^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>3.95</td>
<td>29.63</td>
<td>117.603</td>
<td>15.603</td>
<td>877.937</td>
</tr>
<tr>
<td>MZ1</td>
<td>7.14</td>
<td>30.49</td>
<td>217.699</td>
<td>50.980</td>
<td>929.640</td>
</tr>
<tr>
<td>UZ1</td>
<td>7.07</td>
<td>36.69</td>
<td>259.398</td>
<td>49.985</td>
<td>1346.156</td>
</tr>
<tr>
<td>Total</td>
<td>18.16</td>
<td>96.81</td>
<td>594.140</td>
<td>116.570</td>
<td>3153.733</td>
</tr>
</tbody>
</table>

\[ r = \frac{3\cdot594.14-(18.16\cdot96.81)}{\sqrt{(3\cdot116.57-18.16)(3\cdot3153.733-96.81)}} \]

= 0.58, Say 0.6

From Table 4.25, the coefficient of correlation of silt particles and water losses in furrow conveyance system is positive and strong. This shows that the increase in silt particles in each zone correspond with increase in water losses in the furrow of each zone.

### Testing the Significance of a Correlation

After computing a correlation, the probability that the correlation is a real one and not a chance occurrence was done by conducting a significance test. This is testing the mutually exclusive hypotheses:

- **Null Hypothesis:** \( r_0 = 0 \)
- **Alternative Hypothesis:** \( r \neq 0 \)
The significant level alpha of 0.05 for two tailed test was adopted. Degree of freedom (df) is N-2 which is 1. Therefore, from Appendix VII, the significant of correlation is 0.997 and -0.997. Therefore, 0.6 is less than 0.997 and -0.6 greater than -0.997 which implies it was a chance occurrence and the correlation is statistically insignificant. The null hypotheses are accepted and alternatives are rejected. Hence, the null hypotheses

- There is no significant relationship between soil texture and water losses in the furrow conveyance system.
- There is no significant relationship between soil particles distribution and a water loss in furrow conveyance system is accepted.

4.6 Discussion

4.6.1 Watershed Management and Planning

The goal of watershed management and planning is to work toward an environmentally and economically healthy watershed that benefits all who have a stake in it (Lowell 1994). It should be understood that Ngaciuma-Kinyaritha sub-catchment is the terrestrial and aquatic bio-productive systems that comprises of soil, vegetation, water resources and other biota, ecological and hydrological process that operate within the systems. Thus, it refers to all natural resources that contribute to agricultural production including livestock and forestry. The main objective is to reduce decline in land quality through deterioration of physical, chemical and biological properties of the soil. This is by encouraging the watershed not to lower the current potential capability of producing goods such as crops, livestock, and timber or providing services such as unpolluted water.
In addition the sub-catchment should produce enough quantity water to meet demand for various competing uses and users as observed by Puget Sound Water Quality Authority (1994). According to Terrene Institute (2000), this is achieved through interventions on natural processes and human activities which are no longer able to properly sustain an economic function of the original ecological function. In the view of soil physical properties of the sub-catchment, it is of great important to come up with holistic management and planning of water resources, which complies with Water Act 2002 and focuses on Kenya’s Vision 2030 through active Water User Associations (WRUAs), involving all stakeholders.

Broadly speaking, the soil texture characteristic of the sub-catchment is loamy sand and sandy loam soils with different in clay content, silt content and various sand type distributions. The soils are permeable to water with high infiltration rate, hence good for any interventions to encourage inflows and deep percolation. The particles are also detached from each other hence susceptible to soil erosion.

4.6.2 Sub-catchment Soil Moisture Content

Soil moisture content was found statistically different for the different zones in the sub-catchment. The moisture content in the middle zone 1 gave the highest values followed by upper zone 1, upper zone 2, lower zone; and middle zone 2 had the lowest moisture content. Despite all zone having similar loamy sand soils, they have different percentage soil particles distribution. This depends on the percentage of very coarse sand, coarse sand, medium, fine sand and very fine sand. It also depends on the amount of silt and clay
in each zone. Lower zone has very high very coarse sand and coarse sand but low medium, fine sand, very fine sand and silt. The zone has relatively high clay of 10.42% which makes the zone to hold some moisture. The zone bounders lower Imenti forest as shown in figure 1.1 which has contributed to humus clay in between sand particles, which is a characteristic of Kenya soils (Baker, 1967).

Middle zone 2 has very low moisture content which is attributed to very high very coarse sand and coarse sand but very low medium, fine and very fine sand and insignificant humus. This area is far from forest, hilly and with highly eroded soils. Middle zone 1 has very high very coarse sand and coarse sand but moderate medium fine and very fine sand. It also contains high humus clay of 15.45% since the zone bounders the lower imenti forest and also it receives eroded clay from middle zone 2, upper zone 1 and upper zone 2 since its on lower terrain. This makes the zone to hold highest moisture content. The upper zone 2 has high very coarse sand and coarse sand but has almost uniform although in decreasing medium, fine and very fine sand. The area directly bounder upper ‘Imenti’ forest and it contains high humus clay particles of 10.46% and has substantial silt compared to other zones. This makes the zone to retain some substantial moisture content of 30.44%. Upper zone 1 has relative uniformly distributed sand particles and also high silt of 7.07% and humus clay of 13.25% which is as a result of this area spreading along the upper Imenti forest and Lower Imenti forest. This makes the zone to have relatively high moisture content of 33.13%. Broadly speaking, the whole Ngaciuma – Kinyaritha
sub-catchment has reasonable high moisture content with well drained soil which can encourage high infiltration rates.

