TOWARDS EFFECTIVE WATERSHED MANAGEMENT IN KENYA, A CASE STUDY OF MACHAKOS DISTRICT

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
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IRRIGATION WATER MANAGEMENT

By

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CANDIDATES DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled " **TOWARDS EFFECTIVE WATERSHED MANAGEMNT IN KENYA, A CASE STUDY OF MACHAKOS DISTRICT"**, in my partial fulfillment of the requirement for the award of the degree of Master of Technology in IRRIGATION WATER MANAGEMENT (IWM), submitted in the department of Water Resources Development Training Center (WRDTC), Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from June 2003 to June 2004 under the supervision of **Professor Raj Pal Singh**, ***Professor WRDTC*** and **Dr. Deepak Khare**, ***Associate Professor WRDTC, Indian Institute of Technology, Roorkee.***

I have not submitted the matter embodied in this Dissertation for the award of any other degree.

June 2004

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ABSTRACT

Water resources have diminished with time and space in many catchments due to poor management of the watersheds and over utilization of the resources. Water is a renewable though limited resource and therefore the need for it's long term planning is increasingly being felt. This is a study on water resources availability and utilization in Machakos district in Kenya so as to ascertain the extent of the deficit in the district whose potential has diminished so much resulting to food shortage and land degradation.

The study area is the watershed of the upper Athi river basin in Machakos district. The district in the eastern part of the country covers an area of 6281 km^2 most of which is semi arid. High and medium potential areas where rain-fed Agriculture is carried out is only 26% of the total area while 74% is rangeland with very limited irrigated or rain-fed agriculture. The land use and settlement patterns are based on Agro-ecological zones and are influenced by soil fertility and rainfall. The rocks underlying in the area are mainly sedimentary rocks made up of pre-Cambrian basement series known as the Mozambique belt system.

Generally the soils lie in the range from sandy clay loam to sandy clay and are hydrologically classified in-group C and D. The agro-ecozones range from Zone 2 to Zone 6. The topography of the district is varied and rises from 700 m to 1700 m above the sea level with the highest point being Kilimambogo (Donyo Sabuk) at 2144 m. There are two distinct rainy seasons and the mean monthly temperatures range from 12^0 C to 25^0 C. The rainfall ranges from 700 mm on the plains to 1300 mm on the hills.

The average annual evapotranspiration is about 1630.23 mm. As by 2002,the annual population growth rate was 1.7% and the population was 954,082 persons. It is expected that the population will be 970,440 by 2003, 1,092,606 by 2010 and 1,293,222 by 2020.

The district depends upon rivers and streams, boreholes, springs and roof catchments for the sources of water. Water available from shallow well abstraction is 10.78 Mcm/year. There are 360 boreholes in the district but only 281 are currently operational with a total yield of 12.176 Mcm/year and Yatta canal provides 22.644 Mcm/year. Water used from Athi River (either by pumping or diverting) annually is 157.05 Mcm/year giving the total amount of water available in the district as 205.908 Mcm/year.

The demand for human consumption is 35.754 Mcm/year; the industrial demand is 2.017 Mcm/year and the demand for livestock (Cattle, Shoats, Poultry, Pigs, Rabbits and Donkeys) is 4.835 Mcm/year. The crops grown are Maize, Sorghum, Millet, Pulses, Roots/Tuber crops, Fruit crops, Local market vegetables, Export market Vegetables and Industrial crops. The theoretical net irrigation water requirement (NIR) is 1,099.194 Mcm/year and the actual NIR is 252.635 Mcm/year. The total overall demand is 295.239 Mcm/year against an available amount of 205.908 Mcm/year thus giving a deficit of 89.65 Mcm/year by 2002.The water deficit is expected to be 95.287 Mcm/year by 2003, 133.011 Mcm/year by 2010 and 195.239 Mcm/year by 2020 assuming the same trend of events. The rain-fed area is 323,968 ha and the irrigated area is 13034 ha. The cropping intensity is 167.7% and the irrigated cropping intensity is 10.7% and level if irrigation is 31.95%. An attempt has been made to evaluate the water resources in the study area in Kenya and analysis has been made to assess the level of water scarcity so as to quantify it.

The average rainfall with 10-year return period has been estimated as 1110.00 mm. The Hydrological Soil Cover Complex method and the long term average water balance method by Thornwaite and Mather have been used to estimate the average annual runoff and the values 184.77 mm and 183.50 mm have been obtained respectively. Soil loss has been estimated using the Universal Soil Loss Equation.

Present land treatments have been discussed and analyzed, both Agronomical and Mechanical works. Various methods have been recommended as suitable for the watershed. They include good farm management, companion crops, mulching, trash farming, contour farming, tied ridging or listing, cutoff drains, terraces, bunding, check dams, farm ponds, earth dams and agro-forestry. The total amount of water saved by all these measures is 446.221 Mcm/year (780.02 mm). Importance of participatory approach in watershed management has been discussed in detail pointing out the key areas, where and why it is required.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General

Watershed, which is also known as a drainage basin is the area drained by a stream or a system of connecting streams in such a way that all streams flow originated in the area, is discharged through a single outlet. It is the natural drainage area of a stream, lake, river or tank. It is also referred to as a hydrological entity in which hydrologic cycle completes.

Watershed management refers to the planning implementation and operation of programmes, projects and practices relating to natural resources and includes the physical, biological, social economic, engineering and institutional aspects of the designated watershed. Integrated land use, planning and comprehensive river basin planning is commonly known as watershed management planning. So watershed management is nothing but land management of a stream in a watershed in a better way to improve it's hydrologic regime.

Watershed Management has been defined as follows by different institutions and experts,

(1) The society of American Foresters (1944) states " Watershed management as the management of the natural resources of a drainage basin primarily for the production of water supplies and water based resources, including the control of folds and erosion and the protection of the aesthetic values associated with water ".

(2) The California department of water resources (1964) defines "Watershed management as the management of land, vegetation and water resources of a drainage basin for the control of the quality, quantity and timing of water for the purpose of enhancing and preserving human welfare".

(3) Brooks et al (1991) states " Watershed management is the process of guiding and organizing land and other resources on a watershed to provide desired goals and services without affecting adversely soil and water resources ".

(4) The University of Arizona (1991) states " Watershed management is the study of natural resources with an emphasis on the sustained production of commodities and amenities derived from wild land eco-systems, combined with a special awareness of water ".

(5) Black and Eschener (1995) states " Watershed management is the planned manipulation of one or more of the factors of the environment of a natural drainage so as to effect a desired change in or maintain a desired condition of the water resource ".

(6) Herbert C. Storrey states (1998) "Watershed management is the carrying out of planned practices and operations to attain desired objectives in terms of the functioning of the watershed. The two key words are *planned* and *objectives*. Watershed management does not just happen; things are done or not deliberately done for a specific purpose.

(7) Yadav R C, (2001) explains "Watershed management as a social process of planning, organizing, actuating and controlling through cooperative group actions for securing maximum benefits on a sustainable basis from natural resources viz, land, water, vegetation and animals & Human beings with minimum efforts so as to secure maximum prosperity and happiness of stake holders, user groups and other people and the government. Watershed management embodies two terms i.e. watershed, an hydrologic and hydraulic unit and management, a skill of conducting activities in an organized way. Different schools of thoughts provide scope for definitions of the management concept,

(a) Management may be defined as the art of securing maximum results with a minimum of efforts so as to secure maximum prosperity and happiness for both employer and the employee and give the public the best possible service (John F Wee).

(b) Management is a distinct process consisting of planning, organizing, actuating and controlling performed to determine and accomplish the objectives by the use of people and resources. (George R Terry).

(c) Management is a process by which a cooperative group directs action towards common goals (Joseph Massio).

(d) Management is principally the task of planning, coordinating, motivating and controlling the efforts of others towards a specific objective (James R Lundy).

(e) Management is the art of getting things done through and with people in formally organized groups. It is the art of creating the environment in which people can perform and individuals could cooperate towards attaining the group goals. It is the art of removing blocks to such performance, a way of optimizing efficiency in reaching goals (Harold Koontz).

In as much as watershed management has its roots in forestry, the watershed is generally considered to be the upland portion of the drainage basin. Like any other after system, a watershed system has it's inputs and outputs. The watershed itself, with it's own physiography, soils, geology, vegetation and institutional arrangements, can be considered as a mechanism for converting inputs into outputs. Watershed management contains components from several disciplines, principally engineering, forests, hydrology, soils, veterinary, agriculture, geography and geology.

In order to manage a watershed, three general principles have been identified as (Black, 1970),

(1) The natural ecology of the watershed as a dynamically balanced system,

(2) The runoff and factors affecting it, and

(3) The redistribution of water in the hydrosphere in relation to watershed management practices.

Watershed is concerned with manipulation of watershed responses to meet a certain goal or a set of inter-related goals. The watershed response goals are based on water quantity and quality and are produced by the interaction of the hydrologic inputs, ecosystem dynamics and usually the temporary veneer of human manipulations overlain to push the system towards a desired response. Since the input to the watersheds are susceptible to only minor changes through planned human manipulations, watershed management must involve changes in the pools and processes, the state variables and states of transfer within the ecosystems of the watershed. Sometimes watershed management can meet specified goals simply by manipulation of the biotic components of the ecosystems (e.g. vegetation management), but usually both the living and the non-living components may have to be altered (e.g. vegetation management and drainage modifications). A watershed may be quite small, an acre for example or it may be as large, to hundreds of thousands of square miles embracing much of the landscape, yet from an hydrologic stand point it is a dynamic changeable area.

1.2 Need for Watershed Management

There is a great need in the adoption of integrated watershed management approach, which is used as a unit for planning and management of land, water and other existing available resources of the watershed into productive use. The approach is to be holistic and multidisciplinary and with a practicable approximation of the systems approach. It enables the planners and managers to consider together various physical, biological, economic, socio-cultural and institutional factors operating within the watershed and it's environment and formulate a comprehensive and integrated watershed development plan in order to achieve specific objectives.

There is a need to protect the existing resources within the watershed area. The natural resources together with enhanced human skills; capital, inputs and technology are to be utilized in a manner that would maximize production, income and employment at the same time ensuring environmental security.

Strategies for an integrated watershed management programme must consist of the following:

(1) Identification of the watershed area,

(2) Determination of the correct land cover and land use pattern,

(3) Adoption of integrated watershed management approach in planning and implementation,

(4) Study of drainage pattern and hydrological condition of the watershed,

(5) To find out the appropriate soil and water conservation measures in all the private, community and public lands in the project area, by construction of check dams, water harvesting ponds and contouring etc.

(6) Introduction of improved crop production technologies in arable dry land.

(7) To prevent deforestation and to adopt afforestation in wastelands, barren lands, community lands and tank fore shore area.

(8) Initiation of dry land horticulture in marginal lands and introduction of agric-horticultural systems.

(9) Supporting the existing subsidiary enterprises like sericulture, bee-keeping etc.

(10) To increase pasture development area.

(11) Diversify agriculture with a shift towards commercial crops and high value production.

(12) To improve occupational diversification through trade, industry, tourism and service sectors.

(13) Increase in livestock care and improved breeding.

(14) Maximizing people's participation in integrated development of the area.

(15) Training of Engineers, Agricultural officers and farmers for improvement of crop production technologies, forest raising and maintenance and management of subsidiary enterprise.

(16) Protect and enhance water resources, attention of floods and reduction in siltation of tanks, increase irrigation and conservation of rainwater for crops and thus mitigate droughts.

(17) To utilize the natural local resources for improving agricultural and allied occupation or industries (small and cottage industries) of the local residents of the watershed area.

1.3 Watershed Management Techniques

1.3.1 Criteria for priority of watershed:

The basis for the identification of the priorities will be governed by the objectives, contents and operational details of the development programme. In most of the cases, basic data which will include the physical data, present land use, socio-economic condition and economics of development activities, as well as information needed in some specific cases. This information may be:

(1) Identification of areas contributing maximum runoff.

(2) Identification and demarcation of areas having developmental potential in forestry, grassland and agriculture.

(3) Optimal use of water, by construction tanks especially in drought prone areas.

(4) Categorization of command areas in terms of land irrigability and soil irrigable classes, keeping in view of water requirements and cropping patterns.

(5) Identification of areas having alkalinity along with ownership pattern.

(6) Reclamation of ravines for agriculture and permanent vegetation.

(7) In hilly areas, the suitability classification for afforestation, grassland, horticulture and agriculture have to be identified. Also, criteria and parameters that affect erodability and excessive runoff need to be considered.

1.3.2 Collection of data:

The type of data required include:

(1) Land cover information such as agriculture, forests, natural vegetation, exposed soil area, urban area and water bodies.

(2) Land use information such as agricultural area, pasture lands, and forestry activities.

(3) Geology of the area and the soil characteristics.

(4) Rainfall and runoff.

(5) Topographical information.

(6) Development activities.

(7) Socio-economic consideration.

1.4 Study Area

1.4.1 Objective and the scope of study

The study area is the catchment for the upper Athi River basin who's potential has diminished resulting to food shortages, soil erosion, declining crop yields, deforestation, fuel wood shortage, fodder shortage, water shortage and land degradation. In terms of the physical resource base, it is the disruption of hydrological cycles that will do most damage to the biological and economic productivity. The land use change in Machakos is a story of people maximizing returns to water under changing economic and ecological conditions at different scales and with varying degrees of control over their own and other people's use of the resource. Whereas people formerly concentrated around permanent groundwater sources or along perennial streams, widespread deforestation and soil compaction level have led to transformation of many permanent ground water sources to seasonal supplies and have reduced perennial streams to intermittent flow. This has changed the water quantity and quality and has drastically altered the timing and terms of water availability for agriculture, livestock and domestic use. More over the changes in use pattern aided by those effects has in turn caused further damage and disruption in watershed systems. The main objectives of study include,

(1) Determination of the extent of water shortage (the key player) in the district in a sense justifying the need for watershed management.

(2) Estimate the runoff and the soil erosion from catchment before and after the watershed management measures.

(3) Study the various measures taken elsewhere and recommend the most feasible ones.

(4) Analysis of the existing measures pointing out the failures.

(5) Various approaches to watershed management will be looked into and the feasible ones will be recommended for adoption in the study area.

1.4.2 Country background information

Kenya shown in Fig 1.1 covers an area of approximately 587,900sq.km and 576,000sq.km is land surface of which 461,400sq.km (80%) is classified as arid and semi arid lands (ASALs). The remaining 115,300sq.km is of medium to high potential suitable for general Agriculture. This classification is based mainly on the average annual rainfall and evapotranspiration.

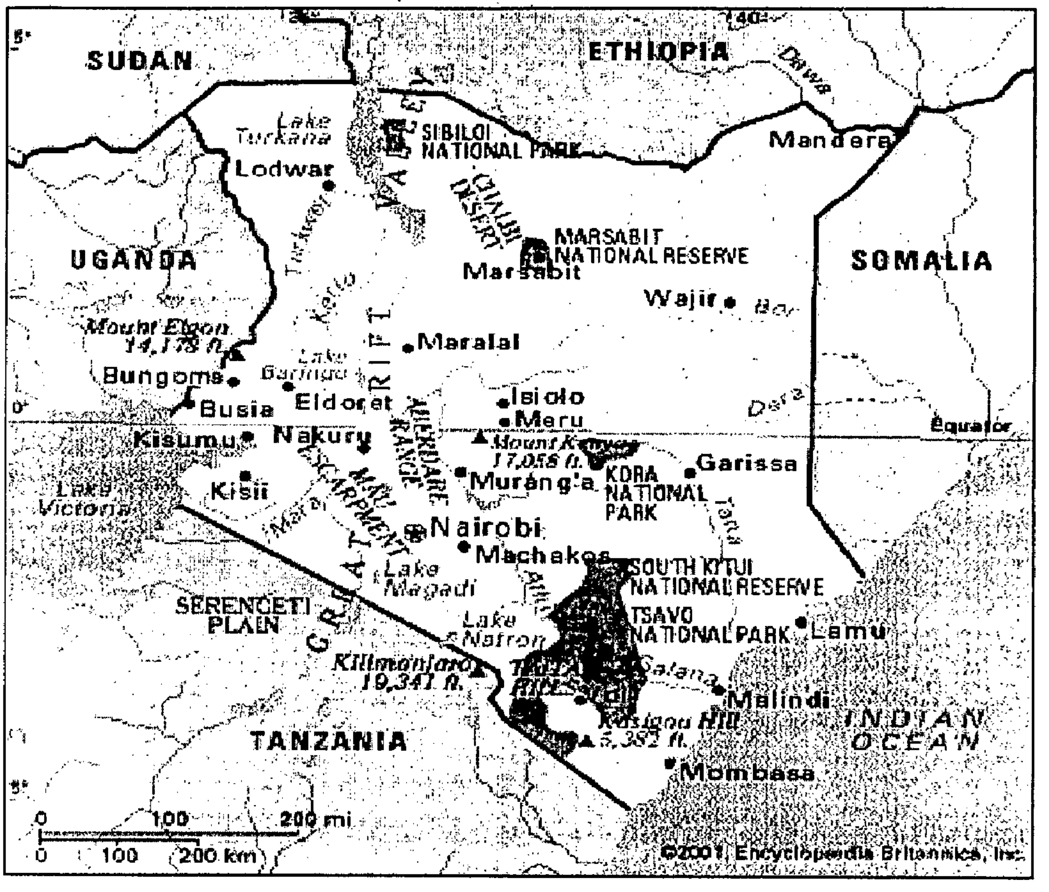


Fig.1.1 is the political map of Kenya.

The high and medium potential areas contain important catchments and are devoted to crop and milk production, while the ASALs are largely used for extensive livestock production and national parks. The medium to high potential areas support 80% of the Kenya's population while the ASALs support the rest of the population and about 50% of the countries livestock herd. The populations as per 2002 estimates was 30 million of which 70% are farmers. The major food crops are maize, wheat, pulses, root crops and tubers (FAO/GIEWS 2000). Maize represents 40 – 45% of the calories. The cash crops include Tea, Coffee, Horticultural crops, cut flowers, pyrethrum, Bananas, etc.

The country receives a mean annual rainfall of 621 mm. According to the National Water Master Plan Report of 1998,the overall national annual water volume potential is estimated at 20,000 m^3 (Auther, 1988) consisting of ground and surface water. The demand is less than 30% of the total water resources potential. However, poor distribution and reliability of rainfall results in water shortages. The ground water potential is estimated to be 619 million cubic meters comprising of deep aquifers exploitable through boreholes and shallow wells. The economical depths at which boreholes draw water in Kenya are found to be about 100 to 200 meters. Only a small fraction of rainwater gets stored as ground water in a given period. In the arid and semi arid climatic zones, the ground water recharge is generally of order of

5% of annual rainfall while in the humid /semi humid zones, the recharge is generally of the order of 10%. However in the sandy aquifers or in unconsolidated basaltic rocks, recharge is much higher, in the order of 30% of rainfall.

Rainwater harvesting from roof and ground catchments have been developed in various districts, especially in the semi arid and arid lands where the perennial rivers are non-existent. However progress is hampered by lack of tested design parameters and absence of appropriate water policy. Water is a renewable resource although the annual amount available remains finite. Assuming a limit for chronic water scarcity as 1,000 cubic meters per capita (World's Universal limit) per annum, then Kenya at 780 cubic meters per capita per annum is already experiencing acute water scarcity.

1.4.3 Machakos district (Background information)

1.4.3.1 Location

Machakos district is in eastern province of Kenya as in Fig 1.2. It stretches from latitudes 0' 45" south to 1' 31" south and longitudes 36' 45" east to 37' 45" east. The district covers an area of 6,281.4 km^2 most of which is semiarid. High and medium potential areas where rain fed agriculture is carried out consists of 1,574 km^2 or 26% of the total area. Administratively, the district is divided into 12 divisions namely central, Kalama, Kangundo, Kathiani, Masinga, Matungulu, Athi River, Mwala, Ndithini, Yathui, Yatta and Katangi shown in Fig 1.3.