4.6.3 Sub-catchment Soil Profile

From soil texture of various zones and through observations of soil profile, it is clear that the whole of sub-catchment has aggregated soil structure. The soil particles have stable clods known as aggregate. This type of soil is generally the most desirable condition for plant growth especially in the critical early stages of germination and seedling establishment. A condition where the soil is optimally loosely friable and porous assemblance of aggregate, permitting free movement of water and air, easy cultivation and planting, unobstructed germination and desirable root growth. The structure of a single grain soil as well as aggregate soils can be considered quantitatively in terms of total porosity and of the pore size distribution. Therefore using the prevailing soil texture, soil moisture content, soil profile and soil structure it is easy to develop a conjunctive watershed management, planning and conservation.

4.7 Riparian Land Abstraction Structures Effects

There are many water abstraction structures constructed close to each other in all tributaries and rivers in Ngaciuma-Kinyaritha sub-catchment shown in Table 4.6. The construction of the structures has contributed to massive destruction of riparian vegetation in the sub-catchment. These resulted from poor allocation by water authority within the watershed. The management of water resources was initially by central
government and the riparian users had very little influence on water allocation and management. This resulted to water abstraction holly dependant on individual or group ability. Water abstraction lacks holistic approach to include all riparian users in harmonization of intake to meet equitable water demand.

4.7 Riparian Land SWOT Analysis

Apart from water abstraction structures that affect riparian land in this sub-catchment, there are other multi-problems that have effect on it. The sub-catchment has also various potentials that can be exploited for planning, management and conservation of this vital riparian land strip. Therefore, SWOT is a very important tool to study riparian land in this basin.

a) Strength

High rainfall the sub-catchment gives a very great potential of water availability with the upper zone and lower zone receiving 1600mm and 1100 mm respectively which has bimodal pattern as shown in Table 4.21. This is the sub-catchment average rainfall for Meru Forest Station between 1986 and 2008. From Figure 4.2, the rainfall potential in the sub-catchment is almost uniform apart with minimum extremes during el nino and la nino. The other important aspect is that the geology of the area results to high infiltration rate resulting to little or no surface drainage depending on rain intensity. Table: 4.26 show various infiltration rates of all soils in the sub-catchment which are loamy sand and sandy loam soils. This proves that the soils can handle high rains intensity. With good riparian land cover, it reduces flood water from polluting rivers.
Table 4.26: Average Intake Rates of Water in mm/hr for Different Soils

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Intake Rate mm/hr</th>
<th>Stream size q 1/sec/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Sand</td>
<td>50</td>
<td>(25 to 250)</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>25</td>
<td>(15 to 75)</td>
</tr>
<tr>
<td>Loam</td>
<td>12.5</td>
<td>(8 to 20)</td>
</tr>
<tr>
<td>Clay loam</td>
<td>8</td>
<td>(2.5 to 15)</td>
</tr>
<tr>
<td>Silty clay</td>
<td>2.5</td>
<td>(0.03 to 5)</td>
</tr>
<tr>
<td>Clay</td>
<td>5</td>
<td>(0.1 to 15)</td>
</tr>
</tbody>
</table>

Source: Ministry of Water and Irrigation, 2005.

Deep soil profile helps to hold high quantities of water which increases ground water storage and holds sub-surface and deep percolated water which recharges springs and rivers. The sub-catchment has generally high potential for rain fed agriculture and with good soil and water conservation there could minimal irrigation.

b) Weakness

i) Poor Soils Consolidation

The sub-catchment has weakness in that the soils are poorly consolidated due to it soil texture, steep slopes and destroyed riparian land that makes it susceptible to erosion and mass movement. Plate 4.1 shows mass movement at lower zone in areas were riparian land is completely destroyed. Mass movement is the down slope movement of earth materials under the influence of gravity. The detachment and movement of earth materials occurs if the stress imposed is greater than the strength of the material to hold it in place. Shear strength is a measure if the resistance of earth materials to be moved. The interlocking of soil particles increases the ability of material to stay in place. Plant roots
also help bind soil particles together and when the riparian vegetation is removed, the shear strength is considerably reduced (Hansen, 1979). Shear stress is primarily a function of the force exerted by the weight of the material under the influence of gravity acting in the down slope direction. The slope of the surface determines the amount of stress that occurs on earth materials. Water destabilizes hill slopes by creating pressure in the pore spaces of earth materials. Water infiltrating into slope materials saturates the soil particles at depth by filling the pore spaces between. The weight of water lying above creates water pressure that drives soil particles. This lessens the friction between them and enables them to slip past one another. Material is mobilized when the shear stress imposed on a surface exceeds the shear strength. The movement, especially in the case of slides and slumps, is along a failure plane.

Plate 4.1: Widening of River Bank in Lower Due to Mass Movement (Position: 00° 03’N, 37° 44’E, 5-4-2010)
ii) Land Use/Cover Changes.

Demographic pressure and economic activities have contributed to forest land encroachment which resulted to decrease of forest cover from 37% to 24% during the period of shamba system (Table 4.27). Plate 4.2 shows a section of lower Imenti forest which under shamba system between 1987 and 2000. The area has not been re-afforested but only creeping and small vegetation is regenerating (DAAD, 2007). Other activities that led to forest destructions include need for timber, firewood and fodder for animals

Table 4.27: Land Use/Cover

<table>
<thead>
<tr>
<th>Land Use</th>
<th>1987</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hectares</td>
<td>Percentage</td>
</tr>
<tr>
<td>Agriculture/Settlement</td>
<td>9969</td>
<td>63</td>
</tr>
<tr>
<td>Forest</td>
<td>5841</td>
<td>37</td>
</tr>
<tr>
<td>Total</td>
<td>15810</td>
<td>100</td>
</tr>
</tbody>
</table>

(DAAD, 2007)

Plate 4.2: Forested Land under Shamba System up to 2000

(Position: 00°07’N, 37°42”E, (6-4-2010)
ii) Water Abstraction method

Over clouding of abstraction structures in a given area and also over trenching along the riparian land poses dangers on riparian vegetation and multi-mass movement. This also leads to illegal water abstraction which hinders water abstraction documentation. Plate 4.6 shows a furrow abstraction deviation at Kienderu area were multi-pipes are used to abstract water.

Plate 4.3: Wasteful and Illegal Rock Barrier Water Abstraction
(Position: 00° 05"N, 37° 40"E, (7-4-2010)

c) Opportunities

One of the great opportunities in the watershed is extended forest which is a water tower for mushrooming springs and river. There is also electrical fence round the forest area including the portion initially under shamba system (Plate 4.4). This will help to prevent human and wild life conflicts. The fencing also minimizes destruction of water tower and encroachment of forest land for agricultural purposes. The sub-catchment has many
springs and rivers which are tributaries of Ngaciuma River and Kinyaritha River. Under good harmonized abstraction system, the water can be able to meet demand of all users as well as reducing conflicts. The area is connected to national electricity grid in all major market centres and homes through rural through rural electrification programme. Plate 3.1, plate 3.7, plate 4.9 and plate 4.12 shows that electricity grid lines are distributed in the whole sub-catchment. Some homes have solar electricity which reduces over reliance on paraffin for lighting in the rural areas. Also, these alternatives source of energy reduces exploiting forested area including riparian vegetation as the sole form of energy.

Plate 4.4: Electrical Fence a Round Imenti Forest

(Position: 00° 04’’N, 37° 37’’E, (7-4-2010)
d) Threats

i) Waste Management

Meru town is the main commercial centre although there are also small market centers in the sub-catchment which includes Gitimene (Naari), Muruguma, Kienderu, Chugu, Kauthene, Rwanyange, Ndiine, and Mugeene. Solid waste from Meru municipality disposed in a dump site at Nkunga in the upper zone. Plate 4.5 illustrates a giant Meru Municipal dumping in Lake Nkunga riparian land. Waste dumping poses high threats in polluting the rivers in the sub-catchment since the lake has underground water exit which is the main source of springs and rivers (DAAD, 2007).

Plate 4.5: Waste Dump Site at Lake Nkunga Wetland Riparian forest
(Position 00°06”N, 37°36”E, (6-4-2010)
Waste from the market center needs to be well managed to minimize water pollution. Effort should also be made to improve riparian land vegetation cover which acts as natural filter of water body.

ii) Erosion

The area is connected by earth roads which are eroded and creates gully which further complicate the problem by silting the main water bodies. Plate 4.6 depicts middle zone 2, 6m deep eroded road at Kienderu village which immediate pollutes Ngaciuma River.

Plate 4.6: Gully Erosion on Roadside

(Position: 00° 05”N, 37° 39”E, (6-4-2010)
iii) Wetland Encroachment

Encroachment of wetlands and all riparian land for agriculture threatens water quality and quantity. Plate 4.7 demonstrates invasion of great Gieto wetland for farming purposes. Direct spraying of crops on the wetland poses other threats on water quality.

Plate 4.7: Gieto Wetland Encroachment for Agricultural Purposes
(Position: 00° 06’N, 37° 40’E, (4-4-2010)

Wetlands should be left in the natural stagnation state to aid in deep infiltration to recharge both rivers and groundwater. Apart from wetland encroachment, farming is done up to the interface of land and water as demonstrated in Plate 4.8. In all areas the distance between riparian land, agricultural land and water body was zero.
Plate 4.8: River Bank Encroachment

(00° 04” N, 37° 42”E, (7-4-2010)

4.8 Catchment Protection and Conservation Strategy

The main problem in the sub-catchment is degradation due to deforestation of Imenti, and lower Imenti forest. Imenti forest is encroached by Agricultural Show of Kenya (ASK) (Plate 4.9). Apart from it being used as show ground, it is used for agricultural purposes. Next to the ASK ground is the source of Kagwankuguru River, a tributary of Ngaciuma River which is threatened in both quality and quantity. Solid waste dumping site by municipal council of Meru at Lake Nkunga poses high potential threats to water quality in the sub-cathment.
Another problem is overgrazing by wild and domestic animals. Most of forest vegetation is destroyed by domestic animals. Plate 4.10 shows part of the forest which has been degraded due to overgrazing. Forest is also degraded by wild animals when they exceed its bearing capacity. Cutting of trees for firewood and timber industry has contributed to the destruction on Imenti forest.
Plate 4.10: Shows destruction of lower Imenti forest by overgrazing.

(Position: 00° 07” N, 37°41”E, Author, 6-4-2010)

Encroachment and cultivation of wetlands has resulted to severe water body damage and contributed to decline in water quality. It has also resulted to high run-off, poor ground water recharge and growth of desertification. Therefore, measures should be undertaken to achieve an enabling environment which protects the water ecosystem and habitat.

4.9 Water Allocation

Poor water allocation has resulted to over concentration of intake structures as shown in Table 4.6. In addition, poor water allocation and undersigned intake resulted to massive
losses of water through illegal water abstraction as shown in plate 4.3. To improve water usage, water metering is essential for better water allocation and water use management in the sub-catchment. Equitable water allocation promotes effective use and gives priority to the reserve. The main objectives should include: ensuring equitable allocation and regulation of water use, meeting the economic and social development objectives through sustainable management of water resources in the basin. The water allocation plans in this watershed should capture the rules and procedures to be used at different competing uses. The over concentration of water can be reduced by harmonizing water abstraction structures which helps in reducing damage of riparian vegetation. This system should discourage all forms of illegal water abstraction and ensure permits system of lawful water use.