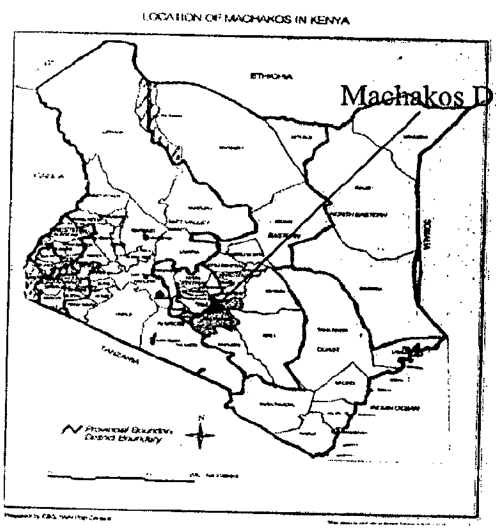


Fig. 1.2 Districts and provinces of Kenya

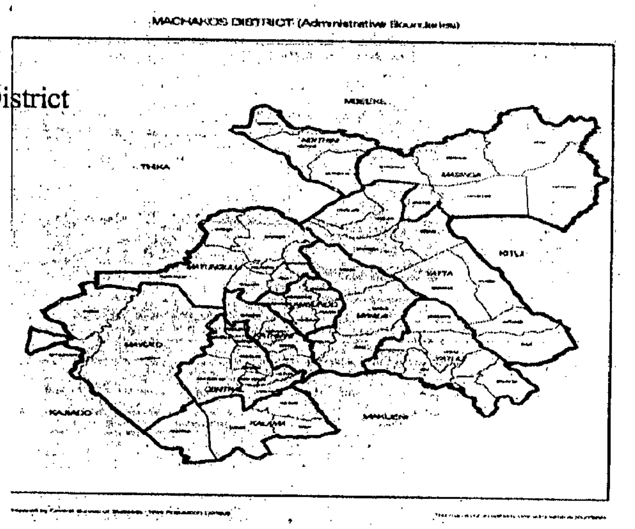


Fig. 1.3 Divisions in the district

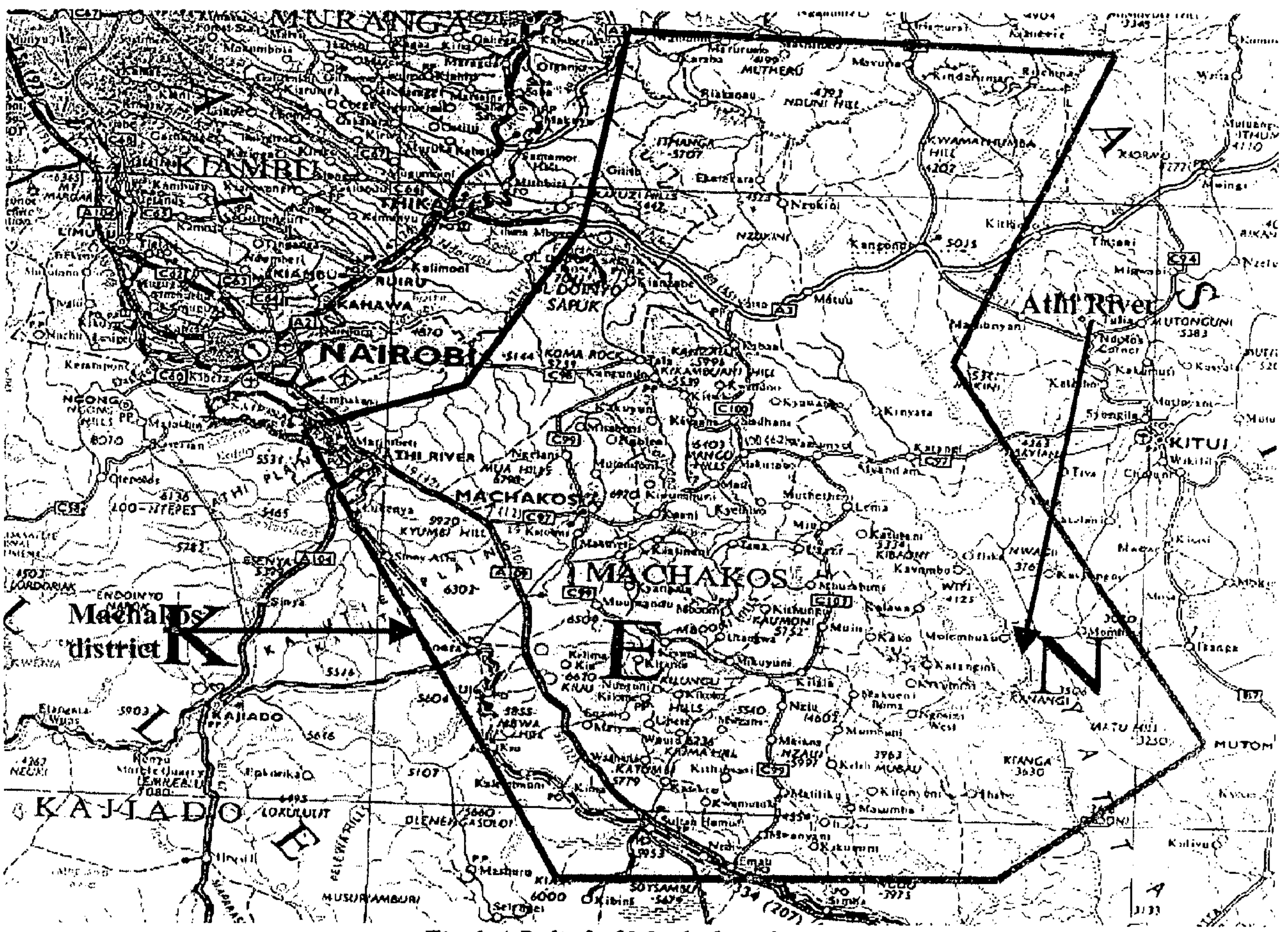


Fig 1.4 Relief of Machakos district

1.4.3.2 Geology

Machakos district shown in Fig 1.4 consists of plains within a horseshoe shaped ridge reflecting the geology of the area. The hills surrounding Machakos are made up of the pre-Cambrian basement series known as the Mozambique belt system. The rocks consists of originally sedimentary rocks all of which have been metamorphosed, some gratinized to a greater extent and are predominantly biotite-granitoid guesses. In the plains between the hills, volcanic deposits and sediments overlie the rocks of the Mozambique belt and sediments from the erosion of the surrounding hills. The soils in the area are a result of the decay of underlying rocks. The basement system (Mozambique belt) rocks in Machakos are mainly gratinitoid guesses, schistose guesses, schists and crystalline limestone of sedimentary origin. Erosion subsequent to the mid-tertiary period has been a result of repeated regeneration with deep incision of the main river courses and extension of the tributaries often following faulting patterns. Superficial deposits present, which include soils, sands and alluvium, are products of sub-aerial denudation under semiarid conditions.

1.4.3.3 Land and soils

About 26% of the total area in the district is classified as agricultural land while 74% is rangeland. Due to land pressure or availability of irrigation facilities, 10% of the rangeland is cultivated either through irrigation or rain fed systems. Land use and settlement patterns are based on agro-ecological zones and are influenced by soil fertility and rainfall. The high settlement is along the hills masses of Matungulu, Kangundo, Kathiani, and Central and Mwala divisions. The hill masses receive moderately high rainfall and have very great agriculture potential and fertile soils. Spatial settlement is found in the low plains where ranching and dairy farming is carried out.

Table 1.1 gives the distribution of population and population densities by division.

Table 1.1: Population densities in the district

Division	Area km^2	1999	2002	2004
Central	491.5	292	307	318
Kalama	330.2	124	130	135
Kangundo	178.2	512	539	557
Kathiani	205.8	462	486	503
Matungulu	634.3	157	165	171
Athi River	957.0	51	54	56
Mwala	481.5	185	195	201
Ndithini	316.8	102	107	111
Yathui	533.0	123	129	134
Katangi	568.0	86	90	94
Yatta	491.0	156	164	170
Masinga	1094.1	68	72	74

Source: District Statistics Office, Machakos

Distribution of soils by type and area

Verisols are poorly drained, deep, grayish brown to black cracking clays. In some places they are bouldery and stony and in others they are sandy. They are of moderate to high fertility.

Acrisols/Ferrasols are deep friable and excessively drained. They range from sandy clay loam to sandy clays. They also range from brown to dark red in color and have a moderate to low fertility. Planasols are imperfectly drained, moderately deep, dark grayish brown to black and very firm. They are of moderate to low fertility.

Cambisols are excessively drained, deep, dark red to dark yellowish, friable sandy clay loam to sandy clay. They are easily erodible forming deep gullies. In some places they have thick acid humid topsoils. They are various fertilities.

Zone 2: This zone has virtually no risk of crop failure. Rainfall is relatively high and more reliable (annual average is about 1200 mm). It covers an area of 185sq. km in Iveti, Mua, and Kangundo.The zone has high population density. The main land use activities in this zone are coffee, maize, beans, citrus fruits, dairy farming and forestry.

Zone 3: Average annual rainfall is 850 mm. It covers an area of 560sq. km and includes lower elevation of Iveti, Kangundo and Mua. The predominant soils are cambisols and arenosols, which are mainly of variable fertility and in some cases ranging from moderate to low fertility. Unsuitable slopes cover some parts. Crops grown in this region include coffee, maize and wheat.

Zone 4: This zone covers a very large part of the district and form parts of Mwala, Ndalani, Kinyatta and Katangi in Yatta, Kangonde and Ndithini in Masinga, parts of Mitaboni and Iveti in kathiani, parts of Mutituni in Central division and parts of Matungulu and Donyo Sabuk in Kangundo.Average annual rainfall is 750 mm. Reliable. Reliability is low and crop failures are common. Drought resistant crops are grown. Livestock activities (cattle and goats) rearing are undertaken. The soils are mainly arenosols, acrisols and ferrasols. They are generally shallow along the plateau and the slopes of Donyo Sabuk.

Zone 5: This covers most parts of Masinga and Yatta, and parts of Mwala bordering the plateau and a small part of Kangundo and Mitaboni.This zone is arid and receives an average of 650 mm per year. Drought resistant crops are grown and ranching activities are also undertaken. The soils are mainly aerosol, vertisols, planasols and aeronosols of which 55 % are of low fertility. Areas around Masinga dam, Kangundo, Kithimani, and Donyo Sabuk have moderate to high fertility. Some pockets in Lukenya also have high fertility.

Zone 6: This is a ranching zone with no rain fed agriculture and it covers Kapiti plains. This zone receives an average rainfall of 500 mm and there is limited irrigation near Athi River town. The soils are mainly vertisols of moderate fertility with a small portion of moderate to high fertility coupled with saline soils. The development potential of the agro economic zones in the district is determined by various factors including rainfall, soil type and pressure on land. The zones classified as high potential are already suffering from high population pressure and the only avenue left is to increase yield per hectare by introducing high yielding varieties of food crops suitable to the kind of climate in the district.

Generally the soils in the district lie in the range from sandy clay loam to sandy clay and are hydrologically classified in groups C and D. The hydrologic soil properties can be classified by the soil characteristics as shown in the table 1.2 below,

Table 1.2: Hydrologic Soil groups (Source: Rawls et al; 1982)

Texture Class	Effective water Capacity (in/in)	Minimum Infiltration rate (fc) in in/hr	SCS Hydrologic Soil Grouping
Sandy clay loam	0.14	0.17	C
Clay loam	0.14	0.09	D
Silt clay loam	0.11	0.06	D
Sandy clay	0.09	0.05	D

1.4.3.4 Physiographic and natural conditions

The district enjoys a pleasant climate although relatively warmer, varying from highland equatorial on the hill summits to semi arid on the plains. The topography of the district is varied and rises from 700 m above sea level on the southern part of the district to 1,700 m above sea level in the west. This is however interrupted by an escarpment and a series of hill masses, the highest of which is Kilimambogo (Donyo Sabuk), which rises up to 2,144 m above the sea level. A huge proportion of district is semi arid and receives very little and erratic precipitation. There are two distinct rainy seasons. The long rains fall between March and May and the short rainfall between October and December. The annual average rainfall varies from 500 mm to 1300 mm with high altitude areas receiving more rain than low-lying areas. The temperatures also vary with altitude. The mean monthly temperatures are ranges from 12^0 C in the coldest months (July – August) to 25^0 C in the hottest months (March and October).

The forests which occupy 2,240.6 ha gazetted forests cover an area of 706.6 ha distributed amongst the Iveti Hills (348.2 ha), Uuni hill (92.7 ha), Kiteta Hill (110 ha), Muumandu hill (139.2 ha), and the forest department compound (16.5 ha). Ungazetted forest is on the Kibauni Hill covering an area of 1,619 ha, Mango Hill (45 ha) and the unsurveyed Kanzalu Hill (110 ha). Kibauni forest hill is being used as a center for development of protective forests through trial of different tree species that may survive in the lower potential areas. The trees planted include Cypress sp., Eucalyptus sp., Pinus Patula, Pinus Radiata, Gravellia sp., Juniperus sp., Acacia forests, Cassia Siamea Croton, Megalocarpus, Jacaranda, M. Moraefolia and Melia Azedirach among others.

CHAPTER 2

LITERATURE REVIEW

2.1 Watershed Management

Watershed Management plays a very significant role in the arid and semi-arid regions that have concentration of eroded and degraded natural resources especially along highlands areas. Loss of vegetative cover followed by soil degradation through various forms of erosion have resulted into lands which are thirsty in terms of water as well as hungry in terms of soil nutrients. All these regions have predominantly livestock-centered farming systems; less biomass for animals not only reduces animal productivity, the inevitable uncontrolled grazing pressure on already eroded lands further worsens the problem and deteriorates the ecological balance. Growing population pressures, higher demand for food and fodder coupled with impact of rapidly changing socio-economic conditions have added fuel to the fire. In order to maximize advantages in developing these watershed areas, all developmental activities should be undertaken in a comprehensive way on watershed basis.

The main principles of watershed management are:

1) To protect, conserve and improve the land resources for efficient and sustained production
2) Utilizing the land according to its capability
3) Putting adequate vegetal cover on the soil during rainy season
4) Conserving as much rain water as possible at the place where it falls
5) Draining out excess water with a safe velocity and diverting it to storage ponds and store it for future use
6) Avoiding gully formation and putting checks at suitable intervals to control soil erosion and recharge ground water
7) Maximizing productivity per unit area, per unit time and per unit of water
8) Increasing cropping intensity and land equivalent ratio through intercropping and sequence cropping
9) Safe utilization of marginal lands through alternate land use systems
10) Ensuring sustainability of the eco-systems benefiting the man-animal-plant-land-water complex in the watershed

2.2 Research contribution in Watershed Management

Many researchers have worked for Watershed Management. Some recent contributions are discussed in the following paragraph.

Chess et al (2000) reported that the issues concerning the requirement for stakeholder involvement alongside government and scientific community participation in watershed management in the USA, including the need for adaptive approaches to participatory processes, are discussed.

Reddy et al (1999) reported that watershed development programmes have been implemented in India for over 20 years. An integrated approach to the programme as a strategy was initiated during the period 1975-83. By the Ninth Five-year Plan a number of agencies have been involved in initiating and implementing the programme in almost all the agro-climatic zones in the country. Furthermore, the programme has been receiving high priority from the Union Government, the state governments, multi-lateral and bilateral agencies and the NGOs. Thus, watershed approach has been identified as a major route and a promising area for development of agriculture. Over the last 20 years of experience in implementation of this programme several areas of successes and shortcomings have been identified. However, for sustainable development of agriculture, the paper argues that unifying the multiplicity of watershed programmes within the framework of an overreaching national initiative is desirable in national interest.

Shah (1999) reported a study that tries to assess the qualitative impact of the National Watershed Development Project for Rainfed Areas (NWDPRA) in 2 micro watersheds, namely, Danta (Saraswati) of Banaskantha district and Dayapur (Lakhpat) of Kutch district in Gujarat state, India. The data for the study were collected from 50 beneficiary households and 25 non-beneficiary households of each watershed during the year 1993-94. The study shows that the Danta watershed was more effective in generating positive impact in moderate to good rainfall situation compared to Dayapur with very low rainfall condition. The NWDPRA turned the cropping pattern in favor of more profitable commercial crops and induced increased use of fertilizer, high-yielding variety and improved seeds. Productivity and cropping intensity has also increased. The construction of check dams, vegetative contour bunds, and embankment to harvest rainwater, and the planting of trees, shrubs, and grasses have greatly helped in reducing soil erosion. It is concluded that a watershed management programme is economically viable, feasible and holds key to the development of rainfed areas.

Singhal (1999) reported that People's participation in watershed management decrease the perpetual dependence of the people on the government thereby making the programme self-sustaining and gaining access to control of the resources. The paper is based on an empirical study of Nada watershed development project situated in Shivalik hills of Haryana, India. The study tried to elicit the level of people's participation in planning, implementation and monitoring of watershed activities. Besides the role of village people in protection of hill resources through Hill Resource Management Societies (HRMS) was also studied. The Participatory Rural Appraisal method was used to elicit information from small and marginal farmers, members of HRMS, Panchayat and Government officials of forest department. The views of women were also taken.

Central Soil and Water Conservation Research and Training Institute (CSWCRTI) (2000-2001) reports that at Badakhera watershed in Bundi district of Rajasthan (developed under TDET, IWDP project), the impact of various biological and mechanical measures was evaluated. Improved technology increased the yield of mustard, wheat, green gram, Soya bean and pigeon pea by 76, 98, 65, and 39% respectively. Conservation measures recorded 76.09 and 47,32% less runoff and soil loss as compared to untreated watershed. At Antisar watershed located at Kheda district of Gujarat, under IWDP Tech-DET project, various conservation and agronomical measures undertaken in demonstration on farmers' fields resulted in increased crop yield by 18 – 155%.

At Kokriguda watershed in Orissa, a study on people's participation indicated that land holding had greatest impact followed by education. Age of the head of family was also having significant impact i.e. the younger the head, the greater was the participation. Intercropping system of ragi + pigeon peas (2:1) gave the highest returns. At Kattery watershed in Tamil Nadu, 60 self-help groups (SHG) were formed with 80%women representation. Overall participation in watershed meetings was 82%, the women participation being the highest. Community contribution to CPRs was 40% in terms of cash and kind. About 56% of persons attended training and the knowledge gained was being utilized in practice. Adoption of soil and water conservation technologies was found to be 26%. A study to evaluate the performance of watershed management programme in 29 shiwalik foothill villages in Haryana state, revealed that only in 7 cases the programme proved successful mainly because of the farmers of these watersheds as well as implementing agencies were able to govern, maintain and manage the system over a period of time and the programme yielded sustainable benefits. In other cases, the programme did not achieve success as the communities were not able develop effective management system.

Many of the water harvesting structures stopped functioning due to various reasons including sedimentation. This declined the income and incentives of the watershed management societies.

Hazra et al (2000) reported that the central plateau and hills region of Uttar Pradesh has experienced severe deforestation, land degradation and erosion. A description is given of a community agro forestry project in seven micro watersheds in the Kharaiya Nala, which together comprised 5395 ha. The holistic management strategy embraced measures to conserve soil and water (through construction of contour trenches and dams, and planting of multipurpose trees, grasses and legumes), improve crop production, regenerate the hills and hillocks that constituted the village common lands, and create an appropriate management plan. The reduction in water and soil loss, changes in soil fertility under silvopastoral and legume pasture systems, improved crop and fodder yield, and changes in domestic livestock to improve milk production are described. Economic analysis showed that virtually the entire expenditure of establishing agroforestry practices was recovered within 3 years. Additional benefits included improved crop productivity on adjoining lands because of reduced scree deposition, aquaculture in impounded runoff water, and employment in basket making.

Kishor (2000) presented an overview of the development of watershed programmes in India. Issues discussed are: problems and prospects of watershed development in India; land and water resources; watershed management and rural development; programmes and progress; people's participation and watershed development; funding of watershed development programmes; and the NABARD IGWDP approach to watershed management.

Qi-Shi et al (2000) reported the problems; counter measures and development of management of the Huangjiaercha small watershed in the Ningxia Hui Autonomous Region of China in different control stages are introduced. The watershed management and agriculture sustainable development model could be divided into three stages: comprehensive control stage, strengthening, promoting, stabilizing stage and a sustainable development stage. The issues related to long-term policy making, population, scientific research and technology extension, and markets should be addressed.

Ramanathan (2000) reported various factors involved in land degradation in India are reviewed (soil erosion by wind and water, water logging, salination, deforestation, removal of vegetation, overgrazing, inappropriate agricultural practices, including misapplication of fertilizer's and biocides), and the classification of degraded land into cultivatable wasteland and uncultivatable wasteland using GLASNOD (Global Assessment of Soil Degraded) and its relationship to catchment hydrology is discussed. Agenda's are presented for the Wasteland Development Programme (WLDP), which aims to bring into cultivation wasteland which is cultivatable, and the Watershed Management Programme (WSMA), which aims to promote activities which conserve as much rainfall as possible in situ in the soil profile or through controlled runoff collection, storage and reuse according to land capabilities.

Rao (2000) presented a paper that discusses the experiences of the Drought Prone Areas Programme in India and raises important issues on the sustainability of watershed development as the programme comes to an end. Following an outline of the present watershed development strategy; prospects for agriculture in 2020; the social, economic and environmental impact of the programme; and the factors accounting for good performance, five major issues are considered: (1) institution-building and leadership formation for ensuring effective participation of people on a sustained basis; (2) capacity building through training at various levels; (3) expert and independent evaluation of the programme; (4) convergence of agriculture development programmes with watershed development; and (5) according high priority to the strategy for the development of rain fed farming in the country.

Reddy (2000) reported that a review of studies pertaining to the economic and ecological impacts of watershed technology in India is presented. The paper attempts to lay the theoretical ground for a detailed and rigorous empirical work through collective action (CA) theories and their adaptability in the context of watershed management. Its objectives are to examine the issues involved in different aspects of watershed development and management, and identify the important strategies that need further attention. Important issues in this regard include: economic and ecological viability of watershed technology; the theoretical framework for collective action in watershed management; and strategies for sustainable watershed management. The proposed empirical study is introduced along with its objectives and methodology. Points to consider include: (1) there is a need to recognize watershed technology as a common good, which needs participatory development; (2) the approach is to recognize CA as a primary objective in watershed development programmes; (3) the state should supply institutions according to demand (at the grassroots level) and these institutions should minimize transaction costs through conductive policy and political environment; (4) there is a need for an interdisciplinary approach to integrating technology (watershed development) and philosophy (CA); and (5) along with the issues of economic viability, equity in the distribution of economic gains among the participants is required.

Reddy (2000) reported that the Rural Development Trust (RDT) is a voluntary organization working in Anantapur District of Andhra Pradesh, India. There has been a committed effort within the RDT to follow the participatory approach to watershed development in the true spirit of the government-funded new Guidelines. The following reflections are based on their experiences through working with people and the Government administration. Issues discussed are: people as the main actors; people's attitudes; the paternal attitudes of government functionaries; divisive and party-political leadership; corruption; inadequate involvement of personnel; the centralized philosophy of management; physical and financial monitoring; cost-sharing (criteria and process in selection of a watershed village; pre-conditions for village selection; and provision for de-selection and penal action); and the future.

Schreier et al (2000) reported a case study on the World Overview of Conservation Approaches and Technology (WOCAT) programme of the World Association of Soil and Water Conservation (WASWC), the aim of which is to contribute to sustainable use of soil and Water through the collection, analysis, presentation and dissemination of soil and water conservation technologies and approaches worldwide

Estrada et al (2001) reported that the watersheds are an attractive unit for development in mountainous landscapes. However, watershed analysis usually requires significantly more time, data and funds, and must include more actors. A watershed analysis was conducted by the Consortium for the Sustainable Development of the Andean Ecoregion research and development programme to promote equitable, competitive, and sustainable development in the rural Andes. This paper outlines the stages in the process of making the watershed analysis operational: estimating soil loss and stream flow under current land use patterns; constructing a farm model; characterizing the externalities of upper catchment management on downstream users; testing new scenarios; and evaluating the impact of land use change on employment. The analytical results from their application in Colombia are discussed. Many off-site effects were very difficult to modify without major changes in land use systems. Frequently, these land use changes (e.g. more pasture or reforestation) pitted soil conservation against rural employment. In other cases, sediment, originating on-farm, but primarily appearing in other parts of the landscape, implied civil engineering rather than on-farm solutions. It was found that good maps and valid models were of growing interest to municipal authorities as they consider alternative development plans. Analysis of externalities of current land use practices indicates that it is unlikely downstream users would pay for upstream soil and water conservation activities. It is suggested that natural resource conservation changes in current land use systems will have a negative effect on employment opportunities in the watershed, probably increasing rural poverty.