Plate 4.11: Total Destruction of Riparian land due to Poor Abstraction

(Position: 00° 04”N, 37°38”E, 6-4-2010)
4.10 General Water Losses in Furrows Conveyance Systems

Tables 4.8 to 4.20 show massive water losses in all furrow conveyance systems in the whole sub-catchment. There are no furrows in the upper zone 2 and middle zone 2 due to steep slopes but from soil texture, one can approximate the massive losses that can be in the zones. Lower zone has an average water loss of 29.68% for every 50m while the upper zone 1 and middle zone 1 have average water losses of 36.69% and 30.49% for every 50m respectively. This amount of water is lost through sub-surface flow or deep percolation since the time taken in flow measurement was shot to register any effect on evaporation. The high loss in upper zone is attributing to high humus clay and a well-distributed soil particles which give many numbers of pores. The zone transverses the Lower Imenti Forest and Upper Imenti Forest hence rich in glacier eroded humus materials. Middle zone1 has high humus clay but fewer number pores due to high very coarse and coarse sand hence less water retained in the soil matrix. The zone is near the lower Imenti Forest and therefore, receives decomposed debris which form humus clay which is in line with Baker (1967). The lower zone is situated far from Imenti Forest and Giaki forest hence very low humus clay hence very low water holding capacity. Water loss in the three zones is high since the soils have high infiltration rates. Proper management of all furrow conveyance water systems is important which should aim at water seepage reduction.
4.11 Factors Leading to Water Losses in Ngaciuma-Kinyaritha

A poor consolidated soil with high infiltration rate is one factor leading to high water losses under poor water uses and management. The soil profile is too deep to allow deep seepage of water particularly on furrow conveyance resulting to massive water losses. In addition, poor method of water abstraction including illegal uncounted for water and riparian land threats contribute to major water losses. To make water availability a reality for both present and future use, there is need to reduce water losses and enhance water protection and conservation.

4.12 Water Pricing Overview

Water has economic value in all its competing use and it should be recognized as an economic good. It’s also important to recognize the first basic right of all human being is to access clean water and sanitation at affordable price (Global Water Partnership, 2000). Also, failure to recognize water as an economic good in the sub-catchment has led to wasteful and environmental damage. Water pricing should take into account the affordability of different users. Users should be educated that under poor water management, the poor people will be hurt most when water becomes scarce in both quality and quantity. Therefore, from economic point of view, water pricing encourages water conservation if correctly designed and enforced. The money raised should be used for development of the watershed. Payment for the service of managing water and the subsequent ploughing back into the same service is a necessary tool (Jaspers, 2002).
4.13 Planning and Management Procedure in Ngaciuma-Kanyiratha Sub-cathment

The per capita water demand of Tana was 724 m$^3$ in 1999 and was estimated to be 387 m$^3$ in 2006, far below the global water requirement of 1000 m$^3$/year (WRMA, 2007). To overcome this water stress problem, a stage-by-stage planning and management needs to be employed. To achieve this, everybody in this sub-catchment including riparian water users, stakeholders and experts needs to be involved at all levels of decision making. Figure 4.3 shows sub-catchment comprehensive planning organization model from the source to the mouth including all stakeholders. The main stakeholders for the sub-catchment includes: KEMU, Meru Municipal Council /county council, water service providers, irrigator, abstractor, NGOs, upper zone water groups, middle zone water groups, lower zone water groups, youth groups, women group observers and government experts. The sub-catchment planning and management should be centred on prevailing soil physical properties with an aim of improving water quality and quantity. Riparian land strip needs to be conserved due to their importance in improving both water quality and quantity in watershed. More importantly, water losses in the points of abstraction and conveyance are of primary concern for water use sustainability. The main role of WRUAs is to develop an Action Plan which is simply a list of the actions the group member ought to adapt in planning and managing the watershed. There are set of activities to be done, time to do each activity and the amount of money required for each undertaking. The WRUAs should be all inclusive and enhancing bottom-up approach. In summary, the components of a good plan should involves local citizens and stakeholders, informing citizens about the plan, and focusing the plan on the part of the watershed that
most affects both water quality and quantity and finally, everything needed to implement the plan.

Source: Author from Field Data (2011)

Figure 4.3: NGAKINYA WRUAs Sub-catchment Planning Organization Model
For effective planning, management and conservation of Ngaciuma-Kinyarita sub-catchment, the WRUAs should maintain at high level the following functions:

(i) Development of strategic sub-catchment plan.
(ii) Development of operational sub-catchment plan.
(iii) Contributing to sub-catchment protection plan and measures.
(iv) Advising on water and waste discharge permits.
(v) Monitoring of water abstractions and water pollution.
(vi) Enforcement of water rights and waste discharge permits.
(vii) Legal action against defaulters.
(viii) Conflict resolution.

It is crucial to arrange aspects of representation and task distribution in a clear set of regulations or standard by-laws that can be modified by the users where local circumstances demand. Apart from rules for representation and functioning, by-laws should also cover aspects of water resources planning; allocation and registration of water rights; tariff structures and fee collection; fund development and application; monitoring arrangements; penalties and sanctioning; conflict resolution and appeal procedures. The experts that are required include technicians from the Ministry of Water and Irrigation for hydrological data, maps, structural design, among others. Other experts needed are from wild life, agriculture, forestry, local government and other professionals who are trained in various water-related disciplines (Field Survey, 2010).
4.14 Conjunctive Water Management

The soil texture, soil moisture content, soil structure and soil profile of a basin are very important for conjunctive water management. From tables 4.2, 4.3 and 4.5, the soils of Ngaciuma-Kinyaritha sub-catchment are very permeable, well-drained and very deep. This makes it possible to employ conjunctive water management using conservation methods which regulates surface run-off and hence encourage inflows and deep percolation. This eventually increases ground water and river recharge. The soil texture of sub-catchment has very high infiltration rate which means the construction of artificial infiltration walls, would increase ground water recharge. In addition, various reservoirs can be constructed with the aim of increasing ground water recharge. This would help the use surface water when it is plentiful and use ground water in periods of water scarcity (Republic of Kenya, 2005). Artificial infiltration is an important intervention that may be used to check ground water conflicts among users aiding in river recharge which encourages sustainable large flows for along time. In the upper zone, artificial infiltration should be encouraged to make water availability a reality since this is the only alternative source of water in the zone apart from roof harvesting. Artificial infiltration has two major advantages in ground water management. The first one is to increase ground water recharge and reducing flood flows. The second is that boreholes would help in meeting water demand for various users in the watershed.
4.15 Water Resource Protection

Water protection within the sub-catchment should be aimed at enhancing control of water resources in both quality and quantity. The protection determined the reserve water for both basic environmental and human uses. The main aim of resource protection was sustainable water management which includes the enhancement and protection of natural flow regimes and improvement of water quality. This is achieved through minimizing negative impacts on forest area where municipal council throws solid waste at Lake Nkunga wetland (DAAD 2007). Poor waste management under loamy sand and sandy loam would result into pollution loading into the river and ground water. It is necessary to take precautionary measures particularly the spread of pit latrine and homestead near wetlands. This results into various benefits like health or safety of human beings, good, aquatic and non aquatic life and environment integrity.

4.16 A Forestation and Re-a forestation Programme

Good agricultural planning on land use is necessary. Areas of extremely high steep slopes should be used for tree planting. This is particular important in middle zone 2 and upper zone 2 where we have very steep slopes. It is, therefore, critical to develop agro-forestry planning and management plan with the aim of increasing water infiltration rates, water conservation and soil fertility through mineral recycling. Also, the roots of trees are extremely important to aid in binding and holding the soil particles together and reducing the likelihood of mass movement of land. Re-forestation programme is necessary on forested areas in lower Imenti forest at ‘Mbeu’ forest and along all riparian
land. This helps in enriching the sub-catchment water tower which increases the water availability. Again this act as natural water filter to improve on water quality, increase water infiltration and also helps in controlling soil erosion in this sub-catchment. The trees also help to generate organic matter which is soil particles binding agent (Baker, 1967).

The major problem is on demarcating or separating riparian from agricultural because the land tenure where the majority of land is on modern/ individual ownership does not recognize any riparian strips. The landowners possess land up to the middle of river which has contributed to total destruction of this important strip as shown in Plate 4.8. In some areas, buildings are constructed next to the riparian and if not address in time this might be the source of domestic waste point pollution as shown in Plate 4.12. A formative action needs to be sought through WRUAs to establish riparian member to develop sustainable riparian with permanent vegetation and establish workable monitoring programme. The species of trees to be planted should be water friendly to ensure both quality and quantity of downstream flow. All wetlands should be left in their natural state since when they are opened up, they start losing a lot of water as shown in Table 4.19 and Table 4.20 on Gieto wetland current meter gauging. The riparian land in the sub-catchment, under proper management will join the upper Imenti forest, lower Imenti forest and Mbeu forest in the lower zone. This would enhance the overall protection of the whole catchment.
Plate 4.12: Riparian Land Encroachment by Buildings

(Position: 00°06' N, 37°40' E, Author, 4-4-2010)
CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Study Objectives and Methodology

The study’s main aim was to analyze selected soil physical properties that control water movement within the sub-surface zones in Ngaciuma-Kinyaritha sub-catchment. The purpose was to establish appropriate water resources planning, management and conservation through reduction of surface run-off but encouraging sub-surface and deep percolation flows in order to make water availability in the sub-catchment a reality and establishing unnecessary water losses. Below are specific objectives:

(i) To analyze and examine soil texture and soil profile physical properties for optimum conjunctive water management in the sub-catchment.

(ii) To investigate factors leading to water losses due to hydro-morphology threats of riparian land in Ngaciuma-Kinyaritha sub-catchment.

(iii) To investigate the water losses in unlined furrow conveyance system in Ngaciuma-Kinyaritha sub-catchment.

Empirical tool used in field data collection were; field soil sampling and laboratory soil texture and soil moisture content analysis, field soil profile measurement, SWOT analysis
and finally direct current meter furrow water flow gauging to determine water losses. These helped to answer the following questions:

(i) How can soil texture and soil profile in Ngaciuma-Kinyaritha sub-catchment be used for optimum conjunctive watershed management, planning and conservation to ensure availability of water?

(ii) How does water abstraction structures and trenching of conveyance system affect riparian land in Ngaciuma–Kinyaritha sub-catchment?

(iii) What is the extent of water loss in the furrow conveyance system in the Ngaciuma–Kinyaritha sub-catchment?

5.2 Summary of Study Key Findings

The study identified the following key findings from analysis of some soil physical properties important for water planning, management and conservation in Ngaciuma-Kinyaritha sub-catchment. The analysis of soil samples in all zones reviewed that overall soil texture of the sub-catchment is loamy sand and sandy loam but with different clay content, silt content and various sand type distribution. The soils are permeable to water with high infiltration rate, hence good for any interventions to encourage inflows and deep percolation. In addition, the particles are also detached from each other hence susceptible to soil erosion. The resultant porosity in the sub-catchment is aggregated soil which is desirable condition for diverse plant growth. The soil moisture content in the three zones is high with very slight variation depending on sand particles, silt particles or
clay particles distribution. The high holding capacity of moisture content of soil is important for sub-catchment management and conservation to increase water availability. The soil profile in the whole Ngaciuma-Kinyaritha sub-catchment is very deep which stands at 82m to be precise to reach parent rock. The soils have high storage potential which can be utilized to reduce flood flows and contribute to high river flows as well as increasing groundwater potential in the basin.