Gardi (2001) reported that the European union (EU) agricultural policy has induced significant changes in crop rotations, especially in marginal areas. The evaluation of the impact on water quality induced by this new agronomic framework is presented in the paper. The discharge, the sediment content and the concentrations of herbicides and nitrates in the Centonara creek, draining a hilly watershed near Bologna, Italy, were measured from October 1994 to September 1996. A geographic information system (GIS) and the crop simulation model CropSyst were used to characterize the relationships between cropping systems, land use, pedological and morphological properties of the watershed as well as nitrate losses. Hydrological results showed that the Centonara creek discharge was characterized by low base flows and by fast increments during flooding. Herbicide concentrations were above the EU 0.1 mg $litre^{-1}$ limit on several occasions, whereas nitrate concentrations were always below the 50 mg $litre^{-1}$ limit established by EU for drinking waters. It was estimated that more than 30% of the nitrogen input in the watershed is due to atmospheric depositions. The purpose of GIS was to subdivide the watershed in 86 agronomically homogeneous areas, which were then utilized as the basis for the application of Crop System Simulations obtained by the model showed that the greatest leaching losses of nitrates were higher than 10 kg ha^{-1} $year^{-1}$ exclusively in the agronomically homogeneous areas characterized by coarser textured soils. Overall, nitrate and herbicide losses were low, mainly due to the differentiation of the cropping systems in the watershed. The combined use of GIS and CropSyst enabled the characterization of the environmental vulnerability in relation to the land use in the watershed by means of pedologic cartography, land use maps and meteorological data. In particular, erosion and herbicide losses were higher in sloping areas planted with spring-summer crops. The increase in row crops cultivations, determined by EU agricultural policy, represents the main impact on water quality of the investigated area.

Kerr et al (2001) reported a chapter that examines factors contributing to incentives for improved agricultural productivity and natural resource management across a broad sample of watershed management projects in India's semi-arid tropics. A variety of factors are found to affect these incentives including population density, infrastructure, social organization and agro climatic conditions. Importantly, participatory projects that focus as much on social organization as on technology transfer are shown to be generally the most successful.

Lu-ShiangYue et al (2001) reported that few places in the world experience the severity of watershed management problems faced by Taiwan. The island is a 74% mountainous region with steep slopes and weak geologic formations. Each typhoon season brings torrential rainfall, resulting in frequent flooding, debris torrents, and landslides. Seasonal water shortages occur in parts of the island, a problem that will become more severe as Taiwan's population expands from its current 590 people per square kilometer. Despite forest exploitation earlier in this century, Taiwan now manages its 58% forest cover primarily for watershed protection with an emphasis on slope stabilization. Watershed protection in the past has relied heavily on engineering structures on hillslopes and along stream channels, which raises some concern about unwanted downstream effects. Forest clearing for crops, road construction and various development schemes are also of concern because of reduced slope stability, increased sediment and pollutant delivery downstream, and increased peak flows. This paper discusses watershed management needs for the coming century, considering cumulative effects of past land use changes on Taiwan's mountainous watersheds, and the issue of non-structural versus structural engineering solutions to watershed problems. Watershed management implications of institutional and policy changes related to forest lands administration are also discussed.

Shah et al (2001) reported a study that seeks to examine the initial experiences of some watershed development programmes in the predominantly dry region of Gujarat, India, in terms of their benefits and their sustainability. Such initiatives have remained limited in terms of coverage of land as well as households. The analysis brings out some useful policy implications with respect to better sharing of irrigation and/or water resources, enhancing the actual benefits from farm economy and cost recovery, as well as cross-subsidization. The early lessons may help improve the implementation, equitable impact and sustainability of future watershed development programmes.

Wang (2001) reported the spatial relationships between land uses and river-water quality were examined for the Little Miami River watershed, Ohio, USA using biological, water chemistry and habitat indicators. Data from relevant federal and state agencies were integrated using Geographic Information System spatial analysis functions. Twenty-two catchments for river segments near headwaters and with water quality monitoring data were delineated and digitized for referencing to the river network. Results are presented from 3 aspects - the impact of waste water treatment plants, the spatial patterns of river-water quality, and the relationship between land uses in the catchments and water quality of the receiving water. The Index of Biotic Integrity measurement from the closest sites to the discharge points demonstrated a statistically significant decrease of water quality downstream from the wastewater treatment plant discharges. A spatial distribution of the urban land use shows that there are 2 major urban areas and a few smaller settlements scattered within the LMR watershed. Among the 22 catchments, urban land percentages varied from 1 to 58% and agricultural land percentages varied between 12 and 95%. The relationship between the water quality of receiving waters and land uses in a watershed indicated that increasing population pressure resulted in increasing pollutant loads and integration pf water quality management and land-use planning was required to protect the river system and promote ecologically and economically healthy land development. The components of watershed management are;

1. Human resource development (skills upgrading, organization development etc.)
2. Soil and water conservation measures.
   - Land treatment (bunding, trenching, vegetative barriers, bench terracing etc.)
   - Drainage lines treatment (gully control works)
   - Water harvesting structures.
3. Agricultural development (seed production, cropping pattern, organic farming, etc.)
4. Alternate land use systems (afforestation, agroforestry, dryland horticulture, fodder production, non-timber products, etc.)
5. Livestock development
6. Watershed plus activities (empowerment, improved conditions of living, etc.)

2.3 Soil and Water Conservation Treatments

As evident from a review of traditional practices and also supported by the recent research experiences, different mechanical structures are dependable means of checking soil erosion and increasing rain water infiltration opportunity time. Such steps show their effectiveness in preventing the land degradation as soon as they are formed. Management approaches that reduce the speed of runoff can significantly improve water quality, most obviously by reducing sediment loads, but also by subjecting surface water to the filtering effects of the soil.

2.3.1 Bunding

Bunds are small earthen barriers provided in agricultural lands with slopes raging from 1 to 6 percent. They control the effective length of slope and thereby reduce the gain in velocity of runoff flow to avoid rill and gully erosion.

Important objectives of the bunding are:

i.) To increase the time of concentration of rain water where it falls and thereby allowing more opportune time for rain water to be absorbed in the soil profile

ii.) Converting a long slope into several short ones so as to minimize velocity and thereby reducing erosive power of runoff water

iii.) To provide field to field access for man and animals for undertaking agronomic activities

iv.) To divert runoff water either for water harvesting purposes or for saving lower lands from excessive sand deposition or getting severely eroded.

Specific site conditions:

Generally, bunds have been classified into two categories:

1) Graded bunds -bunds, which are constructed in medium to high rainfall having annual rainfall of 600 mm above and in soils having poor permeability or those having crust formation tendency.

2) Contour bunds -bunds that are constructed in relatively low rainfall areas having annual rainfall of less than 600 mm; particularly in the areas having light textured soils.

In general, both graded and contour bunds are usually constructed with some deviations and they are adjusted with field boundaries. Extra care should be taken to keep such deviations within permissible limits-not more than 30 cm across valleys and 15 cm on ridges.

Design criteria and procedures:

a) Graded bunds

Graded bunds maybe further classified into two broad classes (i) bunds with channel, and (ii) bunds without channel. According to recent studies, bunds without channel have been found superior, in case there are given longitudinal grades of 0.2% or more; the biggest plus point in favor of these bunds is their easy maintenance. The design criteria for construction of such graded bunds are based on the concept of stable channel design. However, minimum cross section of these bunds is $0.5m^2$, which is reduced to $0.3m^2$ in shallow soils. For heavier soils, the cross sections of these bunds should be $0.75m^2$.

The spacing between two bunds is based on the formula,

V.I. = (S/a+b)0.3

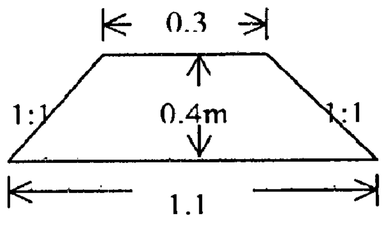
Where V.I. =vertical interval, m

S =slope, %

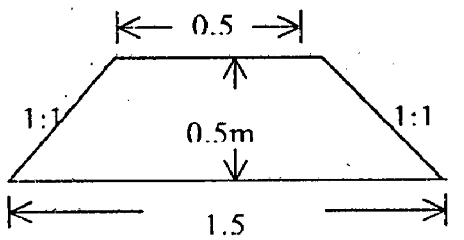
a =constant value ranging from 3.0 to 4.0 for good permeable soils

b =constant with average value of 2.0

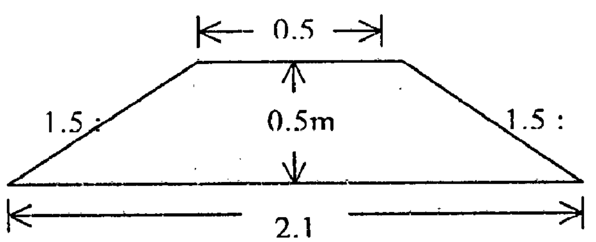
Design details for minimum bund sections for different soil situations are given in figure 2.1. In situations where adequate vegetative protection to the bunds is expected, bund section can be reduced considerably.



(a) FOR SHALLOW SOILS, C.S. AREA=0.28m^2



(b) FOR RED AND ALLUVIAL SOILS, C.S. AREA=0.5m^2

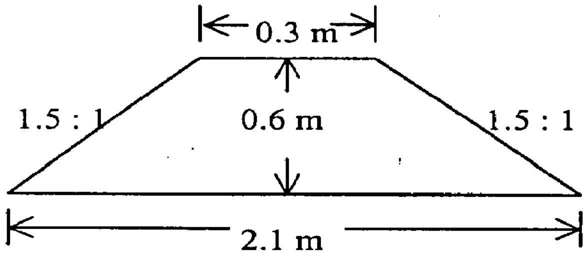


(c) FOR HEAVIER SOILS, C.S. AREA=0.675m^2

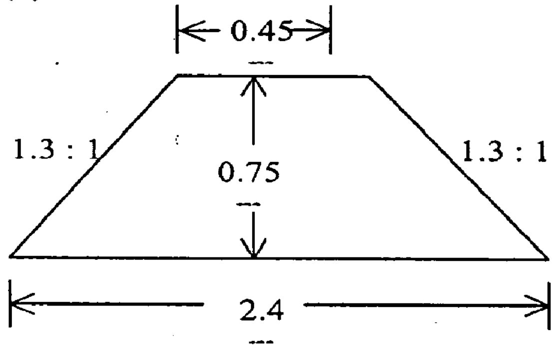
Fig. 2.1 Graded bund sections for different type of soils

b) Contour bunds

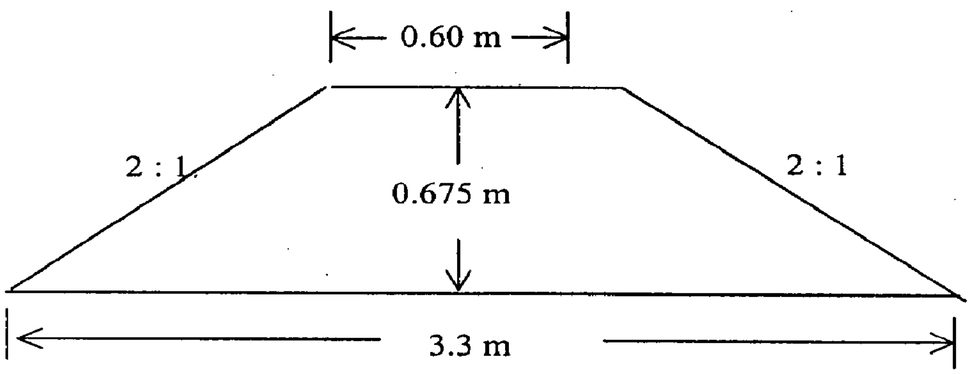
Contour bunds are essentially meant for storing rainwater received during a period of 24 hours at 10 years recurrence interval. The major considerations are maximum depth of water to be impounded, design depth of flow over waste weir and desired free board. Fig 2.2 shows the contour sections for different soils



(a) FOR RED SOILS C.S. AREA=0.72 m^2



(b) FOR SHALLOW TO MEDIUM BLACK SOILS C.S. AREA=1.07 m^2



(c) FOR DEEP SOILS C.S. AREA=1.32 m^2

Fig.2.2 Contour bund sections for different soils

The depth of water expected to be impounded against the bund will largely depend upon rainfall factors, rate of infiltration of the soil and vertical interval between bunds. The following equation is used in arriving at the maximum depth of water to be impounded.

$$F = \sqrt{DR/500}$$

Where F =depth of water to be impounded, m

D =vertical interval, m decided more or less on same principles as explained in case of graded bunds, m

R =maximum rain water on area basis to be stored, mm

The actual height of the bund is decided after allowing adequate free board nearly 20 % of the depth. Usually water storage equivalent to 50 mm of rainfall is considered adequate for design of contour bunds at most of the places.

2.3.2 Trenching

Contour trenches are made in non-agricultural areas for providing adequate moisture conditions in order to raise tree and grass species.

Objectives:

i) To cut down the velocity of overland flow

ii) To store rain water for the benefit of plants

Specific site conditions:

Contour trenches are made in non-cultivable areas having silvi-pasture, silvi-horticulture or agro-horticulture programmes at a spacing of 10 to 30 m.

Design criteria:

For designing trenching system, factors like soil type, slope and suitable tree species for the area are to be considered. Usually they are designed to hold one-day rainfall at 2-year frequency. Generally, trenches are made with a minimum depth of 0.40 m. Similarly, minimum width of 0.45 m is also maintained. In rocky areas, trenching may be difficult because of hard soil strata. In such situations, gabion-crescent bunds made of loose boulders are adopted. Usually there is no maximum limit for length of contour trench and mostly it is decided considering waterway location. However, staggered trenches are constructed across the slope with lengths varying from 5 to 15 m.

2.3.3 Bench terracing

The bench terraces are usually constructed for cultivating sloppy areas by converting the land into series of platforms one above the other (Fig. 2.3). These measures are popular in hilly areas.

Objectives:

i) To control the velocity of overland flow and to check soil erosion on hill slopes

ii) Optimum rain water utilization by increasing infiltration opportunity time for it

iii) To ensure equitable soil moisture distribution and for providing required drainage

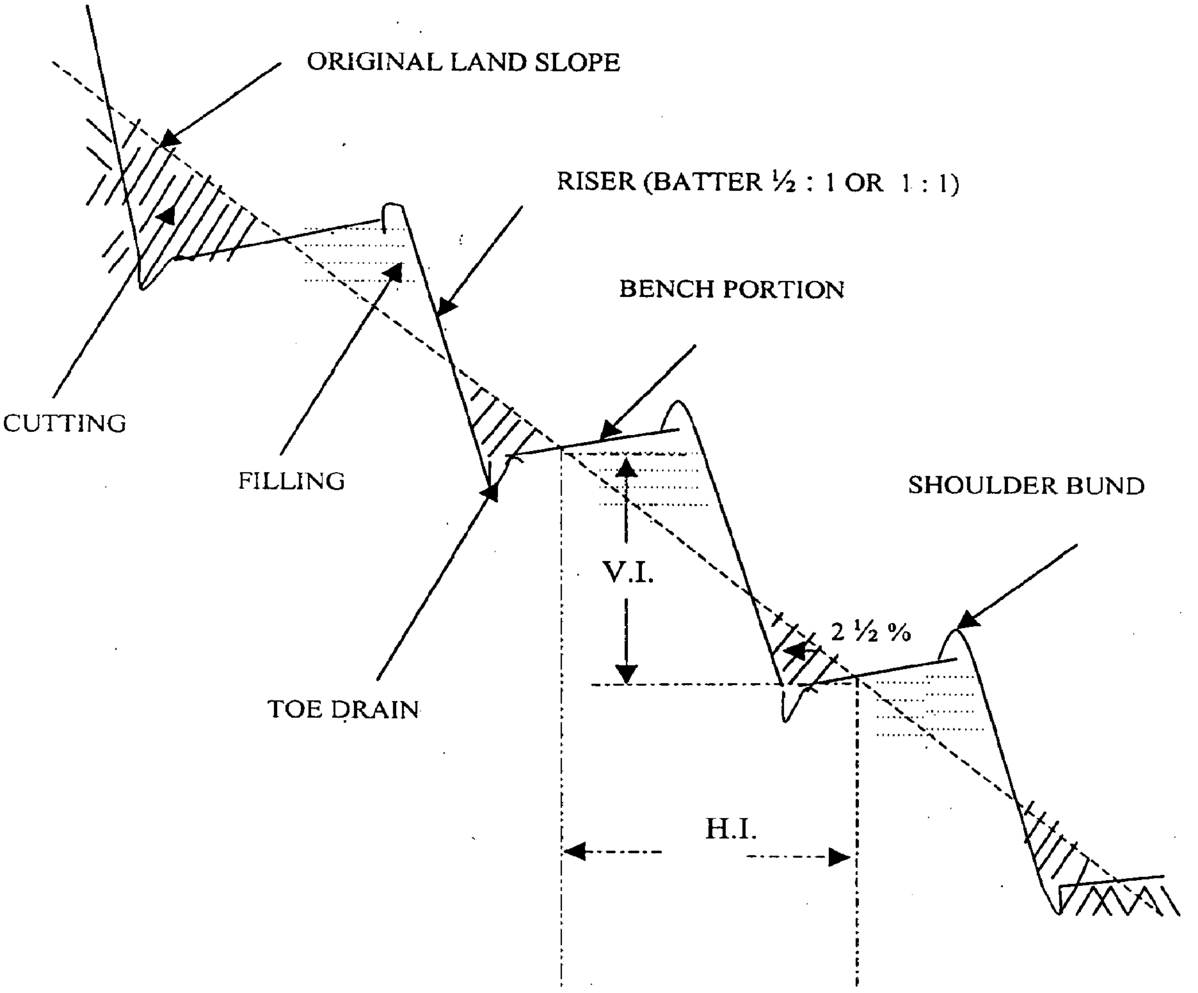


Fig. 2.3 Cross section of bench terrace

Specific site conditions:

Normally, bench terracing is adopted for slopes ranging from 16 to 33%. Because of the increasing population pressure on cultivated lands, even steeper slopes are put under cultivation with bench terracing. A good topsoil depth is required so that proper depth of cut and consequently suitable width of terrace can be adopted without exposing the unproductive subsoil.

Design criteria:

i) Vertical interval, which is usually decided considering soil depth and slope conditions and may vary from 1.5 to 2.5 m.

ii) Net width of the benches, which depend upon the land slope and farm power available for undertaking agronomic operations. In steep sloping hilly areas, the bench width can vary from 5 to 10 m; however, 3 m width is minimum.

The following equations are used for designing bench terraces having inward slope or being table top:

$$VI = 2\,(T-0.15)$$

Where VI =vertical interval, m

T =top soil (solum) depth, m

$$VI = \frac{WS}{100-S}$$

Where VI =vertical interval, m

W =net width of the bench in meter for 1 :1 batter in the riser

S = slope, %

Similarly, for 0.5: 1 batter, the equation would be as follows:

$$VI = \frac{2WS}{200-S}$$

As a general practice, 1 % longitudinal grade is given for the removal of excess runoff. In case of inward sloping benches, 2.5 % inward slope is provided, whereas no cross slope is given in the tabletop benches. The length of terrace is generally limited to 100 m for better moisture distribution. The bench risers are protected with permanent vegetation. For efficient removal of excess runoff, a toe drain (15 cm deep) is provided at the toe of the riser. For safety of the benches against gully formation along the major slope during heavy downpours a shoulder bund, limited to 0. 3 m^2 sections, is maintained at the upper edge of the bench. The bench terrace is also provided with properly designed grassed outlets, mostly known as vertical drains in the hilly areas. These vertical drains are designed on the lines of grassed waterways.

2.3.4 Vegetative Barriers

Vegetative barriers are closely spaced grass hedges or plantations- usually a few rows of grasses or shrubs grown along contours or with little grade for erosion control in agricultural lands. Of late, opinions are gaining ground that vegetative barriers (eg. Vetiver hedge rows Leucaena, lemongrass, and Cenchrus ciliares) alone at suitable interval may be sufficient for runoff and erosion control in relatively flat and slightly undulating topography. But it is, safer to have vegetative barriers only as inter-terrace treatments.

Objectives:

i) To act as a barrier to moderate the velocity of overland flow and as a trap for silt, in that soil quality is maintained

ii) To reduce the cost on terracing as vegetative barrier are relatively cheaper

iii) To augment production of food, fuel, fodder of fiber from farm lands by growing suitable species as vegetative barriers

iv) To add to the income of farmer

Specific site conditions:

Vegetative barriers can be easily established across a wide spectrum of soil-climatic conditions except in class VII lands and desert conditions. Selection of species depends upon site-specific conditions, particularly soil and climatic variables. The major constraint experienced in their sustenance is stray cattle grazing.

Design criteria:

The main item of design is the spacing of the barriers that depends on the vertical drop of the field to be treated. Species to be grown, number of rows, plant-to-plant spacing, and method of planting, etc. are also to be decided in advance. The functional requirement of the vegetative barriers is that it should act as a filter to trap the silt and cut down the velocity of runoff flow. Therefore, the plants will have to be closely spaced.

2.3.5 Grassed Waterways

Grass waterways are drainage channels either developed by shaping the existing drainage ways or constructed separately for affecting the drainage of agricultural lands. They are aligned along the major slopes to handle runoff discharge from contour/graded bunds, bench terraces, contour trenches and contour furrows.

Objectives:

i) To provide drainage to agricultural fields by safely disposing the excess rain water

ii) To convert gullies or unstable channels into stable channels by providing vegetal protection to the soil surface

iii) For channelising and regulating runoff flows for water harvesting purposes

Specific site conditions:

As far as possible, waterways are located along valley lines. But, sometimes it may be necessary to construct waterways along field boundaries for safe disposal of excess rainfall from agricultural fields. Waterways may be located in all classes of lands except bare rocks, where construction may be difficult. However, vegetative waterways should not be used for handling continuous flows, like that from tile drains as problem of wetness may result in poor vegetal growth and soil protection.

Design criteria and procedures:

Design procedures for waterways are essentially similar to those of open channels. But they are generally constructed with shallow depth and flat side slopes to facilitate crossing of the channels by bullocks and farm machinery. The cross section of the waterway may be trapezoidal, triangular or parabolic; in most situations, broad bottom trapezoidal or parabolic channels are used. The depth of waterway may range from 0.15 to 0.50 m and side slopes are kept flatter 4 : 1. The gradient of the waterway is generally decided by the existing slope of the ground. The design cross sections should be such that the computed velocities are within permissible limits and the capacity of the channel is sufficient to carry the peak discharge for a 10-year frequency. Generally, flow velocities are computed using Manning's formula.

The permissible velocity in a grass waterway depends on nature of soil and type of vegetation. In most light soils, the maximum velocity may be 1.5 m/sec, whereas the velocity can be exceeded even up to 2.5 m/sec in erosion resistant soils having a good sod cover.

The final channel dimensions are arrived at after allowing a free board of about 0.15 m. For general field works, the carrying capacities of waterways for different flow depths and channel gradients are given in Table 2.1 . The capacities given in the table are based on assumption of a good grass cover. If the waterways are very long, variable cross sections may be adopted for economy in such conditions. A typical example of the design of grass waterway is given under case study.

Table 2.1 Values of discharge in m^3/sec per meter width of grass waterway

Depth of Flow (m)	Slope (%) 2.0	1.0	0.75	0.5
0.075	0.030	0.020	0.020	0.020
0.150	0.093	0.067	0.057	0.047
0.225	0.180	0.133	0.103	0.093
0.300	0.293	0.207	0.170	0.150
0.375	0.417	0.293	0.237	0.207
0.450	0.567	0.407	0.330	0.283
0.525	0.660	0.520	0.427	0.370

(Source: Hudson, 1971)

2.4 Water Harvesting Structures

Supplemental irrigation at times becomes essential for survival of horticultural and agricultural crops in drought-prone areas with undependable and erratic rainfall. In order to accomplish this, excess rainwater has to be conserved/stored in soil profiles and in different storage structures.

2.4.1 Farm ponds

Farm ponds are bodies of water; made either by constructing an embankment across a watercourse or by excavating a pit or the combination of both.

Objectives:

i) To provide water storage for life saving irrigation in a limited area

ii) To provide drinking water for livestock and human beings in arid areas

iii) To serve as water storage for providing critical irrigations to limited number of fruit plants for establishment

iv) To moderate the hydrology of small watersheds

Specific site conditions:

Dugout ponds are generally created by excavating pits in area having flat topography and mostly in situations where water table is close to the ground level. On the other hand, impounding type of farm ponds are common feature wherever there are well defined waterways with rolling type of topography.

Design criteria:

Farm pond size is decided on the total requirement of water for irrigation, livestock and domestic use. If the rainfall in the region is very low, the capacity of the pond will only include the requirement for livestock and domestic use. An allowance of 20 % is always added to the pond capacity towards storage losses.

Pond =Irrigation requirement + Livestock requirement + Domestic requirement + 20 % of the sum of the above towards evaporation and other losses

The size of farm pond is also decided upon the amount of anticipated runoff water entering the pond. The pond size should be one half or less than the total amount of annual runoff expected from catchment so that more than one filling can be obtained during the year. In low rainfall areas, 1 ha catchment may provide 100 m^3 of runoff for pond designs. In medium rainfall regions 1 ha catchment can yield 200 m^3 of water for storage purposes. Whereas design features of embankment type ponds are governed by physiography, excavated ponds may be constructed either square or rectangular in shape.

Once the capacity of the pond is determined taking into account the total requirement of water for irrigation, livestock and domestic use and the same is estimated to be equal or less than runoff availability; the next step is to work out the dimensions of the pond. The permissible depth of the pond, on the selected site, is to be determined first for ease in excavation and better retention of water; the side slope are decided later depending on the capacity of pond and soil type. To save the sidewalls from caving in, the side slopes are also made flatter than the natural angle of repose of the material (soil) being excavated. In most cases the side slopes should be flatter than 1: 1. All farm ponds must have the provision for removal of excess runoff water when the pond is full. The kind of spillway to be used will depend on the size of watershed and other site characteristics. Generally, ponds having watersheds ranging from 4 to 12 ha require a combination of mechanical and vegetative spillways; for ponds having drainage area less than this a good vegetative spill may suffice.

The commonly used spillway with farm ponds is the drop inlet spillway. In some cases, this type of spillway may also be used to supply the water for irrigation by having sluice gate arrangement at different heights of inlet well/riser. Small diameter pipes are particularly susceptible to clogging with trash and rodents. For this, the size of barrel and riser should be kept more than 15 and 20 cm in diameter respectively.

Farm ponds must be provided with a sod spillway or emergency spillway to dispose the over flow water after heavy rains. This spillway should discharge into a grass waterway or a natural drain that does not have steep grade to cause excessive erosion. The required width of spillways depends on the size of the watershed areas; sod spillway is essentially a grassed waterway having flat grades.

2.4.2 Minor Irrigation Tanks/Low Earthen Dams

Low Earthen Dams, designed on the basis of engineering principles, are constructed across the streams for creating water reservoirs for providing one or two irrigations to the crops at critical periods.

Objectives:

i) To provide irrigation source for the crops grown under its command

ii) For irrigation of drought by providing much needed water.

Design criteria and procedures:

Following aspects are considered as basic requirements for designing earthen dams:

i) Hydrologic data

ii) Information on soils and geology

iii) The nature and properties of the soils in the command area, and

iv) Profile survey and cross sectional details of the stream

In order to arrive at proper design of the earthen dam, site selection is very crucial. As far as possible, a narrow gorge should be selected for erecting the dam in order to keep the ratio of earthwork to storage at minimum. Runoff availability for the reservoir should be computed on the basis of rainfall-runoff relationship for the locality. In case such data are not available, the runoff availability may be worked out based on Strange's table (Table 2.2)

Depending upon the assumed depth of ponding and the corresponding area to be submerged, suitable height of dam may be selected to provide adequate storage in a given topographic situation; such dams are constructed with height ranging from 5 to 15 m.The cross section of dam is decided by trial and error; selection and other specifications are finalized considering the following criteria:

i) There should be no possibility of the dam being over-topped by flood water

ii) The seepage line should be well within the toe at the down stream face

iii) The upstream and downstream faces should be stable under the worst conditions

iv) The foundation shear stress should be within safe limits

v) There should be no opportunity for free flow of water

vi) The dam and foundation should be safe against piping and undermining

The upstream face should be properly protected against possible wave action

Table 2.2 Proportion of estimated runoff to rainfall (Strange's table)

Total monsoon rainfall (mm)	Percentage of runoff to rainfall		
	Good catchment	Average catchment	Bad catchment
250	4.3	3.2	2.1
375	9.4	7.0	4.7
500	15.0	11.25	7.5
625	20.6	15.4	10.8
750	26.3	19.7	13.1
875	31.9	23.9	15.9
1000	37.5	28.1	18.7
1125	43.1	32.3	21.5
1250	48.8	36.6	24.4
1375	54.4	40.8	27.2
1500	60.0	45.0	30.0

(Source: Singh, 1957)

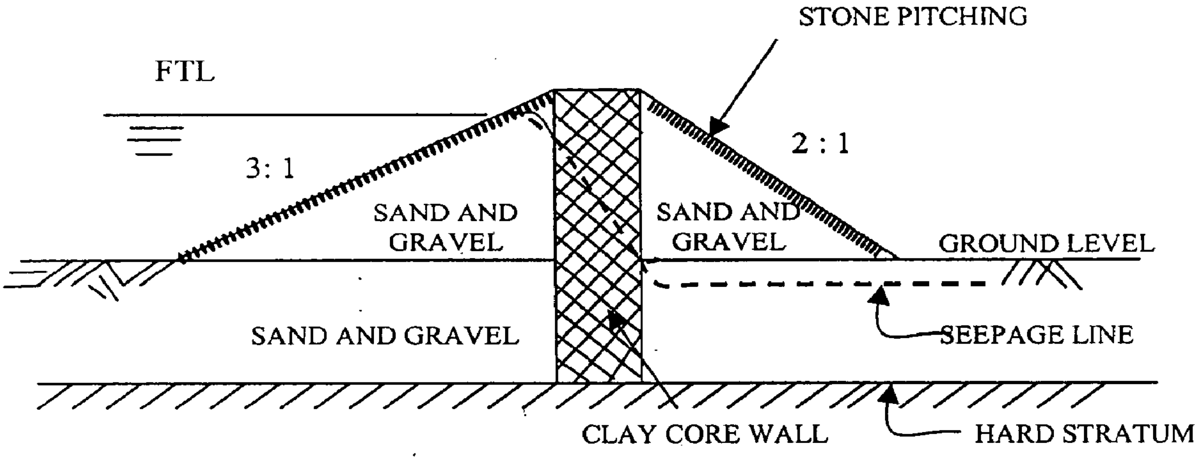
Typical cross sections of earthen dams are as follows (Figure *2.4*):

Case I : If only sand and gravel are available at the site, a 3 to 5 m thick clay core wall is a must; soil for this can be brought from nearby old tanks. The core wall should extend from the hard stratum up to the top of the dam (Fig. *2.4 a*)

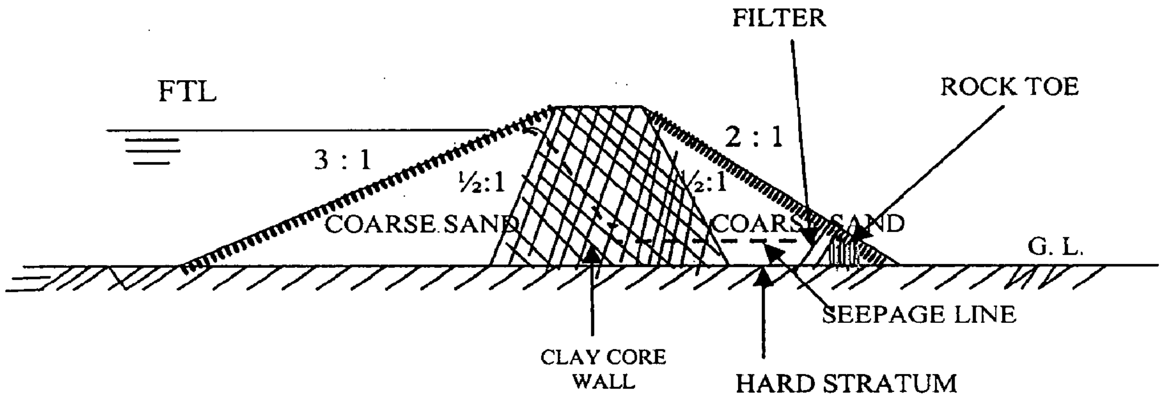
Case II: If both clay and silt in top soil and sub-soil but mostly coarse sand in shallow sub-soil layers are available and the foundation is impervious; it may be necessary to provide rock-toe drains at the downstream to keep down the seepage line (*Fig. 2.4 b*)

Case III : If both sand and gravel is plenty as well as silty-clay in fair proportion are available at the site but foundations are very pervious; a suitable arrangement in the form of a horizontal blanket may be necessary (*Fig. 2.4 c*)

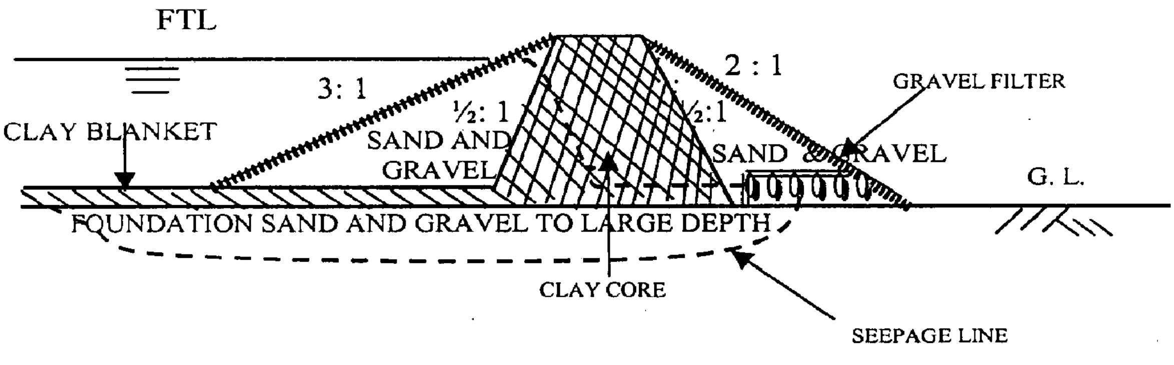
In general, the capacity of the dam is worked out by finding out the water-spread area and the expected impounded depth of water. The top width of the bund (dike) is decided depending upon the use of the dam as a road or path. Where it is not used as a road, a minimum width of 1.5 m may be adequate.



(a) CASE I



(b) CASE II



(c) CASE III

Fig. 2.4 Typical cross sections of earthen dams with different types of materials and on different types of foundations

Height of the dam:

The height of dam is arrived at by working out the difference between the reduced levels of the top of the bund and the bed level of the Nala. The maximum dam height should not exceed 20 m; height of each segment depends upon bed levels of Nala along the cross section.

Side slopes:

Side slopes of the bund are governed by the material used for construction. Minimum side slopes are 3 : 1 on the upstream side and 2 : 1 on the downstream side; steeper side slopes may sometimes be adopted in case of lower bund heights but these should be restricted up to 2 : 1.

Free board:

A minimum free board of 1.5 m is usually provided for all small irrigation tanks.

Emergency spillway:

All the irrigation tanks are provided with emergency spillway s to remove peak rate of runoff at 50 years recurrence interval. These can be masonry structures in case suitable site is not available for locating a vegetative emergency spillway.

Mechanical spillway:

Earthen dams are provided with a mechanical spillway for frequent removal of runoff before it touches emergency spillway. The minimum size of the spillway may be between 0.5 to 1.5 m depending upon the size of the dam.

Sluice arrangement:

The sluice is kept at the dead storage level and the gate is designed for regulating quantity of water required to irrigate the command area.

2.5 Soil Erosion and Loss

Soil is one of the very important resources for agricultural production and it is vulnerable to erosion by flowing water and wind.

Soil erosion is caused by various factors such as clearing of forests in order to get more land for cultivation, improper use of land, shifting cultivation and the logging for timber and fuel production. Especially the land on steep slopes without appropriate protection is susceptible to erosion.

Increase of population and development of nature for industrialization tend to accelerate the process of erosion. Soil erosion resulted to loss in the fertile topsoil causing agricultural production to decrease. Soil erosion in catchment area removes vegetation and organic matters from the surface and decrease the intake rate of the soil. Thus, increased surface runoff brings flood that can not be coped with the conventional river channel. Moreover, soil erosion leads to silting of irrigation and drainage canals, insufficient irrigation and drainage, aquatic weed growth and declining fish production in the rivers and lakes. Soil erosion aggravates the environment and gives much harm to the local population both the economic and social aspects.

The main factors affecting soil loss are rainfall intensity and duration, types of soil, land slopes and ground surface condition.

In order to solve and minimize all these problems and to conserve the environment soil conservation is to be adopted and implemented. Soil conservation is to keep the soil from continuous loss and utilize it without waste for high-level agricultural production. Soil conservation prevents lowering of soil productivity and occurring of sediment problems that cause land damage, flood damage, water quality and environment problem.

2.5.1 Estimation of Soil Loss

The Universal Soil Loss Equation (USLE) is the most widely accepted method of estimating sediment loss. This equation was developed from more than 40 years of data measured from small plots located in many states. It is useful to determine the adequacy of conservation measures in farm planning and to predict non-point sediment losses in pollution control program.

The average annual soil loss as determined by Wischmeier (1976) can be estimated from the equation:

$$A = R\,K\,L\,S\,C\,P$$

Where A =average annual soil loss (metric tons/ha)

R =rainfall and runoff erosivity index by geographic location as given in Table 2.3

$= E = 12.1 + 8.9 \log i$

Where E = kinetic energy

i =intensity in mm/hr

K =soil erodibility factor (see Table 2.4) which the average soil loss in ton/acre per unit of erosion index for a particular soil in cultivated continuous fallow with an arbitrarily selected slope length L of 22 m (73 ft) and slope steepness S, of 9 percent.

LS =topographic factor

L =slope length factor; the ratio of soil loss from the field slope length to that from a 22 m length on the same soil type and gradient

$=(l/22)^x$

where x = a constant, 0.5 for slopes >4 percent, 0.4 for 4 percent, and 0.3 for <3 percent

l = slope length in m

S =slope gradient factor, the ratio of soil loss from the field gradient to that from a 9 % slope, on the same soil type and slope length.

$$=\frac{(0.43+0.30s+0.043s^2)}{6.574}$$

where s = field slope in percent

C =cropping management factor, which is the ratio of soil loss for given conditions to soil loss from cultivated continuous fallow as given in Table 2.5

P =conservation practice factor, which is the ratio of soil loss for a given practice to that for up and down the slope farming as given in Table 2.6

Table 2.3 Frequency of Annual and Single-Storm Erosion Index, R

Location	Return Period in Years			
	2	5	10	20
ANNUAL EROSION INDEX, R				
Little Rock, Ark.	308	422	510*	569
Indianapolis, Ind.	166	225	275*	302
Devils Lake, N.D.	56	90	120*	142
SINGLE-STORM EROSION INDEX, R				
Little Rock, Ark.	69	115	158	211
Indianapolis, Ind.	41	60	75	90
Devils Lake, N.D.	27	39	49	59

Source: Wischmeier and Smith (1965)

Table 2.4 K, Soil-Erodibility Factor by Soil Texture in t/a *

Textural Class	Organic Matter Content (%)		
	0.5	2	4
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Very fine sandy loam	0.47	0.41	0.33
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Silty clay	0.25	0.23	0.19

* *Selected from USDA-EPA, Vol. 1 (1975)* and are estimated averages of specific soil values. For more accurate values by soil types use local recommendations of Soil Conservation Service or state agencies.

Table 2.5 Ratio of Soil Loss from Crops to Corresponding Loss from Continuous Fallow[a] (C Factor)

Cover, Sequence, and Management	Crop Yields		Crop-Stage Period[b]				
	Meadow (tons)	Corn (bu)	0 (%)	1 (%)	2 (%)	3 (%)	4 (%)
Ist-yr corn after meadow, Rdl [c]	2	60	15	30	27	15	22
2nd-yr corn after meadow, Rdl	3	70	32	51	41	22	26
2nd-yr corn after meadow, RdR [d]	3	70	60	65	51	24	65
3rd- or more yr corn, RdL	-	70	36	63	50	26	30
Small grain w/ meadow seeding:							
(1) In disked corn residues							
After Ist-corn after meadow	2	60	-	30	18	3	2
After 2nd-corn after meadow	2	60	-	40	24	5	3
(2) On disked corn stubble, RdR							
After Ist-corn after meadow	2	-	-	50	40	5	3
After 2nd-corn after meadow	2	-	-	80	50	7	3
Establishes grass and legume meadow	3	-	-	-	0.4	-	-

[a] Portion of 100-line published table *(Wischmeier, 1960)*

[b] Crop-stage periods are defined below:

0 Turn plowing to seedbed preparation

1 Seedbed- first month after seeding

2 Establishment-second month after seeding

3 Growing cover- from 2 months after seeding to harvest

4 Stubble or residue-harvest to plowing or new seedbed

[c] RdL, crop residues left and incorporated by plowing

[d] RdR, crop residues removed

Source: *Smith and Wischmeier (1962)*

Table 2.6 Recommended Conservation Practice P[a]

Percent Slope	P_c Contouring (Maximum slope length in m)	P_{sc} Strip Cropping[b]	P_{tc} Terracing and Contouring[c]
Parallel to Field Boundary	0.8[d]	-	-
1.1-2	0.6 (150)	0.30	-
2.1-7	0.5 (100)	0.25	0.10
7.1-12	0.6 (60)	0.30	0.12
12.1-18	0.8 (20)	0.40	0.16
18.1-24	0.9 (18)	0.45	-

[a] Factor for up and down slope is 1.0

[b] A system using 4-year rotation of corn, small grain, meadow, meadow. Use with terraces for farm planning.

[c] Recommended only for computing soil loss from the field or loss to the terrace channel with upslope plowing.

[d] For slopes up to 12 % only

Source: *Wischmeier and Smith (1965)*

2.5.2 Runoff Estimation

Conservation structures and channels must be designed to handle natural flows of water from rainfall or melting snow. Runoff constitutes the hydraulic load that the structure or channel must withstand. Runoff defines as the portion of precipitation that makes its way toward stream channels, lakes, or oceans as surface or subsurface flow. The term runoff usually means surface flow.

Runoff process:

Before runoff can occur, precipitation must satisfy the demand of evaporation, interception, infiltration, surface storage, surface detention, and channel detention.

Factors affecting runoff:

Rainfall duration, intensity, and aerial distribution influence the rate and volume of runoff. Total runoff for a storm is clearly related to the duration for a given intensity. Infiltration will decrease with time in the initial stages of a storm. Thus a storm of short duration may produce no runoff, whereas a storm of the same intensity but of long duration will result in runoff.

Rainfall intensity influences both the rate and volume of runoff. An intense storm exceeds the infiltration capacity by a greater margin than does a gentle rain; thus a volume of runoff is greater for the intense storm even though total precipitation for two rains is the same. The intense storm actually may decrease the infiltration rate because of its destructive action on the soil structure at the surface.

Watershed factors affecting runoff are size, shape, orientation, topography, geology, and surface culture. Both runoff volumes and rates increase as watershed size increases.

Predicting runoff:

Methods of runoff estimation necessarily neglect some factors and make simplifying assumptions regarding the influence of others. Methods presented here are applicable to small agricultural watersheds less than a few hundred hectares.

Design runoff rates:

The capacity to be provided in a structure that must carry runoff may be termed the design runoff rate. Structure and channels are planned to carry runoff that occurs within a specified return period. Vegetated controls and temporary structures are usually designed for a runoff that may be expected to once in 10 years. Expensive, permanent structures will be designed only once in 50 or 100 years.

2.5.2.1 Rational Method

The rational method of predicting a design peak runoff rate is expressed by the equation,

$$q = 0.0028\,CIA$$

where q =the design peak runoff rate in m^3/sec

C =the runoff coefficient

I = rainfall intensity in mm/h for the design period and for a duration equal to the time of concentration of the watershed.

A =watershed area in acres

The time of concentration of a watershed is the time required for water to flow from the most remote (in time of flow) point of the area to the outlet once the soil has become saturated and minor depressions filled. One of the most widely accepted methods of computing time of concentration was developed by Kirpich (1940),

$$T_c = 0.0195\,L^{0.77}\,S^{-0.385}$$

Where T_c =time of concentration in min.

L =maximum length of flow in m.

S =the watershed gradient in m per m of the difference in elevation between the outlet and the most remote point divided by the length, L.

Rational method is considered sufficiently accurate for runoff estimation in the design relatively inexpensive structures where the consequences of failure are limited. Application of rational method as presented here is normally limited to watersheds of less than 800 ha (2000 acre).The values of runoff coefficients and Hydrologic Soil Group Conversion Factors are shown in Tables 2.7 and 2.8.