The study established the challenges and opportunities adopted in the study of riparian land threats in sub-catchment using SWOT analysis matrix. The strengths includes: adequate rainfall, soils with high infiltration rates, deep soil profile, fertile soil, local involved in water allocation and proactive Ngaciuma-Kinyaritha WRUAs. The opportunities includes presence of Imenti forest, many springs which run throughout the year, constructed electrical fence around the forest, high rainfall, availability of diverse sector technical officers, and good rural electrification programme. Weaknesses included: Poor soil consolidation, land use/cover change, poor design of water abstraction structures, illegal water abstraction, over crowding of abstraction structures, poor water allocation and water use control and finally over trenching of riparian land for water conveyance systems. On the other hand, some threats included: poor waste disposal from urban centers, soil erosion in the area, wetland encroachment for both agriculture and building construction purposes, illegal logging of trees from the riparian land strip and chemical pollution.
The furrow conveyance water system results indicate massive losses of water in all zones metered. This contributes to emerging hydro-solidarity conflicts on down flows water scarcity among riparian users. Comparing the results with the study by Asnakew (2003) on water losses in montmorillontic clay, the water losses in Ngaciuma-Kinyaritha is very high. This basin, therefore, requires lining of furrows or complete change of conveyance system for environmentally sound water sustainability as a precautionally measure.

5.3 Conclusions

The study revealed that soil texture of Ngaciuma-Kinyaritha sub-catchment is loamy sand and sandy loam which has high infiltration rate significant for deep rain water percolation to enrich groundwater recharge under good soil and water management. In addition, the sub-catchment has high soil moisture content and well-aerated good for agricultural purposes. Field measure revealed very deep soil profile with a potential of high water storage capacity. The analysis of soil physical in this study gave fundamental factor necessary for an excellent and holistic water planning, management and conservation of Ngaciuma-Kinyaritha sub-catchment. Major challenges that threaten riparian in the subcatchment are: over crowding of abstraction structures, poor water allocation and water use control, over trenching of riparian land for water conveyance systems, poor waste disposal from urban centres, chemical pollution and finally riparian land and wetland encroachment. However, the sub-catchment can boast of adequate rainfall, soils with high infiltration rates, deep soil profile, fertile soil for excellent vegetation growth, forest area
which is the source of all rivers in the basin, and electrical fence around the forest. In addition, the study revealed that the water losses in all furrows were significantly high in all gauged zones. From the study water losses in Ngaciuma-Kinyarah are due to poor water abstraction structures, poor soil consolidation and water seeping through unlined canals with very deep soil profile.

5.4 Recommendations
From the findings, the following recommendations will help WRUAs with collaboration with government agencies and NGO working in Ngaciuma-Kinyaritha sub-catchment to manage water resources in the basin sustainably.

(i). Water management and development should be based on participatory approach, involving users, planners and policy makers at all levels.

(ii). The sub-catchment receives high rainfall and from soil physical properties, the soils have high infiltration rates plus high water storage potential and therefore, artificial rain water infiltration should be encouraged with a view of increase groundwater recharge for future demand.

(iii). The sub-catchment should establish a riparian boundary and regulations on water activities in all rivers and wetlands. This would help in management of riparian land in the watershed.

(iv). There should be a good land use planning for example pollution control measures for both point sources and non-point resources. Waste disposal at Lake Nkunga should be relocated by the municipal council of Meru.
(v). Soil and water resource conservation and management should be enhanced through sensitization of all stakeholders in the catchment by harmonized government agencies in the sub-catchment.

(vi). A good afforestation, re-forestation and agro-forestry programme ought to be developed to enrich the water tower as well as helping high moisture content retention and soil erosion control in the whole sub-catchment.

(vii). The water abstraction system should be harmonized to reduce water losses and massive destruction of riparian land vegetation. There is need to develop a good irrigation water conveyance system in order to achieve effective water use. Lining of canals using local available materials like clay soil, polythane papers, concrete or complete change of furrow system is necessary and ought to be implemented immediately.

(viii). Water allocation for all uses and users including ecological water from the source to mouth in the sub-catchment plus a well-designed and enforced water pricing methods needs to be developed.

(ix). WRUAs should have well-representative officials in each zone, the upper, the middle and the lower to avoid association break up due to imbalanced representation.

5.5 Policy Implication of the Research Study

(i). The study helps to relate soils and hydrological characteristics in Ngaciuma-Kinyaritha sub-catchment which contributes more on needs for management of
wetlands and wetland resources according to legal notice number 19 on the environmental management and co-ordination wetland regulations of 2009. More importantly, the study raises need to defining the riparian land strips and developing its management strategy.

(ii). The study suggests need to develop waste management policy in this sub-catchment which includes handing of wastes in transportation and disposal as a precautionally measure to water quality.

(iii). The study will help the policy-makers to reduce water scarcity by establishing good planning, management and conservation of the basin. As expressed in NWRMS (2005), this aims at addressing extreme climate variability and more importantly rainfall patterns which is extremely variable in spatially, temporally and intensities. The policy should aim at reducing sub-catchment degradation which causes run-off, flash flooding, reduce infiltration, erosion and siltation which undermines sustainable water resources in the basin with more focus in farming methods; encroaching wetland, riparian land and forest land.