Table 2.7 Runoff Coefficients, C for Agricultural Watersheds (Soil Group B)

Cover and Hydrologic Condition	Coefficient C for rainfall rates of		
	25 mm/h (1 iph)	100 mm/h (4 iph)	200 mm/h (8 iph)
Row crop, poor practice	0.63	0.65	0.66
Row crop, good practice	0.47	0.56	0.62
Small grain, poor practice	0.38	0.38	0.38
Small grain, good practice	0.18	0.21	0.22
Meadow, rotation, good	0.29	0.36	0.39
Pasture, permanent, good	0.02	0.17	0.23
Woodland, mature, good	0.02	0.10	0.15

Source : Horn and Schwab (1963)

Table 2.8 Hydrologic Soil Group Conversion Factors

Cover and Hydrologic Condition	Factors for converting the runoff coefficient C from group B soils to [a]		
	Group A	Group C	Group D
Row crop, poor practice	0.89	1.09	1.12
Row crop, good practice	0.86	1.09	1.14
Small grain, poor practice	0.86	1.11	1.16
Small grain, good practice	0.84	1.11	1.16
Meadow, rotation, good	0.81	1.13	1.18
Pasture, permanent, good	0.64	1.21	1.31
Woodland, mature, good	0.45	1.27	1.40

[a] Factors were computed from Table 2.9 by dividing the curve number for the desired soil group by the curve number for group B

Table 2.9 Runoff Curve Numbers for Hydrologic Soil-Cover Complexes for Antecedent Rainfall Condition II, and $I_a = 0.2\,S$

Land Use or Cover	Treatment or Practice	Hydrologic Condition	*Hydrologic Soil Group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row Crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
	Terraced	Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Terraced	Poor	63	73	80	83
	Terraced	Good	51	67	76	80

and Use or Cover	Treatment or Practice	Hydrologic Condition	*Hydrologic Soil Group			
			A	B	C	D
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods (farm wood-lots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		-	59	74	82	86
Roads and right-of-way (hard surface)		-	74	84	90	92

*Soil Group	Description	Final Infiltration Rate (mm/h)
A	Lowest Runoff Potential. Includes deep sands with very little silt and clay, also deep, rapidly permeable loess.	8-12
B	Moderately Low Runoff Potential. Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.	4-8
C	Moderately High Runoff Potential. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after pre-saturation.	1-4
D	Highest Runoff Potential. Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface.	0-1

Source: U.S. Soil Conservation Service, National Engineering Handbook, Hydrology, Section 4 (1972) and U.S Dept. Agr. ARS 41-172 (1970)

2.5.2.2 Soil Conservation Service Method

This method describe by U.S. SCS (1973) was originally developed for uniform rainfall using assumptions for a triangular hydrograph as shown below in Fig. 2.5. The time to peak flow,

T_p $=D/2 + T_L$ $=D/2 + 0.6\ T_c$

Where T_p =Time to peak

D =duration of excess rainfall

T_L =time of lag

T_c =time of concentration

Time of concentration is the longest travel time and is not the time of peak as in the rational equation. Time of lag is an approximation of the mean travel time. The time of peak is necessary to develop a design hydrograph for routing runoff through a storage reservoir or for combining hydrographs from several watersheds. For some small watersheds the time of peak may exceeds the time of concentration. The time of recession for the triangular hydrograph is taken as 1.67 T_p, thus the total time of flow is 2.67 T_p. The peak runoff rate derived from the triangular hydrograph is,

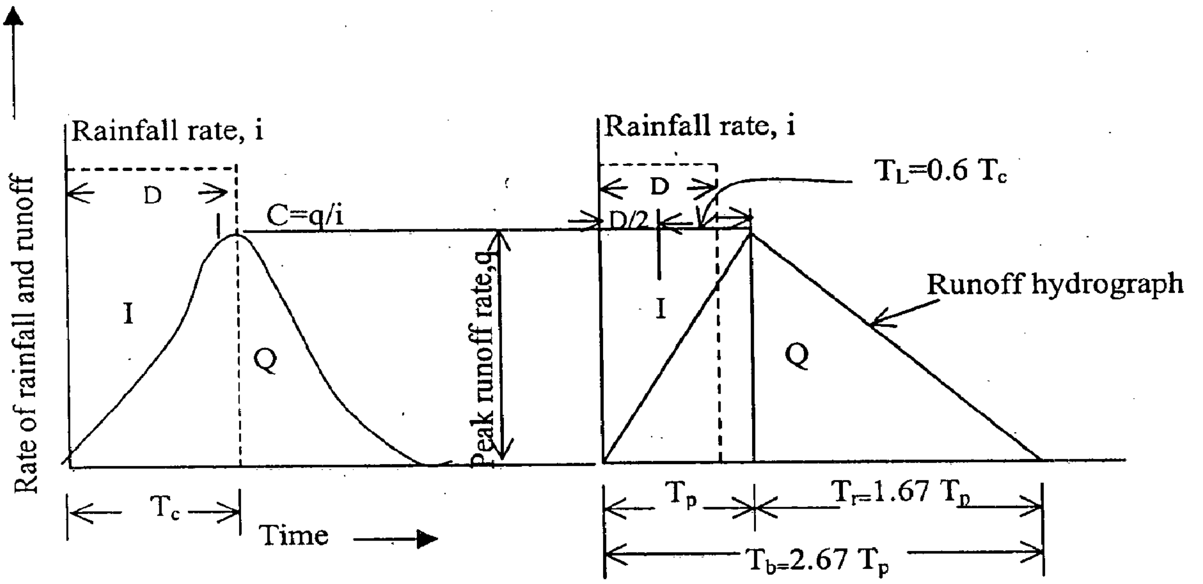
q $=0.0021\ Q\ A/T_p$

where Q =runoff volume in mm depth (area under the hydrograph)

q =runoff rate in m^3/sec

A =Water shed area, in ha

T_p =time of peak in hours



(a) Rainfall and runoff with assumptions for the rational equation

(b) Soil Conservation Service triangular hydrograph method of runoff estimation

Fig. 2.5 Triangular Hydrograph

Runoff Volume:

It is often desirable to predict the total volume of runoff that may come from a watershed during a design flood. Total volume is of primary interest in the design of flood control reservoirs.

Estimation of runoff volume using SCS Method:

The Soil Conservation Service Method (SCS) was developed from many years of storm flow records for agricultural watersheds in many parts of United States.

The SCS equation is represented by:

$$Q = \frac{(I - 0.2S)^2}{I + 0.8S}$$

Where Q =direct surface runoff in depth in mm

I =Storm rainfall in mm

S =maximum potential difference between rainfall and runoff in mm starting at the time the storm begins.

For convenience in evaluating antecedent moisture, soil conditions, land use, and conservation practices, the U.S. soil Conservation Service (1972) defines

$$S = \frac{25400}{N} - 254$$

Where N =an arbitrary curve number varying from 0 to 100. Thus, if

N =100, then S =0 and I = Q

Curve numbers can be obtained from Table 2.9. These values apply to antecedent rainfall condition II, which an average value for annual floods. Correction factors for other antecedent rainfall conditions are listed in Table 2.10.

Table 2.10 Antecedent Rainfall Conditions and Curve Numbers (for $I_a = 0.2S$)

Curve Number for Condition II	Factor to Convert Curve Number for Condition II to Condition I	Factor to Convert Curve Number for Condition II to Condition III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

Condition	General Description	5-day Antecedent Rainfall (mm) Dormant season	5-day Antecedent Rainfall (mm) Growing season
I	Optimum soil condition from about lower plastic limit to wilting point	<13	<36
II	Average value for annual floods	13-28	36-53
III	Heavy rainfall or light rainfall and low temperatures within 5 days prior to the given storm	>28	>53

Source: *U.S Soil Conservation Service, National Engineering Handbook, Hydrology, Section 4 (1972).*

Condition I is for low runoff potential with soil having low antecedent moisture suitable for cultivation. Condition III is for wet conditions prior to the storm. As indicated in Table 2.10 no upper limit for antecedent rainfall is intended.

The limits for the dormant season apply when the soil is not frozen and when no snow is on the ground.

2.6 Application of information Technology in planning of Watershed Management programmes (WMP)

2.6.1 Remote sensing

Implementation of the technical appraisal necessary for WMP planning can be simplified by the adoption of remote sensing approaches. The potential for using remote sensing is high and would be recommended for any planner requiring adequate data for integrating WMP into development plans. Remote sensing is defined as a method or approach of obtaining information about an object or location at the earth's surface or the atmosphere by using a monitoring device that is not in contact with the object or location being targeted. Normally, the monitoring devices are called sensors and are mounted in platforms that are either aircrafts or satellites (Harris, 1987). On these platforms, sensors are mounted with the capacity to collect information by sensing the electromagnetic emissions or reflections in a wide range of wavelengths, usually between the visible at one end and the microwave at the other. Remote sensing is a very important and useful tool for planning water resources programmes for several reasons as explained below:

(i) WMP planning requires an integrated catchment approach.

The whole catchment needs to be covered adequately in the database used for planning. This requires data collection from very large areas including inaccessible parts. Remote sensing makes the job of obtaining the comprehensive data possible, easy and often cheaper.

(ii) Following (i) above, integrated catchment approaches to water resources planning require the collection and handling of substantial amount of data. By using remote sensing, data is collected in a form suitable for handling by computers.

2.6.2 Rainwater Harvesting for Natural Resources Management

Remote sensing provides a means for extrapolating in-situ point observations because it produces spatially continuous data. Further, the cost of repeated observations is low, making it possible to monitor changes in crop development, hydrology and climate. Remote sensing can be applied for obtaining several types of data needed for WMP planning (Prince et al, 1990; Prinz et. al., 1994). These include:

- Land, topography and soil characteristics.

• Vegetation cover and other land uses.

• Climate.

• Water resources and hydrology.

The use of remote sensing specifically for watershed management planning was very well demonstrated by Tauer and Humborg (1992). They made two important observations from their study. First, the utilization of data from remote sensing facilitates the rapid survey of large areas. Secondly, there is increased possibility of automatic transferability of results and the ease with which up-to-date data can be acquired.

2.6.3 Land, topography and soil characteristics

Interpretation of images from remote sensing can provide reconnaissance of the land surface characteristics and soils. Methods have already been developed for using reflectance properties to assess the differences in soils in terms of texture, moisture, organic matter and iron oxide (Hoffer, 1978 as quoted in Harris, 1987). All these four factors differ significantly along the catena, especially during the dry season. In addition, the ability of remote sensors to differentiate vegetation covers can also be used for mapping catena sequences and hence the potential for WMP. The use of remote sensing data certainly requires adequate survey of randomly selected sample areas of the target. This is normally called ground truthing or Area Frame Sampling (AFS). The sampled areas should be true representatives of the different land covers and uses. Remote sensing has been shown to be able to produce estimation of rainfall over large areas (Engmann, 1995; Prince, 1990). The estimation is achieved through the use of remote sensing capability in monitoring:

• Cloud characteristics (e.g. type and brightness),

• Cooling effect of rainfall upon the soil surface, and

• Soil moisture changes.

2.6.4 Water resources and hydrology

The attraction to use remotely sensed data in planning comes from the possibility of simultaneous observation of the whole catchment. Remote sensing cannot be used to measure runoff directly. However, it can be used to provide the most important parameters for hydrological models. These parameters include catchment geometry, topography, stream network, sub-catchment boundaries, land use classes and soil moisture (Engmann, 1995). Surface water in lakes, sheet floods, streams or rivers are easy to detect in remotely sensed data (Prince, 1990). It is now possible to remotely measure the soil moisture content, especially in the areas with sparse vegetation cover

2.6.5 Global Positioning Systems (GPS)

The GPS is a system that allows instantaneous determination of three-dimensional position and speed of objects on land, sea and air. The GPS consist of 24 hours operational satellites controlled from Colorado Springs in the USA. These satellites carry on board transmitters that transmit signals giving the position of the satellite. Signals simultaneously collected by a receiver from four satellites are processed to determine the position of that receiver at that time.

2.6.6 Geo-referenced Information Systems (GIS)

Planning and management of rainwater resources requires access and use of large amounts of data. Depending on the availability of data, the planning process may require data collection, storage, processing, retrieval and presentation. The primary requirement for effective planning in general and for rainwater resources in particular is the high capability to access, handle and manage information. This, together with the fact that most of the data required planning for rainwater resources is geographic, point to priority need for access to a computerized Geo-referenced Information System (GIS). Planning constitute decision-making and requires easy access to information. GIS is the best way of handling this information for the following reasons:

- Nearly all of the information for WMP planning has some geographical facts,
- The data that is available for planning is of different types (spatial and non spatial) and from different sources,
- The visualization capability of GIS makes understanding data easier,
- Sharing of information is made easier and efficient, and
- GIS can help planners to think globally while planning locally.

This sensitizes planners on the power of GIS as an effective and efficient tool for information management, which is a pre-requisite for effective planning. GIS is defined as any system of procedures for assembling, storing, manipulating and displaying geo-referenced data and information. A computer-based system has four main capabilities. These are, input, management, manipulation and analysis, and presentation and reporting (Aronoft (1989) as quoted in ICIMOD, 1996). The data and information in GIS is presented in layers each presenting different types of data, e.g. roads, streams, and reservoirs in relation to common reference.

2.6.7 Rainwater Harvesting for Natural Resources Management

Manipulation and Analysis of data and information from a database and undertaking combinations and analysis necessary to meet the objective of a given task is necessary. One important activity is the overlay analysis. One layer may for example contain information on hydrometric stations and the flow records over a certain period. Another layer may contain information on rainfall over the same area and the same period. These two layers can be combined to produce a data set of runoff–rainfall relationship of the catchment. Further, if there is information on vegetation cover, it is possible to assess the effect of such cover on runoff-rainfall relationship. The output of GIS will include statistical tables, graphs, maps, three-dimensional images, text tables and photographs. It is even possible to produce multimedia reports from GIS.

2.6.8 Principal components and functions of GIS (after, ICIMOD, 1996).

GIS has the capability to answer the following five types of questions

(a) What exists in/at a location?

For any given location defined in the GIS it is possible to get answers to the questions such as:

• What is the type of land use on sub-catchments X?

• How many hectares are cultivated in sub-catchment Y?

• What is land slope in sub-catchment Z?

(b) Where do these particular locations exist?

• what is the location of land that is highly eroded?

• which parts of the catchment become flooded for more than 30 days during the rain season?

• which parts are occupied by forests soils ?

(c) What Trends have occurred over time in a given location?

The power of GIS provides a cost-effective way of assessing changes that have occurred over time in a given location. It is for instance possible to compare forest cover now and 30 years ago, and deduce amount of changes.

(d) What spatial patterns exist?

The GIS can be used to match data to see if there is a pattern. For example: Are streams flowing from cultivated areas carrying high sediment load? Or what types of land use lead to high sediment load in streams?

DATA ACQUISITION AND PROCESSING

3.1 Population

Kangundo and Kathiani divisions have the highest population densities of 539 and 486 persons per sq, km respectively as per 2002 census as they have relatively of high economic potential than the other divisions. These divisions although covering the least areas have fertile soils that support both cash and food crops and receives moderate rainfall. Athi River division, which is among the biggest in the area have the lowest density of 51 and 54 persons per sq. km (1999 and 2002) although over 50 % of the population is concentrated in Athi River town. The densely populated divisions have scattered type of settlement with small farms ranging from 1 to 10 hectares.

The annual average district population growth rate is 1.7 %. The rural and urban population as per 2002 census was 532,137 and 421,945 persons respectively. Table 3.1 shows the district's population projection from 2002 to 2020.

Table 3.1 Population projections

Year	Population	Year	Population
2002	954,082	2012	1,130,070
2003	970,440	2013	1,149,281
2004	987,079	2014	1,168,819
2005	1,004,002	2015	1,188,689
2006	1,021,002	2016	1,208,900
2007	1,038,725	2017	1,229,448
2008	1,056,543	2018	1,250,349
2009	1,074,342	2019	1,271,604
2010	1,092,606	2020	1,293,222
2011	1,111,180		

3.2 Physiograghic and natural conditions/Climate

The district enjoys a pleasant climate varying from highland equatorial on the hill summits to semi arid on the plains. The topography of the district is varied and rises from 700 m on the southern part of the district to 1,700 m above sea level in the west. This is however interrupted by an escarpment and a series of hill masses, the highest of which is Kilimambogo (Donyo Sabuk), which rises up to 2,144 m above the sea level. As indicated, a huge proportion of district is semi arid and receives very little and erratic precipitation. There are two distinct rainy seasons. The long rains fall between March and May and the short rainfall between October and December as shown in Fig.3.1. The annual average rainfall varies from 500 mm to 1300 mm with high altitude areas receiving more rain than low-lying areas. The rainfall however is very unreliable and varies from year to year making it difficult for farmers to plan their farming activities and thus affecting both livestock and agricultural production. The temperatures also vary with altitude. The mean monthly temperatures are ranges from 12^0 C in the coldest months (July – August) to 25^0 C in the hottest months (March and October).

Table 3.2 shows average rainfall figures for various stations for a period of 30 – 80 years and Table 3.3 gives the average daily minimum and maximum temperatures in the study area.

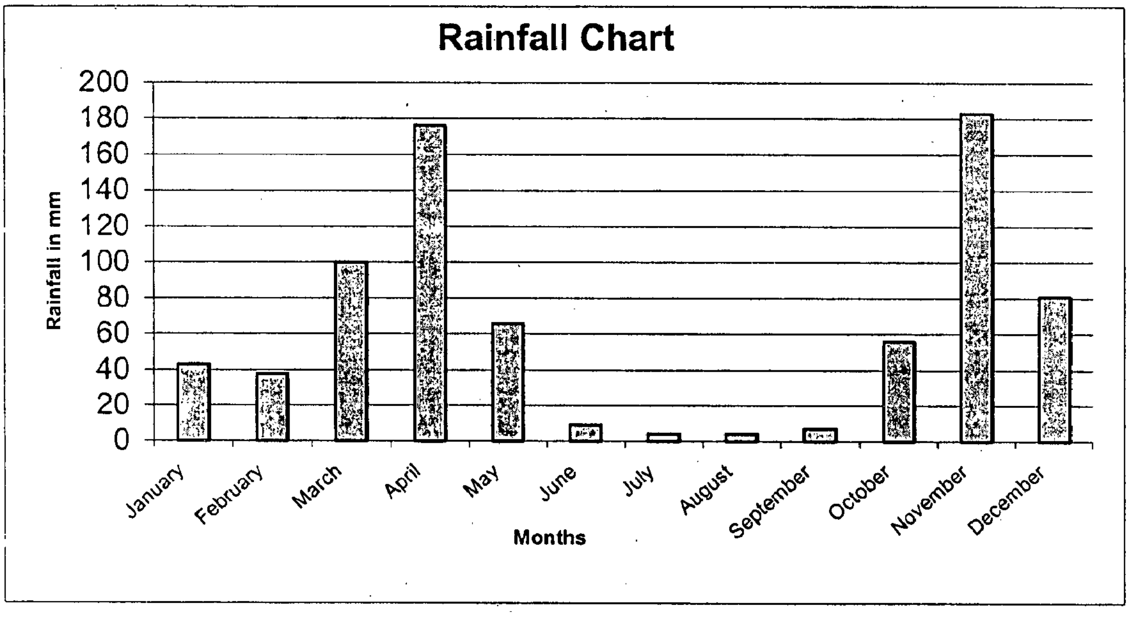


Fig 3.1 Average Annual Rainfall Distribution

(Source: Ministry of Agriculture and livestock development, Machakos District)

Table 3.2 Average rainfall figures

Station Altitude (Meters)	Annu Rainf all	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mks DC's office(1640)	898	52	51	124	205	74	12	5	6	8	53	189	120
Matungulu (1542 m)	991	49	42	146	230	73	3	4	3	7	60	245	129
Konza (1707 m)	569	36	26	69	144	64	11	3	3	6	32	102	73
Kabaa (1219 m)	731	31	28	102	169	63	9	4	3	4	64	197	58
StonyAthi (1625 m)	557	41	31	55	143	71	10	7	5	6	34	92	64
Katumani (1600 m)	717	41	41	42	142	72	8	3	3	4	37	177	98
Ngoliba (1265 m)	974	63	39	136	212	100	8	6	6	6	68	225	104
Manza (2073 m)	608	44	41	106	150	36	10	0	0	2	42	221	21
Uuni Forest (1622 m)	984	38	55	144	207	78	9	2	5	16	100	262	78
NYS Yatta (1530 m)	586	34	28	75	156	27	12	2	1	7	69	116	60
Average Rainfall	700	**43**	**38**	**100**	**176**	66	**9**	**4**	**4**	7	**56**	**183**	**81**
Effective Rainfall		**15.3**	**12.8**	**55.0**	**115**	**29.6**	**0**	**0**	**0**	**0**	**23.6**	**121**	**39.8**

(Source: Ministry of Agriculture and livestock development, Machakos District

Table 3.3. Average daily minimum and maximum temperature

MONTH	Max	Min	AVERAGE
JANUARY	23.67	12.51	18.09
FEBRUARY	23.36	12.01	17.69
MARCH	25.10	21.08	23.09
APRIL	24.20	21.61	22.91
MAY	24.61	21.61	23.11
JUNE	17.71	7.69	12.70
JULY	17.40	8.84	13.12
AUGUST	17.80	8.43	13.12
SEPTEMBER	22.86	8.16	16.57
OCTOBER	24.90	10.27	17.59
NOVEMBER	21.70	11.15	16.43
DECEMBER	21.40	12.43	16.92
AVERAGE	22.06	12.99	17.61

(Source: NYS Yatta School of Agriculture, Machakos)

3.3 Water resources

Water is a renewable though a limited resource therefore the need for it's long term planning is increasingly being felt. The district depends upon rivers and streams, dams, borehole, springs and to small extent roof catchments for the sources of water. There are three main rivers, Athi, Tana, and Thika that traverse the district. The rivers have water through out the year but their tributaries dry up during the dry season. Thika River is used as a source for the Yatta furrow running a distance of 65 km serving the northern part of Yatta division. Tana River has been harnessed for hydroelectric power generation at Masinga, Kamburu, Gitaru, Kindaruma and Kiambere dams. These reservoirs present great potential for irrigation and provision of water for domestic and industrial use. The potential has however not been utilized and much of the water drains to the Indian Ocean without any significant impact on the development of the district. The presence of Hills like Iveti, Kanzalu range, Mua Hills and Kangundo Hills among others have lead to the presence of many springs and the opportunities for gravity water supply projects. Because of the intermittent nature of the rivers, there are few irrigation projects most of which are very small. Major Dam sites identified are at Wamunyu and Katwanyaa. The great Kilimanjoro

Water supply project serves parts of Machakos, Kajiado and Makueni Districts and also parts of Machakos and Athi River towns. Athi River being a major Industrial town harboring the Export Processing Zone is jointly served by Kilimanjaro water supply project and the Greater Nairobi Water supply.

3.3.1 Water resources available

1. Water available from shallow safe well abstraction is 10.78 Mcm/year (million cubic meters per year) (National Water Master Plan, Ministry of Water Resources Development).

2. Borehole safe abstraction.

Table 3.4 shows the distribution of the boreholes by Division,

Table 3.4 Borehole distribution

Division	No. of Boreholes	Division	No. of Boreholes
Central	10	Athi River	130
Kalama	3	Mwala	7
Kangundo	17	Ndithini	20
Kathiani	7	Yathui	9
Masinga	5	Yatta	28
Matungulu	23	Katangi	6
Total no. of boreholes			**360**

The number of boreholes operating is 270

The number of protected wells is 79

The number of protected springs is 202

The total yield of the boreholes is 1,851.939 m^3/hr or 16.223 Mcm/year.

Therefore the Approximate yield of the boreholes is (270/360)*16.223 = 12.176 Mcm/year.

(Source: Ministry of Water Resources Development, Machakos District).

3. Surface Water Storages/Supply

(a) Mbiuni Water Supply - 800 cubic meters per day

(b) Wamunyu Water Supply - 1100 „

(c) Kibauni „ - 2500 „

(d) Siathani „ - 250 „

(e) Kathiani „ - 800 „

(f) Machakos Town „ - 3500 „

(*Source: Ministry of Water Resources Development, Machakos District*).

Therefore, the total storage/supply is 8,950 cubic meters/day or

3,226,750 cubic meters/year or

3.227 Mcm/year

4. Water supply from the Yatta furrow/Canal

(a) Domestic allocation = 0.141 cubic meters/second

(b) Irrigation purposes = 0.991 cubic meters/second

(c) Therefore, the total is 1.132 cubic meters/second or

97,804 cubic meters/day

34.232 Mcm/year

From the intake data, the intake is able to take average 90% of the design volume, then the total amount of water diverted per year is 34.232 x 0.9 = 30.8088 Mcm/year

26.5% of this is lost through seepage and deep percolation. Therefore the water that is actually available is 22.644 Mcm/year

5. Water available Athi River

The Average flow rate of the Athi River is 33.2 cubic meters/second or 33.2 x 3600 x 24 x 365 = 1,046.995 Mcm/year

About 15% of this volume is either pumped directly to the fields or diverted from the Athi River and it's tributaries for irrigation purposes *(Source: Tana and Athi Rivers Development Authority)*.

Therefore, the amount used from the river per year is

1,046.995 x 0.15 = 157.05 Mcm/year

The total amount of water available in the district is

10.780 Mcm/year

12.167 Mcm/year

3.267 Mcm/year

22.644 Mcm/year

<u>157.05 Mcm/year</u>

<u>205.908 Mcm/year</u>

3.3.2 Potential Water Demand analysis (2003)

Water demand can be categorized into the following groups

(a) Municipal (urban) and Rural demand

(b) Agriculture

(c) Industry

(d) Infrastructures e.g. Hydropower, Navigation, etc

The per capita demand varies from one place to the other and it is influenced by the following factors

(a) Climatic factors

(b) Economic „

(c) Environmental „

(d) Technological Development

The demands are,

3.3.2.1 Human Use/Consumption

The rural population is 541,266

The urban population is 429,214

The recommended use of water in the Machakos District in Kenya is 140 liters /day/person for urban users and 70 liters /day/person for rural consumers *(21st century water challenges in Kenya by Makhanu and Nakagawa).*

Therefore the Total Human Consumption will be

Rural – 542,266 x 70 = 37,866,620 liters /day/person

Urban – 429,214 x 140 = 60,089,960

97,956,580 liters/day or

97,956.58 cubic meters /day

So, per year it will be 97,956.58 x 365 = 35.754 Mcm/year

3.3.2.2 Industry

According to the National Water Master Plan of 1998 by the Ministry of Water resources Development, the requirement for use by industry in 2003 is 5525 cubic meters /day. This is the same as saying 5525 x 365 = 2.017 Mcm/year.

3.3.2.3 Livestock

The district comprises of 76% Rangeland hence the potential for beef production. High population pressure has lad to sub-division of Ranches calling for some intensive production system. High yielding dairy breeds and crosses are replacing pure beef breeds. Livestock production ranges from Ranching to Small Scale Household level. Almost every household in the district owns cattle and or goat, sheep and poultry. Other livestock enterprises include Pigs, Rabbits, Bees and Donkeys. Large-scale livestock production is carried out in cooperative, company and institutional ranges. Table 3.5 below gives the livestock population and the total amount of water consumed by the livestock is as in Table 3.6.

Table 3.5 Livestock population statistics

CATTLE	Pure/Crosses	31,540
	Beef	245,000
SHOATS	Goat	231,900
	Sheep	118,100
	Local	620,310
	Layers	107,450
	Broilers	112,870
POULTRY	Turkey	1550
	Duck	860
	Geese	280
	Log Hives	31,160
	Kenya Top bar hive	10,790
	Lang Stroth	2,115
PIGS		3,675
RABBITS		7,410
DONKEY		10,840

(Source: Ministry of Agriculture and Livestock Development, Machakos district)

Table 3. 6 Water consumption amounts

TYPE	BREED	NUMBER OF UNITS	DAILY USE/UNIT (LITERS/DAY)	TOTAL DAILY USE (LITERS/DAY)
CATTLE	Pure/Crosses	31,540	60	1,892,400
	Beef	245,000	30	7,350,000
SHOATS	Goat	231,900	10	2,319,000
	Sheep	118,100	10	1,181,000
POULTRY	Total	620,310	0.25	210,830
PIGS		3,675	20	73,500
RABBITS		7,410	0.25	1,852.50
DONKEY		10,840	20	216,800
TOTAL				**13,245,382.5**

Therefore the Water Consumption for Livestock will be 13,245,382.5 liters/day or 13,245.38 cubic meters /day or 4.835 Mcm/year

The sub-total will be

35.754 Mcm/year
2.017 Mcm/year
<u>4.835 Mcm/year</u>
<u>42.606 Mcm/year</u>

3.3.2.4 Agriculture

Food crops grown within the districts includes maize, sorghum, millet, beans, cowpeas, pigeon peas, Green grams and root crops mainly cassava and sweet potatoes. The horticultural crops have been taking a center stage as diversification and irrigation is improved. Those include mainly Mangoes, Citrus, Asian vegetables, French beans and lately floriculture. The industrial crops grown within the district include coffee and cotton. Below is a table showing the crop production statistics for 2002 *(Source; Ministry of Agriculture and Livestock Development Machakos District).* Tables 3.7 to 3.11 show the area covered by food crops and their respective production.

Table 3.7 Food crops

CROP	TOTAL AREA (HA)	TOTAL PRODUCTION (TONS)
Cereals		
Maize	164,000	94,320
Sorghum	5,210	2,638.8
Millet	1,750	886.50
Pulses		
Beans	69,800	32,184.0
Cowpeas	20,700	8,352.0
P/peas	68,200	46,080
G/grams	7,300	3,024
Chick peas	580	234.0
Dolichos	650	270.0
Roots/Tubers		
S/potatoes	4,330	22,640
Arrow roots	640	3,840
Cassava	4,175	28,000

Source: Ministry of Agriculture and Livestock Development, Machakos district

Table 3.8 Fruit crops

CROP	TOTAL AREA (HA)	TOTAL PRODUCTION (TONS)
Bananas	1,754	17,189.2
Citrus	1,817	22,952.2
Paw paw	2.138	20,952.4
Mangoes	1,281	15,243.9
Avocados	414	6,085.8
Passion Fruits	286	2,602.6
Guavas	83.5	759.85
Loquats	12	
Peaches/Plums	86.5	666.05
Apples	23	193.2

Table 3. 9 Local market vegetables

CROP	TOTAL AREA (HA)	TOTAL PRODUCTION (TONS)
Tomatoes	415	7,055
Cabbages	150	1,500
Kales	350	4,200
Onion	162	1,944

Table 3.10 Export market vegetables

CROP	TOTAL AREA (HA)	TOTAL PRODUCTION (TONS)
Thin chilies	102	83,454.5
French beans	487	414,851.9
Tindori	40	33,333.3
Dudhi	41	67,090.9
Brinjals	98	79,706.7
Turia	36	23,261.5
Valore	62	36,072.7
B/chilies	120	92,307.7
Karella	67	63,907.7
Okra	85	65,385.6

Table 3.11 Industrial Crops

CROP	TOTAL AREA (HA)	TOTAL PRODUCTION (TONS)
Coffee Cherry	1,357	14,289,628
Mbuni		886,746
Cotton	350	17.5

3.3.3 Estimation of crop water requirements

This refers to the total amount of water that the crop requires for optimum production. The difference between the crop water requirements and the effective rainfall is the net crop water requirement or net irrigation requirement. In it's calculation the following terms used are hereby explained,

1. Average effective rainfall (Pe) – This is the rainfall amount stored in the root zone. It is calculated using the FAO method
   Pe = 0.8P – 25 if P>=75mm/month
   Pe = 0.6P – 10 if P<=75mm/month
2. Eto – Reference or potential crop evapotranspiration (mm)
3. Etc – Evapotranspiartion of a particular crop (mm)
4. Kc – Crop coefficient for evapotranspiration (Etc/Eto). FAO crop coefficients adopted.
5. NIR – Net irrigation requirement (Etc + Seepage or Percolation-Pe)

The evapotranspiration has been computed using the **cropwat** software, which utilizes the Penman-modified method and Table 3.12 given below gives the climatic factors considered and the resultant reference/potential evapotranspiration.

Table 3.13 gives the Net Irrigation Requirements (NIR) for maize and the NIR for the other crops has been similarly estimated and given in Table 3.14.While calculating NIR, it is assumed that all the area under cultivation will be irrigated but in the actual sense a lot of land has been opened for agriculture because of the water shortages otherwise under irrigation, less area will be required to produce the same crop. For instance the recommended production of maize in the district under optimal conditions is about 3.4 tones per hectare. The area required under these optimal conditions is only 27,946.7 hectares. Table 3.15 below gives finer details of the actual Net irrigation requirement considering only those crops that require irrigation for increased production and the actual area utilized when there is enough water.

Table 3.12 Evapotranspiration

Month	Temperature Max	Temperature Min	Sunshine Hours	Average Humidity %	Eto mm/day	Eto mm/month
January	23.67	12.51	10.6	40	4.52	140.12
February	23.36	12.01	10.6	60	4.51	126.28
March	25.10	21.01	10.5	50	5.28	163.65
April	24.20	21.61	10.1	40	4.90	147.0
May	24.61	21.61	10.1	40	4.67	144.77
June	1 7.71	7.69	10.0	50	3.36	100.80
July	17.42	8.84	10.0	50	3.32	102.92
August	17.42	8.43	10.1	40	3.75	116.25
September	22.63	8.16	10.3	30	4.95	148.50
October	24.86	10.27	10.4	50	4.99	154.69
November	21.70	11.15	10.4	50	4.60	138.00
December	21.24	12.43	10.6	60	4.75	147.25
Average annual evapotranspiration						**1,630.23**

Table 3.13 Computation of NIR for maize

Period/ Crop	Eto (mm)	Kc (Average)	Etc (mm)	Rainfall (mm)	Pe (mm)	NIR (mm)
Maize						
October	74.85	0.6	44.91	56.0	23.6	21.31
November	138.00	1.0	138.00	183.0	121.4	16.6
December	147.25	1.2	176.7	81.0	38.9	137.8
January	140.12	0.6	84.07	43.0	15.8	68.27
March	81.30	0.6	49.10	100.0	55.0	-0.9
April	144.00	1.0	147.0	176.0	115.8	31.1
May	144.77	1.2	173.73	66.00	29.6	144.12
June	100.80	0.6	60.48	9.0	0.0	60.48
			873.98		**400.1**	**478.98**

Table 3.14: NIR for different crops

Crop	NIR (mm)	Area (ha)	Total NIR (Mcm/year)
1. Maize	479.88	164,000	787.003
2.Sorghum	303.73	5,210	15.824
3. Millet	212.73	1,750	3.723
4. Pulses	181.89	167,230	304.175
5. Root/tuber crops	65.13	9,145	5.956
6. Local market veg.	462.82	1,072	4.961
7.Eport market veg.	429.35	1,138	4.886
8. Coffee	872.19	1,357	11.836
9. Fruit Crops	846.44	7,895	66.826
Total			**1,205.19**

Table 3.15: Actual NIR for different crops

Crop	NIR (mm)	Area (ha)	Total NIR (Mcm/year)
1. Maize	479.88	27,950	134.13
2.Sorghum	303.73	1,055.2	3.20
3. Millet	212.73	355	0.75
4. Pulses (Beans)	181.89	14,304	26.02
5. Local market vegetables	462.82	1,072	4.985
6.Eport market vegetables	429.35	1,138	4.886
7. Coffee	872.19	1,357	11.836
8. Fruit Crops	846.44	7,895	66.826
Total		**55,126.2**	**252.633**

The overall water demand in the district is 42.606 +252.633 = 295.239 Mcm/year

The amount of water available in the district is 205.908 Mcm/year,

Therefore the deficit in the district is 295.239 – 205.908 = 89.65 Mcm/year (2002). This value in depth is given by (89.65 Mcm/55,126.2 ha) x 1000 = 162.63 mm

3.3.4 Projected Water Demand up to 2020

The demand and deficit for every year from 2003 to 2020 has been analyzed and given in Table 3.16. The units are Million Cubic meters /year

Table3.16: Projected annual demand of water and corresponding deficit.

Year	Industry (Mcm)	Agriculture (Mcm)	Livestock (Mcm)	Human (Mcm)	Total Demand (Mcm)	Deficit (Mcm)
2003	2.017	258.589	4.835	35.754	301.195	**95.287**
2004	2.051	262.985	4.917	36.361	306.314	**100.406**
2005	2.086	267.456	5.000	36.980	311.522	**105.614**
2006	2.122	272.003	5.086	37.610	316.821	**110.913**
2007	2.158	276.627	5.172	38.248	322.205	**116.297**
2008	2.194	281.330	5.260	38.900	327.684	**121.776**
2009	2.223	286.112	5.350	39.560	333.245	**127.337**
2010	2.270	290.976	5.441	40.232	338.919	**133.011**
2011	2.308	295.922	5.533	40.916	344.679	**138.771**
2012	2.347	300.953	5.627	41.611	350.538	**144.630**
2013	2.387	06.069	5.723	42.319	356.498	**150.590**
2014	2.428	311.272	5.821	43.038	362.559	**156.651**
2015	2.470	316.564	5.919	43.770	368.723	**162.815**
2016	2.511	321.946	6.020	44.514	374.991	**169.083**
2017	2.554	327.419	6.122	45.708	381.803	**175.895**
2018	2.597	332.985	6.226	46.040	387.848	**181.940**
2019	2.641	338.645	6.332	46.823	394.441	**188.533**
2020	2.686	344.402	6.440	47.619	401.147	**195.239**

3.3.5 Cropping Pattern/Present Land Use

The area covered by each particular crop in a given season and the Net and gross cropped areas are shown in Table 3.17.

Table 3.17: Gross and Net cropped Area.

Crop	Short Rains Area (ha)	Long Rains Area (ha)	Gross Cropped Area (ha)	Net Cropped Area (ha)
1. Cereals	94,500	76,460	170,960	94,500
2. Pulses	92,900	51,180	144,080	90,150
3. Roots/Tuber Crops	4,500	3,400	7,900	4,500
4. Fruit Crops	7,925	-	7,925	7,925
5. Local Market Crops	1,077	1,077	2,154	1,077
6. Export Market crops	1,138	1,138	2,276	1,138
7. Industrial Crops	1,707	-	1,707	1,707
Total	**203,747**	**133,255**	**337,002**	**200,997**

The rain fed area = (170,960+144080+7900+854) = 323,968 ha,

The irrigated area = (7,925+2,154+2,276+854) = 13,034 ha,

The weighted irrigated area is 21,638 ha.

1. % Cropping Intensity = $\frac{\text{Gross Cropped Area x 100}}{\text{Net Cropped Area}}$

   = 337220/200997 x 100 = 167.7%

2. Irrigated Cropping Intensity = $\frac{\text{Gross Irrigated Area x100}}{\text{Net Cropped Area}}$

   = 13034/200997 x 100 = 6.5%

3. Weighted Irrigated cropping Intensity = Irrigated Cropping Intensity considering a factor of 2 for Fruit crops

   = 21638/200997 x 100 = 10.8%

3.3.6 Level of irrigation

The level of irrigation is given = $\frac{\text{Water Applied during Irrigation}}{\text{Total Water demand (Agricultural)}}$ x 100

The Average demand in the district is 258.589 Mcm/year

The actual water applied to the field as irrigation is,

1. Local Market Vegetables = 4.985 Mcm/year
2. Export Market Vegetables = 4.886 Mcm/year
3. Coffee = 5.918 Mcm/year
4. Fruit Crops = 66.826 Mcm/year

   Actual water applied = 82.615 Mcm/year

Therefore, the Level of Irrigation (L.I) = $\frac{82.615}{258.589}$ x 100 = 31.95%

In view the above deficit, something must be done to reverse the situation and avail the much-needed water. Watershed management is one feasible method that can reverse the trend provided it is sustainable. It will in cooperate many techniques and can help improve both surface storage and ground water recharge thus availing the much-needed water.

CHAPTER 4

ESTIMATION OF RUNOFF

4.1 General

Runoff is that portion of rainfall, which moves down the stream, channel, river or ocean or sub surface flow. If a farmer can intelligently harvest the runoff from his field and store it or recycle it for supplemental irrigation to his crops, it will be possible to maximize the crop production and thus obtain good returns.

4.2 Rainfall– Runoff Analysis

4.2.1 Estimation of Return period from rainfall data.

The design volume or rainfall and it's return period are the basis of the design of any water harvesting structure. The return period is calculated so as to find out the quantity of rainfall, which is likely to occur within a given interval (years). It is calculated by placing the total rainfall data in descending order and calculating the probability 'P' of an event by the Weibull formula,

$$P = m/(n+1),$$

and the return period $T = 1/P$ (in years).

Where,

m is the ranking position of the event or rainfall and,

n is the number of years of record.

The variation of rainfall magnitude is plotted against T on a semi-log paper. The analysis is based on data from National Youth Service Yatta Institute of Agriculture in Kenya and is given in Table 4.1. Table 4.2 shows the rainfall, it's probability and the associated return period. Fig. 4.1 shows the above-described plot and for a given return period, any associated rainfall can be read directly.

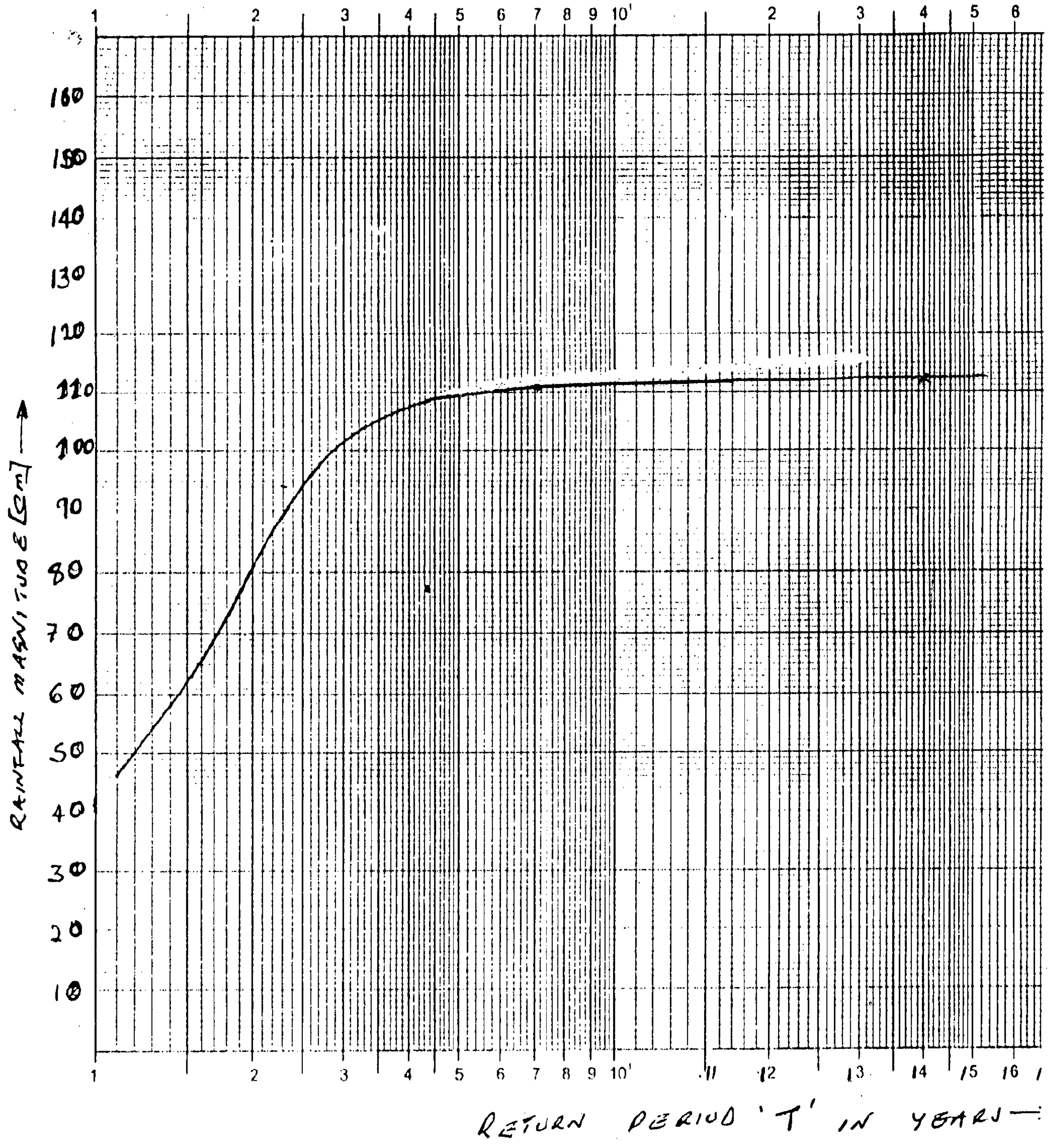


Fig. 41 Rainfall Frequency Curve.

Table 4.1: Average annual Rainfall

Year	Rainfall in (cm)	Year	Rainfall in (cm)
1982	111.78	1989	110.45
1983	64.69	1990	109.20
1984	95.97	1991	48.53
1985	68.43	1992	50.51
1986	105.65	1993	59.77
1987	45.93	1994	94.42
1988	67.39		

Table 4.2: Probability and return periods of rainfall

Rank (m)	Rainfall in descending order (cm)	Probability P= m/(n+1)	Return Period T = 1/P
1	111.78	0.071	14.00
2	110.45	0.143	7.00
3	109.20	0.21	4.67
4	105.65	0.29	3.50
5	95.97	0.36	2.80
6	94.42	0.43	2.33
7	68.43	0.50	2.00
8	67.39	0.57	1.75
9	64.69	0.64	1.56
10	59.77	0.71	1.40
11	50.51	0.79	1.27
12	48.53	0.86	1.17
13	45.93	0.93	1.08

4.2.2 Water balance

Long-term average water balance for a given soil can be estimated using a method proposed by Thornwaite and Mather, 1957. The soil in the district is sandy clay loam to sandy clay and has an available moisture holding capacity of about 165 mm. The average root depth is 1.5 m. Other values are given in Table 4.3 and all the values are in mm.