(iv). The study has highlighted need for mutual gain approach to negotiation which should be encouraged in a basin planning, management and conservations including exploring interests and then distributing values to all interested groups in the whole basin. As Bisset (2000) observes any policy aimed at watershed management needs public involvement and consultations due to dynamic changes
in policies as while as coping with changes at global and national level. The study results aid the sub-catchment in coping with evolving policies of the multilateral and bilateral agencies by creating water planning, management and conservation policy aimed on promotion of good governance, emphasis on poverty alleviation and gender sensitivity and finally promotion of environmental capacity developments to improve basin governmental capacity to make effective decisions based on sound utility integrity and ecological sustainability.

5.6 Suggestions for Future Research in the Study Area

This study was mainly based on analysis of some physical soil properties on water availability in Ngaciuma-Kinyaritha sub-catchment. The study revealed great potential of water availability to meet the demands of all users under holistic planning, management and conservation of this sub-catchment. Potential areas for future research and developments include:

(i). Assessment of the non-biodegradable waste materials effects to rain water infiltration rate in the sub-catchment.

(ii). To evaluate on water abstraction thresholds in the sub-catchment to aid in developing both present and future water demand planning and management.

(iii). Develop decision support systems to be used as a tool for monitoring and information system in the sub-catchment for analysis of complex water resources system in an integrated way.
(iv). Assessment of surface water monitoring network that is accessible and representative to all sub-catchment tributaries and rivers.

(v). To evaluate a groundwater network monitoring system that will ensure sustainability of future water demand.
REFERENCES


International Journal of Environmental Science and Technology, Vol. 2, No. 3, Autumn, pp. 253-258 Terrene Institute College of Natural Resources, University of Mazandaran, Sari, Iran Watershed Management Department, College of Natural Resources, University of Mazandaran, Sari, Iran College of Agriculture, University of Mazandaran, Sari, Iran


WRMA. (2003). Borehole Completion Records. WRMA Tana catchment area, Meru catchment management unit.
APPENDIX I: SOIL PROFILE ROADSIDE SITES

- Centre Road
- Site 1
- Site 2
- Site 3
- To Nanyuki
- Jeru
- Mikinduri
- Gitaro
- Olaki
- Gitaro Farm
- From Meru

Centres
Road

Profile site
Site 1 at Gitaro Nyeru Technical
Site 2 at KEMU
Site 3 at Kamoja Market

BY AUTHOR 2009
APPENDIX II: TABLES FOR SOIL PHYSICAL ANALYSIS AND SIEVE TYPES

Parameters characterizing the 12 soil textural class within the USDA soil textural triangle

<table>
<thead>
<tr>
<th>Class</th>
<th>Silt%</th>
<th>Sand%</th>
<th>Clay%</th>
<th>n%</th>
<th>Log K_s inches h^{-1}</th>
<th>Log ψ_{cm}</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>5</td>
<td>92</td>
<td>3</td>
<td>37.3</td>
<td>0.524</td>
<td>0.675</td>
<td>3.387</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>12</td>
<td>82</td>
<td>6</td>
<td>38.6</td>
<td>0.371</td>
<td>0.806</td>
<td>3.864</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>32</td>
<td>58</td>
<td>10</td>
<td>41.6</td>
<td>0.003</td>
<td>1.120</td>
<td>4.500</td>
</tr>
<tr>
<td>Loam</td>
<td>39</td>
<td>43</td>
<td>18</td>
<td>43.5</td>
<td>-0.226</td>
<td>1.317</td>
<td>5.772</td>
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<tr>
<td>Silt loam</td>
<td>70</td>
<td>17</td>
<td>13</td>
<td>46.8</td>
<td>-0.624</td>
<td>1.657</td>
<td>4.977</td>
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<tr>
<td>Sandy clay loam</td>
<td>15</td>
<td>58</td>
<td>37</td>
<td>41.6</td>
<td>0.003</td>
<td>1.120</td>
<td>7.203</td>
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<tr>
<td>Clay loam</td>
<td>34</td>
<td>32</td>
<td>34</td>
<td>44.9</td>
<td>-0.394</td>
<td>1.461</td>
<td>8.316</td>
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<tr>
<td>Silt clay loam</td>
<td>56</td>
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<td>34</td>
<td>47.6</td>
<td>-0.731</td>
<td>1.749</td>
<td>8.316</td>
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<tr>
<td>Silt clay</td>
<td>6</td>
<td>52</td>
<td>42</td>
<td>42.3</td>
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<td>47</td>
<td>48.1</td>
<td>-0.792</td>
<td>1.801</td>
<td>10.383</td>
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<tr>
<td>Clay</td>
<td>20</td>
<td>22</td>
<td>58</td>
<td>46.1</td>
<td>-0.547</td>
<td>1.592</td>
<td>12.132</td>
</tr>
<tr>
<td>Silt</td>
<td>88</td>
<td>7</td>
<td>5</td>
<td>48.0</td>
<td>-0.777</td>
<td>1.788</td>
<td>3.705</td>
</tr>
</tbody>
</table>

N, porosity, pore size distribution index, K_s saturated hydraulic conductivity and ψ_{cm} soil matrix potential at saturation. Values are obtained trough univariate regression equations of Cosby et al., (1984). Note that 1 inch h^{-1}=0.30cm h^{-1}

SOIL TEXTURE CLASSIFICATION

<table>
<thead>
<tr>
<th>Name of soil separate</th>
<th>Diameter limit (mm)</th>
<th>USDA classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>Less than 0.002</td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>0.002-0.05</td>
<td></td>
</tr>
<tr>
<td>Very fine sand</td>
<td>0.05-0.1</td>
<td></td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.1-0.25</td>
<td></td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.25-0.50</td>
<td></td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.5-1.0</td>
<td></td>
</tr>
<tr>
<td>Very coarse sand</td>
<td>1.0-2.0</td>
<td></td>
</tr>
</tbody>
</table>

Source: Marshall (1947)
### APPENDIX IV: SOIL SAMPLING SITES

#### Lower Zone Soil Sampling Points

<table>
<thead>
<tr>
<th>Point Number</th>
<th>Coordinate Position</th>
<th>Altitude (ft)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00° 03&quot;N, 37° 45&quot;E</td>
<td>3724</td>
<td>At the mouth of Kinyaritha River</td>
</tr>
<tr>
<td>2</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3724</td>
<td>At the bottom of the hill.</td>
</tr>
<tr>
<td>3</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3724</td>
<td>At the middle of the hill</td>
</tr>
<tr>
<td>4</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3735</td>
<td>At the top of the hill</td>
</tr>
<tr>
<td>5</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3735</td>
<td>At the road junction</td>
</tr>
<tr>
<td>6</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3745</td>
<td>On the road side</td>
</tr>
<tr>
<td>7</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3745</td>
<td>At the shopping centre</td>
</tr>
<tr>
<td>8</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3758</td>
<td>On the road side</td>
</tr>
<tr>
<td>9</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3786</td>
<td>Slight colour change</td>
</tr>
<tr>
<td>10</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3780</td>
<td>At two shops</td>
</tr>
<tr>
<td>11</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3805</td>
<td>On road side</td>
</tr>
<tr>
<td>12</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3833</td>
<td>At the bridge</td>
</tr>
<tr>
<td>13</td>
<td>00° 03&quot;, 37° 45&quot;</td>
<td>3833</td>
<td>On road side</td>
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<td>14</td>
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<td>On road side</td>
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<td>00° 03&quot;, 37° 45&quot;</td>
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<td>Colour change</td>
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<td>00° 03&quot;, 37° 45&quot;</td>
<td>3883</td>
<td>Colour change</td>
</tr>
<tr>
<td>17</td>
<td>00° 03&quot;, 37° 45&quot;</td>
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Middle Zone 2 Soil Sampling Points
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Upper Zone 2 Soil Sampling Points

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</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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<td>On the road side</td>
</tr>
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</tr>
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</tr>
<tr>
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Upper Zone 1 Soil Sampling Points

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<th>Remarks</th>
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<td>At Chiru village</td>
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<tr>
<td>2</td>
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</tr>
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</tr>
<tr>
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</tr>
<tr>
<td>5</td>
<td>00°07”, 37°42”</td>
<td>4628</td>
<td>At Meru college</td>
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<tr>
<td>6</td>
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</tr>
<tr>
<td>7</td>
<td>00°07”, 37°42”</td>
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</tr>
<tr>
<td>8</td>
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</tr>
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</tr>
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</tr>
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<td>Upward junction from tarmac</td>
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<td>On the roadside</td>
</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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<td>Longitude</td>
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</tr>
<tr>
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Source: Author from Field Data (2010).
APPENDIX V: HYDROLOGY AND GEO-ELECTRIC DEPTH OF THE SUB-CATCHMENT

HYDROLOGY

The physiography of the area is tectonically and geographically controlled and wholly associated with the volcanicity of Mt. Kenya. The project is characterized by north-eastern to northern trading ridges and valleys on the higher parts on the slopes of MT. Kenya (2900-2700m above sea level) and low lying plains (2600m) are flat and gentle sloping northwards.

The soils are mainly reddish brown volcanic soils with clay loams to clay sub-soils particularly along the valleys. The soils are medium to highly fertile and their infiltration capacity is medium. They are well-drained. The geology of the area is predominantly composed of the Mt. Kenya volcanic suites which are made up of eruptive basalts, phonolite and pyroclasts and the satellite vent basalts, trachytes and agglomerates.

The vegetation is mainly composed of higher altitude bushes and shrubs and lower altitude coarse grasses and scattered trees. The mean annual rainfall of the area is about 700 millimeters which partly percolates and infiltrates to recharge the aquifers. Lateral transmission of ground-water from the Mt. Kenya catchments zone is expected to recharge the regional aquifers in the area.

The only boreholes drilled near the farm are about 2 kilometers from the project farm. The data of these are tabulated below:

<table>
<thead>
<tr>
<th>BOREHOLE NUMBER(C-)</th>
<th>TOTAL DEPTH (M)</th>
<th>WATER STRUCK LEVEL(s) (M)</th>
<th>WATER REST LEVEL (M)</th>
<th>TESTED YEILD (M3/HE)</th>
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<td>DRY</td>
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<td>-</td>
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<td>638</td>
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<td>82</td>
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<td>660</td>
<td>82</td>
<td>79</td>
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GEO-ELECTRIC DEPTH

One geo electric depth probe No. ER99-009 was carried out in the project area with a view to determine the nature of the subsurface. This is for possible occurrence of fractured and weathered zones within the subsurface.
Tabulated below is interpretation of this depth probe giving the true resistivity and expected formations.

<table>
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<tr>
<th>DEPTH PROVE NUMBER</th>
<th>LAYER THICKNESS (M)</th>
<th>TRUE RESISTIVITY (OHMM)</th>
<th>EXPECTED GEOLOGICAL FORMATIONS</th>
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Source: WRMA 2003
## APPENDIX VI: Soil Texture Sieve Analysis

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<th>Zone</th>
<th>Sieve Size (mm)</th>
<th>Weight of Empty Sieve (g)</th>
<th>Weight of Sieve Plus Soil (g)</th>
<th>Weight of soil (g)</th>
<th>Percentage Particle Size</th>
<th>Average Particle Size</th>
<th>Soil particle Types</th>
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<td>Trial 3</td>
<td>Trial 1</td>
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(Ian, 2000)