Available moisture content = Field capacity - Permanent wilting point

Therefore the available water in the soil will be 165 mm of water/meter of soil, and this gives the total available water in the soil to 165 mm x 1.5 = 250 mm.

Table 4.3: Estimated Runoff by month

No	Item	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	**P**	43.0	38.0	123.7	215.6	66.0	9.00	4.00	4.00	7.00	56.0	253.4	81.0
2	**PET**	140.1	126.3	163.7	147.0	144.8	100.8	102.9	116.3	148.5	154.7	138	147.3
3	**P-PET**	-97.1	-88.3	-40.0	71.55	-78.8	-91.8	-98.9	-112	-142	-98.7	115.4	-66.3
4	**APWL**	-163	-252	-292	0	-78.8	-171	-269	-382	-523	-622	0	-66.3
5	**SM**	140	80	70	250	200	130	90	50	30	18	250	200
6	**δSM**	-60	-60	-10	180	-50	-70	-40	-40	-20	-12	232	-50
7	**AET**	103	98	133.7	147	116	76	44	44	27	68	138	131
8	**D**	37.12	28.28	29.97	0	28.77	24.80	58.92	72.25	12.15	86.69	0	16.25
9	**S**	0	0	0	71.55	0	0	0	0	0	0	115.4	0
10	**TAR**	28.9	14	7	71.55	35	17	8	4	2	1	115.9	57.9
11	**R**	15	7	4	36	18	9	4	2	1	0.5	58.0	29.0
12	**De**	14	7	3	35	17	8	4	2	1	0.5	57.9	28.9

The total average runoff as per the above table is 183.5 mm.

Where,

(1) P is the precipitation/Rainfall

(2) PET is the potential evapotranspiration

(3) P –PET is difference by subtraction. If P< PET then this is a dry month else if P > PET then this is a wet month.

(4) APWL – Accumulated potential water loss is the accumulation of the negative values of P – PET (when P < PET).

(5) SM is the Soil Moisture. This is the water retained in the soil after accumulated water loss and it can be read from Fig.4.2

(6) δSM is the change in soil moisture during the month. It is given by SM at the end of the current month – SM at the end of the previous month.

(7) AET is the actual evapotranspiration. When P > PET, then AET = PET and when P < PET, then AET = P + | δSM |.

(8) D is the soil moisture deficit, PET – AET.

(9) S is the water that cannot be stored in the soil (surplus). It is given SM (per month) + (P – PET).

(10) TAR is the total available runoff. The entire moisture surplus does not runoff in the same month. Runoff leaving the basin should be established from field measurements.

(11) R is the Runoff and it is given by 50% of TAR

(12) De is the detention and it is given by TAR – R

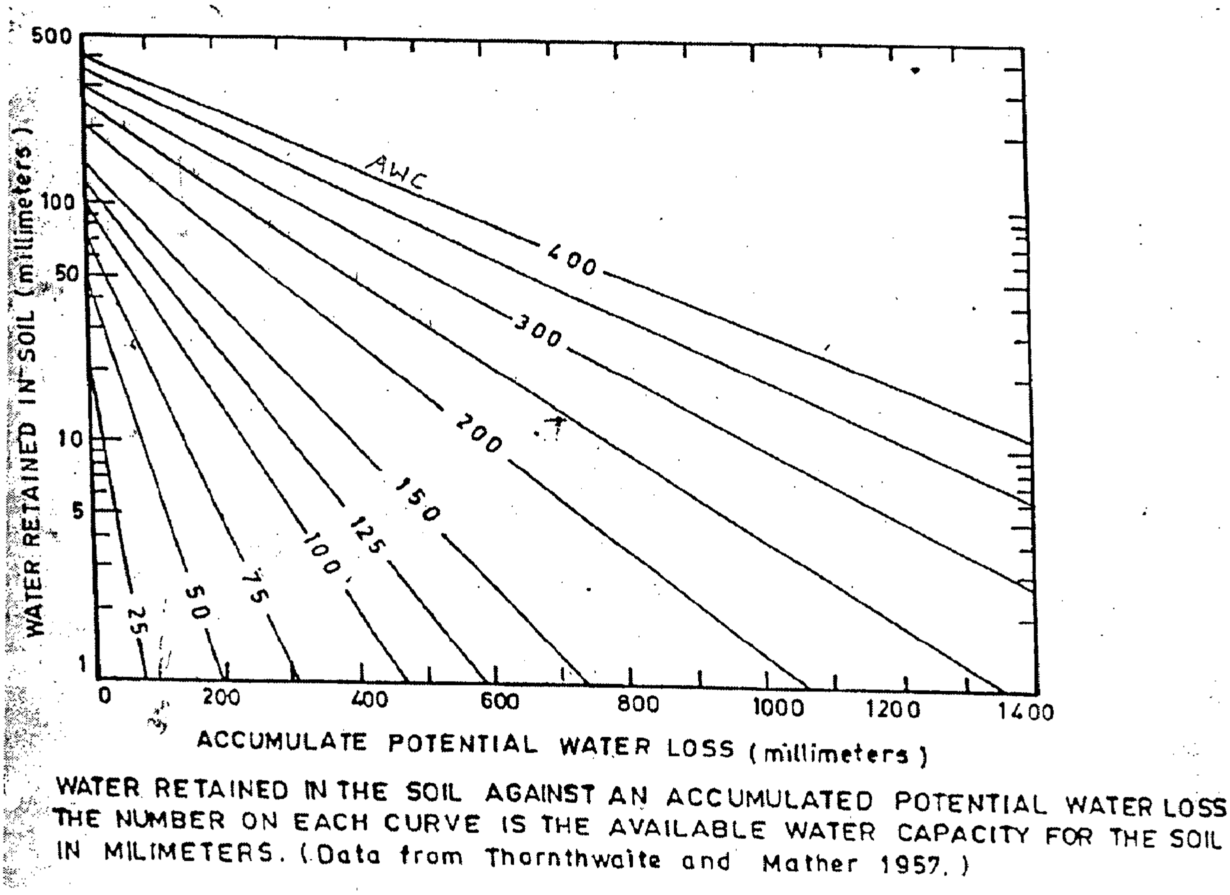


Fig. 4.2 Water retained in the soil after accumulated water loss

Source: Chaube U C, 2003

4.3 Rational Method

There are two single methods used for estimating runoff rate, known as the rational formula and cook's method. They are both useful and as they will not give exactly the same result they, they can both be used and the results compared to check on the reliability of the estimate. The rational formula is given below,

$$Q = CIA/360,$$

Where,

Q is the Runoff rate (m^3/s),

C is the Runoff coefficient (Between 0 and 1),

I is the rainfall intensity in mm/hr,

A is the area of the catchment in ha.

Typical values of runoff coefficients are given in Table 4.4.The value of intensity in mm/hr for use in the rational formula is the highest that can be expected in a ten-year return period for a time equal to the time of concentration of runoff at the outlet of the catchment also known as the design storm. Fig 4.3 shows a typical rainfall –duration curve for a ten-year return period. Table 4.5 gives approximate values for the time of concentration for small catchments.

Sample Calculation

A small catchment is on the hillside of Machakos District has 200 ha used for cultivation. It is assumed to be rectangular in shape along the slope (long and narrow).

Area = 200 ha,

= 200 x 2.5 = 500 Acres

The time of concentration Tc from Table 4.5 is 41 minutes,

= 0.68 hrs.

From Fig 4.1, Rainfall intensity is 80 mm/hr

C for Machakos hill condition from Table 4.4 is 0.52

Therefore Q = CIA/360,

= (0.52 x 80 x 200)/360

= 23.11 m^3/s

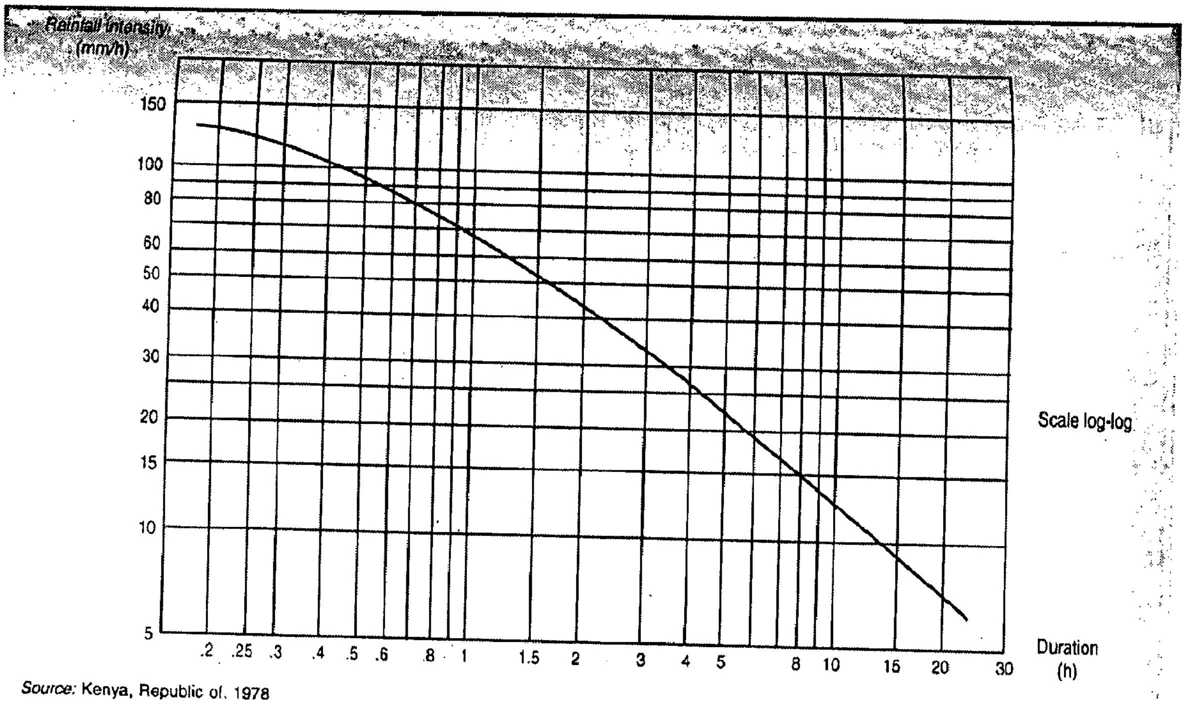


Fig 4.3 rainfall –duration curve for a ten-year return period

Table 4.4 Runoff coefficient values for use with the rational formula

Topography and Vegetation	Soil Texture		
	Open sandy loam	**Clay and silt loam**	**Tight Clay**
Woodland			
Flat 0 - 5% slope	0.10	0.30	0.40
Rolling 5 –10% slope	0.25	0.35	0.50
Hilly 10 – 30% Slope	0.30	0.50	0.60
Pasture			
Flat 0 - 5% slope	0.10	0.30	0.40
Rolling 5 –10% slope	0.16	0.36	0.55
Hilly 10 – 30% slope	0.22	0.42	0.60
Cultivated			
Flat 0 - 5% slope	0.30	0.50	0.60
Rolling 5 –10% slope	0.40	0.60	0.70
Hilly 10 – 30% slope	0.52	0.72	0.82
Urban Areas	30% of area impervious	50% of area impervious	70% of area impervious
Flat 0 - 5% slope	0.40	0.55	0.65
Rolling 5 –10% slope	0.50	0.65	0.80

Source: Hudson 1995

Table 4.5 Time of concentration for small catchments

Area (ha)	Time of concentration (minutes)
0.4	1.4
2.0	3.5
4.0	4.0
40.0	17.0
200.0	41.0
400.0	75.0

Source: Hudson 1995

4.4 Cook's Method

This method is suitable for soil conservation works in rather small catchment areas (runoff areas). Under African conditions there are high rainfall intensities even in dry areas. The runoff is influenced more by the local surface conditions within the catchment area, than the rainfall intensity. Consequently rainfall intensity can be disregarded in the calculations. The calculations of runoff is based on the following characteristics of the area,

(1) Vegetative cover,

(2) Infiltration rate of water into the ground,

(3) Topography inclusive of the slopes.

Table 4.6 gives the numerical values for these three characteristics under African conditions:

Table 4.6 Characteristics and values under African conditions

Vegetative cover	Infiltration rate	Topography
Forest or thick grass cover (10)	Well drained soils e.g. Sand (10)	Flat land or gentle slope (0 – 5%)
Scrub or medium grass cover (1)	Moderately pervious soil e.g. Silt (20)	Moderate slope (5 – 10%)
Cultivated land (20)	Slightly pervious soil e.g. loam (25)	Rolling or hilly land (10 – 30%)
Bare or sparse Cover (25)	Shallow soils with impeded Drainage (30)	Steep slopes (exceeding 30%) Mountains
	Clay and Rock (40)	
	Impervious soils and water Logged areas (50)	

Source G Wenner, 1981

From each of the three columns the most appropriate value should be selected, and the values should be added to give the numerical figure for these characteristics. The runoff in cusecs can be read from Table 4.7,4.8 and 4.9 using the areas in acres and the sum of the characteristics. The tables are for square, rectangle across the slope (broad and short) and rectangle down the slope (long and narrow) respectively.

Table 4.7 Characteristics of square runoff areas

Runoff areas in acres	25	30	35	40	45	50	55	60	65	70	75	80
5	3	5	7	9	11	13	15	17	19	21	25	30
10	5	8	11	14	17	21	25	30	35	40	46	52
15	7	11	15	20	25	30	35	42	50	58	66	75
20	10	15	20	25	30	38	46	55	65	75	85	95
30	12	18	25	33	42	52	64	76	90	105	120	135
40	15	20	30	40	50	65	80	95	110	130	150	175
50	17	25	35	50	65	80	100	120	140	165	190	215
75	20	35	50	70	90	115	140	170	200	235	270	310
100	25	45	65	90	120	150	180	220	260	300	350	400
150	35	60	90	125	165	210	260	310	365	425	500	580
200	40	80	120	170	220	270	350	400	470	550	640	750
250	50	90	140	190	245	310	385	470	565	670	785	910
300	60	100	150	210	280	360	453	550	660	780	910	1050
350	70	120	180	240	330	430	540	640	760	890	1030	1160
400	80	140	200	280	370	490	600	710	860	990	1160	1280
450	90	150	220	300	410	540	660	780	940	1090	1280	1390
500	100	160	240	330	450	590	720	850	1030	1200	1390	1520

Source G Wenner, 1981

Sample calculation

A small catchment is on the hillside of Machakos District has 200 ha used for cultivation. It is assumed to be rectangular in shape along the slope (lone and narrow).

Area = 200 ha,

= 200 x 2.5 = 500 Acres

The characteristics are as follows,

(1) Cultivated land - 20,

(2) Slightly Pervious soil e.g. loam - 25,

(3) Rolling or hilly - 15

The sum of the characteristics is 60. From table 4.9, for 500 acres the runoff is 740 cusecs. Therefore,

Q = 740 x 0.0283 = 21.94 m^3/sec.

The value 21.94 m^3/sec obtained using cook's method compares well with 23.11 m^3/sec obtained when using the rational method. Smaller catchments can be identified and similar techniques can be used because the district has varied characteristics.

Table 4.8 Characteristics for broad and short runoff areas

Runoff areas in acres	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
5	4	6	8	10	12	15	18	21	24	27	31	35
10	7	10	12	15	20	26	32	38	44	51	58	65
15	9	14	19	25	32	40	48	57	66	75	85	95
20	12	18	25	32	40	50	60	70	80	95	110	125
30	16	25	35	45	55	70	85	100	115	135	155	175
40	19	30	42	55	70	90	110	130	150	175	200	225
50	23	35	50	65	85	110	135	160	185	210	240	275
75	30	50	70	95	120	150	185	220	255	295	340	390
100	35	60	85	120	160	205	250	295	345	395	450	510
150	45	85	125	170	220	280	340	410	485	560	640	725
200	55	100	150	205	280	360	445	535	630	730	830	935
250	65	125	190	260	340	440	550	665	780	900	1020	1145
300	80	145	220	300	390	490	600	720	850	990	1150	1350
350	100	170	260	340	460	580	700	830	980	1160	1340	1510
400	110	210	290	400	520	670	800	920	1120	1300	1500	1660
450	120	220	320	440	580	740	880	1020	1240	1420	1670	1810
500	130	230	340	470	630	800	960	1110	1350	1560	1800	1970

Source G Wenner, 1981

Table 4.9 Characteristics for long and narrow runoff areas

Runoff areas in acres	25	30	35	40	45	50	55	60	65	70	75	80
5	3	4	5	6	8	10	12	14	16	19	22	25
10	4	6	9	12	15	18	22	26	30	35	40	45
15	6	9	12	16	20	25	30	35	41	47	53	60
20	7	11	16	21	27	33	39	46	54	62	70	80
30	9	15	21	28	36	46	56	66	76	88	100	115
40	12	20	28	36	46	58	70	85	100	115	130	145
50	15	25	35	45	60	75	90	105	120	135	155	175
75	20	32	45	60	80	100	120	145	170	195	225	255
100	25	40	55	75	100	130	160	190	220	255	290	330
150	32	55	80	105	140	180	225	270	315	360	410	470
200	40	70	100	135	180	235	290	345	405	470	540	615
250	45	80	120	160	215	280	345	415	490	570	660	760
300	50	90	135	190	250	320	400	480	570	670	780	900
350	60	100	150	200	280	370	470	550	660	770	890	1000
400	70	120	170	240	330	420	520	610	740	860	1000	1100
450	80	130	190	260	360	470	570	670	820	940	1100	1200
500	90	140	200	280	390	510	620	740	890	1040	1200	1320

Source G Wenner, 1981

4.5 Hydrological Soil Cover Complex Number Method

It estimates the direct runoff (depth) or rainfall excess storm wise. This method is based on maximum retention (s) of the watershed which is determined by the wetness of the watershed i.e. the antecedent moisture condition and the physical characteristics of the watershed. The following Rainfall – Runoff relation is normally used for small watersheds.

$$Q_r = \frac{(P - I)^2}{(P - I + s)}$$

Where,

I = 0.2s for this soil condition,

Q_r is the actual runoff,

P is the mean rainfall determined over 1 0 years frequency for 6 hr rainfall.

$$Q_r = \frac{(P - 0.2s)^2}{(P - 0.2s + s)}$$

$$Q_r = \frac{(P - 0.2s)^2}{(P + 0.8\ s)}$$

The Curve Number equation is given by,

$$CN = 25400/(254 + s)$$

In this watershed AMC 11 condition that is actually the average condition is taken.

Table 4.10 Runoff Curve Number values without watershed management

Land Use	Area (ha)	Treatment/ Practices	Hydrologic condition	Curve Number
Maize	153,850	Contoured +Terraced	Poor	82.0
Millet/Sorghum	7,655	Contoured +Terraced	Poor	81.0
Root/Tuber crops	9,145	Contoured +Terraced	Poor	81.5
Pulses	132,390	Contoured +Terraced	Poor	81.5
Coffee/Fruit Trees	9,252	Contoured +Terraced	Poor	77.0
Forest Land	2,241		Fair	73.0
Pasture Land	313,567		Poor	86.0

Total area = 628,100 ha,

Therefore the Weighted Curve Number (CN) will be,

CN = {(153850 x 82) + (7655 x 81) + (9145 x 81.5) + (132390 x 81.5) + (9252 x 77) + (2241 x 73) + (313567 x 86)}/628100

= 83.77

But CN = 25400/ (254 + s)

Then, 83.77 = 25400/ (254 + s)

S = 49.21 mm or 4.92 cm.

$$Q_r = \frac{(P - 0.2s)^2}{(P + 0.8\ s)}$$

$$= \frac{(23.5 - 0.2 \times 4.92)^2}{(23.5 + 0.8 \times 4.82)}$$

= 18.477 cm or 184.77 mm.

Therefore the Actual runoff is approximately 184.77 mm and this compares well with the value 183.5 mm got using the water balance method. The 25% of the rainfall lost as runoff is more than the deficit, which stands at 162.63 mm by 2002. Fig. 4.4 shows the difference between annual rainfall and runoff, and for the district it is 400-800 mm. Average rainfall is 700 mm and runoff is 185 mm giving an average difference of 515 mm.

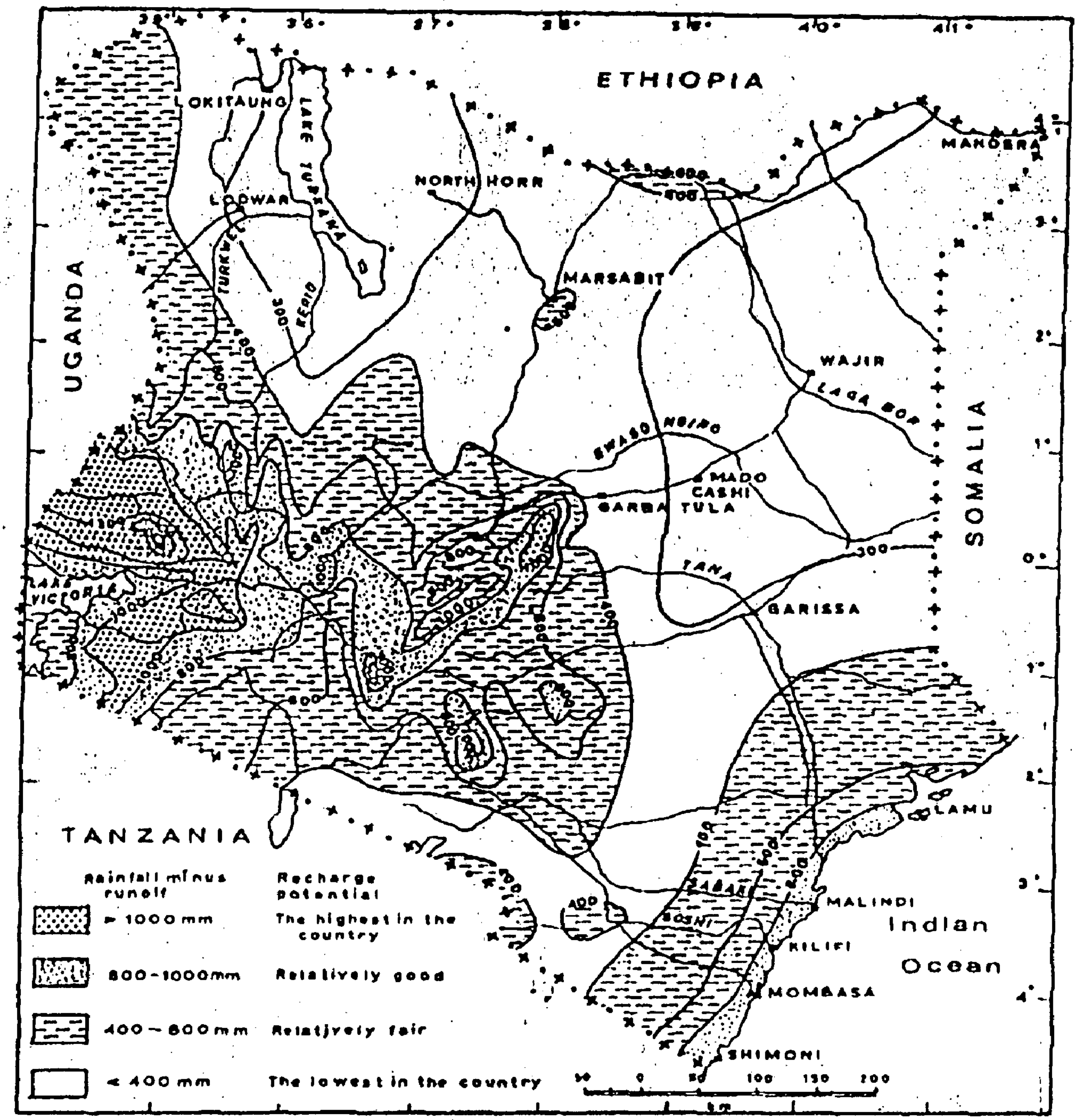


Fig. 44 The difference between average annual rainfall and runoff (source: National Water Master Plan, Stage 1. 1980, TAMS).

CHAPTER 5

SOIL LOSS ESTIMATION

5.1 General

Soil is one of the vital resources for agricultural production and it is susceptible to erosion by flowing water. Soil erosion is caused by a complex of factors such as the clearing of forests in order to get more land for cultivation, improper use of land, shifting cultivation and the logging for timber and fuel production. Especially, the land on the steep slopes without appropriate protection is vulnerable to erosion.

Increase in population and development of nature for industrialization tend to accelerate the process of erosion, while soil erosion result in the loss of fertile top soil causing agricultural production decrease and the changing of river regime causing flood damage. Soil erosion in the catchment area removes vegetation and organic matter from the surface and decreases the intake rate of soil. Thus, increased surface runoff brings floods, which cannot be taken care off by the conventional river channel.

Also soil erosion leads to silting of the irrigation and drainage canals, insufficient irrigation and drainage, aquatic weed growth and declining fish production in the rivers and lakes. Soil erosion aggravates the environment and thus gives much harm to the local population both in economic and social fields. Soil conservation is to prevent soil from being carried away and utilize it without waste for high-level agricultural production. Soil conservation prevents lowering of the soil productivity and sedimentation that may lead to flood damage, lowering of water quality and environmental effects.

5.2 The Universal Soil Loss Equation (USLE)

The most widely used method for the prediction of soil loss is the universal soil loss equation (USLE). It may be used to,

(1) Predict average annual soil loss from a field slope with specific land use condition.

(2) Guide the selection of cropping and management system and conservation practices for specific soils and slopes.

(3) Predict the change in soil loss that would result from a change in cropping or conservation practices on a specific field.

(4) Determine how conservation practices may be applied or altered to allow more intensive cultivation.

(5) Provide soil loss estimates for conservationists to use in determining conservation needs.

The tolerable mean annual soil loss according to Wischmeir is,

(1) On Shallow soils - 1 to 3 tons /acre, often 2 tons/acre,

(2) On deep soils of sand and silt – 4 tons/acre,

(3) On deep soils of loam and clay – 5 to 7 tons/acre, often5 tons/acre.

A very deep fertile loam derived in situ from volcanic formations situation occurs in Kenya and a value of 12.5 – 15 tons/hectare or 5 – 6 tons/acre is appropriate to use.

The USLE is expressed as below.

A = RKLSCP and the factors are as explained in Chapter 2.

(1) R – Rainfall Erosivity factor. R for Machakos district is 200. This value is for southeastern Kenya down to Indian Ocean. Most of it is subtropical with less intensive rain. The mountain areas with higher rainfall are not supposed to have much greater figures as such rains usually have small rain droplets.

(2) K – Soil Erodibility factor.

Various types of soils have different degrees of erodibility as shown in Table 5.1 below

Table 5.1 Degrees of erodibility of soils

Soil	**K**	**Comments**
Sand and loamy sand	0.10	Low because of high infiltration
Sandy loam and silt loam	0.25	
Loam	0.40	High because of low infiltration and weak cohesion
Clay loam	0.30	
Clay	0.20	Low because of strong cohesion

Source: Wenner, 1981

K for Machakos District is taken as 0.2

(3) LS – The Length-Slope factor or The Topographic factor. This can be read from charts provided and this factor for the study area it is Table 5.5.

(4) C – Cropping management factor, considers the soil loss under specific cropping management compared with the loss from a continuous fallow, as well as the

influence of rainfall during the different crop stages. The protective effect of crop and its management varies during a year and as also does the erosivity. Therefore the factor of C is determined for five crop-stage periods namely,

(a) Fallow or preparation of seedbed.

(b) Seedbed – 1st month after seeding,

(c) Establishment – 2nd month after seeding,

(d) Growing cover – 3rd month from weeding to harvest,

(e) Stubble – From harvest to ploughing.

Weighted value of C is ultimately computed.

Table 5.2 gives C values for some selected crops.

Table 5.2 values of C for some crops

Crop	Weighted value of C
Maize	0.7
Sorghum	0.6
Cassava	0.5
Cotton, Tobacco, cover crops	0.5

Source C G Wenner

The worst crop management practice has a value of 1, but good management techniques have C values down to 0.05. The management often required for good erosion control coincides with intensive, efficient profitable farming. This is illustrated in table 5.3 below that shows that soil and water losses were reduced to something like 1/15 by improved crop management.

Table 5.3 The effect of crop management on the soil and water losses from maize

Plot A, Maize at medium Level of production		Plot B, Maize at high Level of production
25000 Plants /ha	Plant population	37000 Plants/ha
N 20 kg/ha, P_2O_5 50 kg/ha	Fertilizer application	N 100 kg/ha, P_2O_5 80 kg/ha
Removed	Crop residues	Ploughed in
5 ton/ha	Crop yield	10 ton /ha
250 mm	Runoff	20 mm
12.3 ton/ha	Soil loss	0.7 ton/ha

Source: Hudson, 1981

(5) P – Conservation practice factor – defined as the ratio of soil loss for a given conservation practice to the soil loss obtained from up and down the slope. It consists mainly of contouring, terracing and strip cropping (2 – 7% slope). As seen from Table 5.4, as the land slope decreases from medium to zero, the effectiveness of contour tillage to reduce soil loss decreases compared to non-contoured tillage filed. When the slope increases from medium to steep slope, the contour row diminishes its capacity to detain water on soils.

Table 5.4 Recommended values of conservation practices factor (P)

S. No	Slope %	Value of conservation practice factor (P)		
		Contouring	Contouring + strip cropping	Terracing + contouring
1	1.1 – 2.0	0.60	0.30	-
2	2.1 – 7.0	0.50	0.25	0.1
3	7.1 – 12.0	0.60	0.30	0.12
4	12.1 – 18.0	0.80	0.40	0.16
5	18.1 – 24.0	0.90	0.45	-

Source Hudson, 1991

5.2.1 Estimation of annual soil loss

Table 5.5 below gives the soil loss in tons/acre before any watershed management is done in Machakos district.

R = 200

K = 0.2

C = 0.7 (normal crop management factor for maize in Machakos district)

LS = Shown in the table as obtained from the Graph

P = Differs from slope to slope and it is shown in the table.

A = RKLSCP

Table 5.5: Estimation of soil lost without watershed management in tons/acre

% Slope	R	K	Ls	C	P	Tons/acre	Tons/ha
4	200	0.2	0.8	0.7	0.6	13.44	33.60
6	200	0.2	1.2	0.7	0.5	16.80	42.00
8	200	0.2	1.75	0.7	0.6	29.40	73.50
10	200	0.2	1.3	0.7	0.6	40.32	100.80
12	200	0.2	1.3	0.7	0.6	53.72	134.30
14	200	0.2	1.2	0.7	0.8	89.60	224.00
16	200	0.2	1.6	0.7	0.8	112.00	280.00
18	200	0.2	1.8	0.7	0.9	156.24	390.00
20	200	0.2	2.4	0.7	-	-	
						63.94	**159.85**

This value 63.94 tons/acre (159.85 tons/ha) without watershed management measures is very much above the tolerable limit for this area and so the watershed management measures are really a must.

CHAPTER 6

PRESENT LAND TREATMENTS

6.1 Agronomical Methods

6.1.1 Strip Cropping

Strip cropping is the farming of the sloping land in alternate, contoured strips of inter-tilled row crops and close growing grasses (or other crops ground cover crops) aligned at right angles to the direction of natural flow of runoff as in Fig 6.1. The close-growing strips slow down runoff and filter out soil washed from the land in the inter-tilled row. This control of runoff also allows increased opportunity for infiltration of the runoff and thus increased moisture in the soil. The strip widths are varied depending on the soil type and the slope. This practice requires a lot of land and it is only practiced in the low-lying areas where population pressure is not high.

6.1.2 Trash lines

Trash lines made by laying crop residues or trash in lines along the contour as shown in Fig. 6.2. They slow down runoff and trap eroded soil eventually forming terraces. This is practiced where and when crop residues are available.

6.1.3 Grass Barrier Strips

The barrier strips are planted along the contours. They are planted with fodder grass such as Napier or are left with natural grass as shown in fig.6.3. This practice is common in the hilly areas even on the slopes as steep as 35 %.

6.1.4 Reduced or Minimum tillage

This is a practice in which the soil is tilled to some extent but not completely inverted. This kind of tillage is not evident in the district.

6.1.5 Forests

Agro-forestry is practiced a lot by the farmers especially those on high and medium potential areas. Almost 70% of the farmers practice this system. The trees planted provide fuel and timber to the farmers thus saving the forests. A lot of tree planting in the forests has been done although it has been outmatched by the rate of logging for timber. The district is said to be timber hungry and a lot needs to be done to put more land under forest so as to achieve the universal limit of more 17%.

done although it has been outmatched by the rate of logging for timber. The district is said to be timber hungry and a lot needs to be done to put more land under forest so as to achieve the universal limit of more 17%.

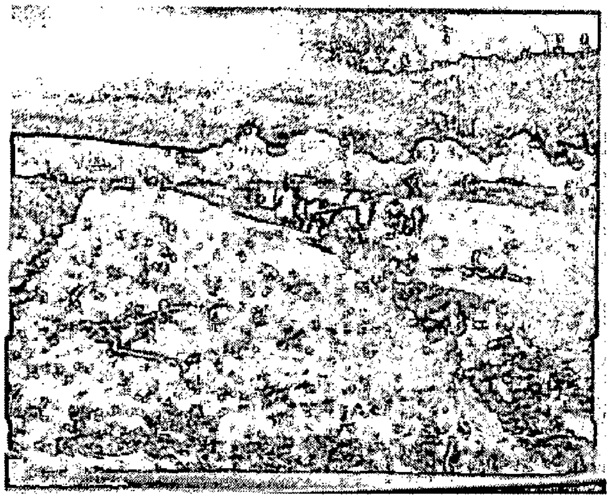


Fig. 6.1 Unploughed strip of land

Fig. 6.2 Trash lines

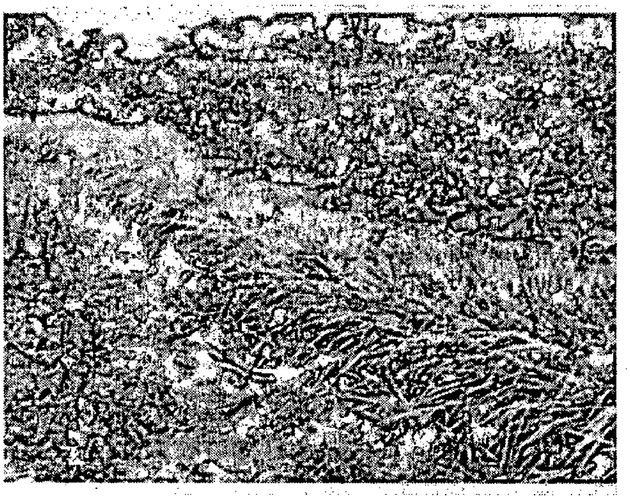


Fig. 6.3 Grass Strips

6.1.6 Contour Farming.

This involves aligning plant rows and tillage lines at right angles to the normal flow of runoff. It creates detention storage within the soil surface horizon and slows down the rate of runoff, thus giving the water the time to infiltrate into the soil. This practice is done 100% on all the farmland in the district.

6.1.7 Mulch Tillage

This involves covering bare soil with mulch or plant litter to prevent or reduce the evaporation of the soil moisture and minimize the erosive energies of rain falling directly onto soil particles. The mulch is usually crop residue such as maize stalks sorghum trash and wheat straw. This is not practiced in the district because all the crop residues are fed to livestock.

6.2 Mechanical Protection Works

6.2.1 Terraces

Fanya Juu terraces shown in Fig. 6.4 have an origin in the district. A Fanya Juu terrace is constructed by digging a trench and throwing the soil uphill to form an embankment. It can be developed into a bench terrace if enough soil moves down the slope and lodges above the embankment. They are either retention or graded channels so as to retain or drain excess water. Soil and rainwater are conserved within the bunds and the bunds are usually established with planted fodder grasses. Each farm using this technology is surveyed to see if it needs a cutoff drain to be installed in order to protect the terraces from surplus rainfall. About 70% of the cultivated land in the district is terraced.

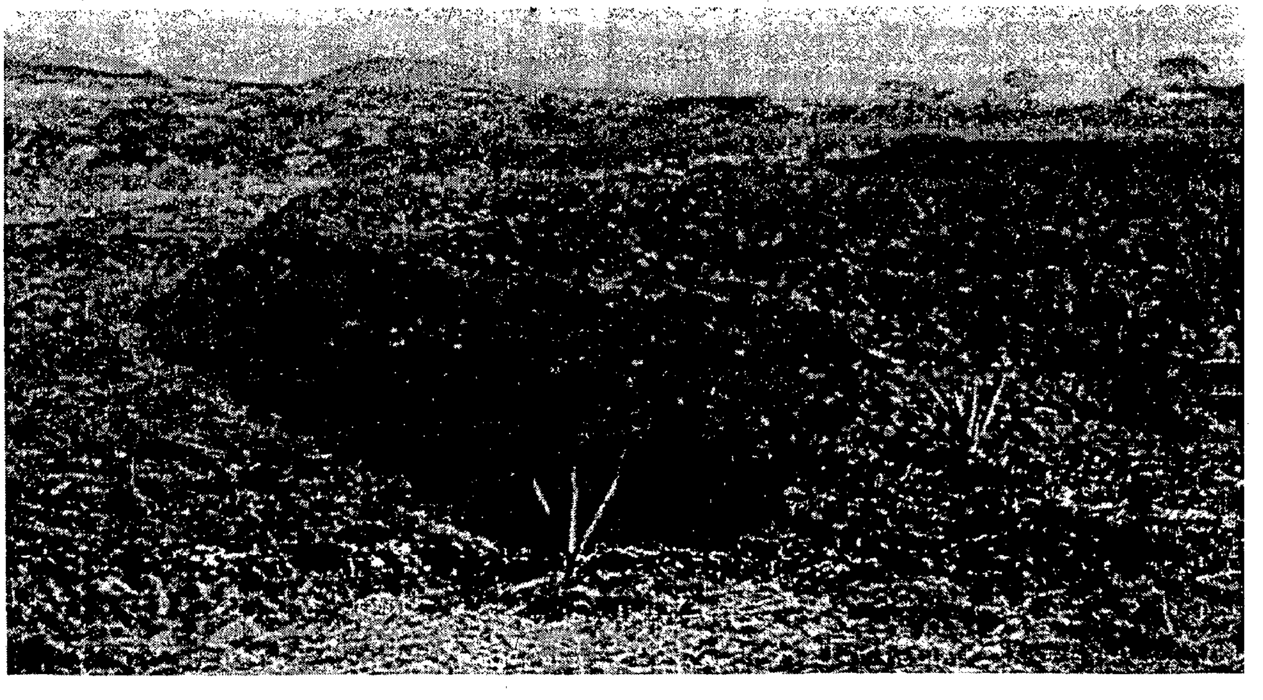


Fig. 6.4 Fanya Juu Terraces

6.2.2 Contour Bunds

There is no evidence for there use in the district possibly because of the cost and lack of technical know-how.

6.2.3 Check Dams.

They are structures built across a gully or a small stream. They are meant to check and control the growth of a gully and help in its healing. They are used to trap water and either store it for future use or allow it to infiltrate into the soil slowly without causing any major damage to the land and at the same time trap any soil that is being carried by the flowing water. There are various types of check dams depending on the material used. The following are found in the district,

(1) Gabions – Basically made of wire mesh boxes filled with stones. This method was very common at the initial stages of reclamation of the big gullies. The initiative was government and NGO supported and when they withdrew, sustainability was difficult because of the cost involved and also the farmer's feeling that they do not own the structures hence government property. Most of the dams have been filled and new embankments are required.

(2) Sisal embankments – Sisal shown in fig. 6.5 has proved to be a very effective form of embankment. When planted across a gully, it is able to grow well and hold the soil and reduce the erosive power of the flowing water. It is cheap because the crop is available freely in the district and almost all the farmers are using them when necessary.

(3) Stone Walls – Stonewalls have been constructed across gullies and streams to store the water that is flowing and also trap any soil that may be flowing along with the water. The walls are made where stone is locally available. This method is still very common especially on the slopes, Fig. 6.6 and 6.7 shows bench terraces and stone terraces respectively.

(4) Trash walls – Trash has also been used to create a wall for trapping the soil and reducing the velocity of flow of the water. The most common materials are tree branches, sorghum trash, maize stalks, etc

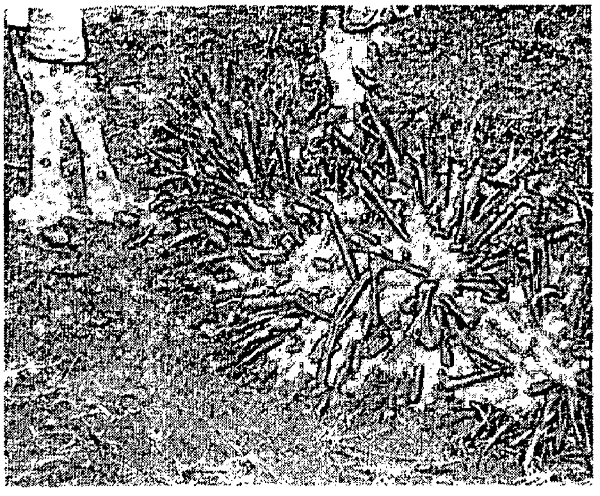


Fig. 6.5 Gully control by Sisal Plants

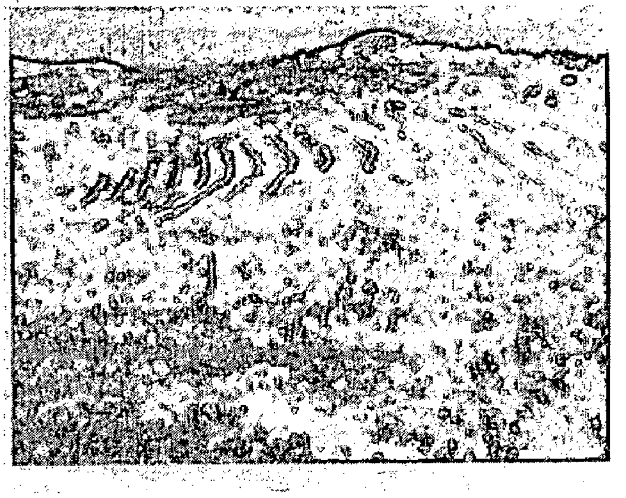


Fig.6.6 Bench Terrace

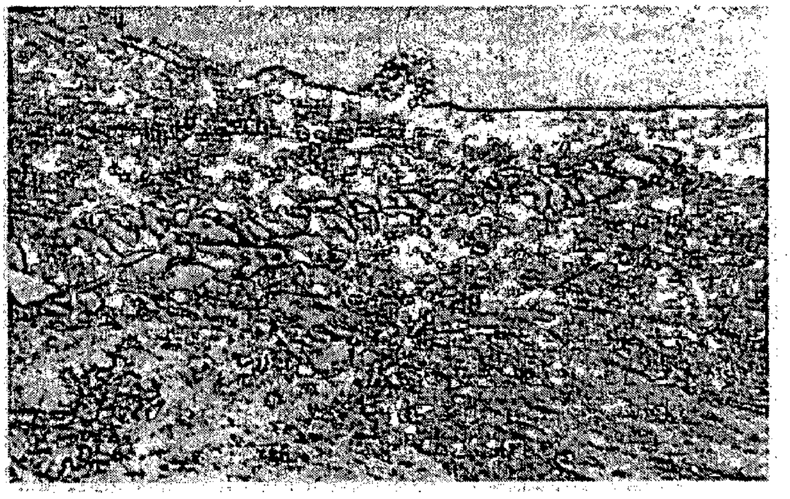


Fig.6.7 Stone Terrace

6.2.4 Earth Dams and farm ponds

Water is impounded for use at a later date or to allow it to infiltrate slowly into the soil without causing any harm to the soil. Earth Dams are common in the district but their development is solely by the government. Most of them have been silted up and no major desiltation is evident. Farm ponds are only used by the farmers in the lower slopes where vegetable growing is common. Still this requires a good amount of money and a suitable place where the water table is not so low, so there is limitation in its adoption and use. However it is highly suitable.

WATERSHED MANAGEMENT MEASURES RECOMMENDED

7.1 Cultural Measures

The cultural methods tend to affect the crop management factor C in the Universal Soil Loss Equation. Good methods will reduce the value of C and thus reducing the soil loss from an area and hence the water flowing from the area.

7.1.1 Farm Management

Good farm management can reduce the amount of erosion much more than terraces especially on gentle slopes. It looks after the soil as well as the crops. The following properties will reduce erosion,

(1) High percentage of clay, the particles of which are not easily detached by flowing water.

(2) Clods and large pores, which give a high infiltration rate

(3) High percentage of organic matter.

(4) High fertility.

(5) Prevalence of specific chemicals (divalent ions).

Out of the five above properties, the first one regarding soil particles cannot be changed by farm management but the remaining can be changed. If the surface of the ground is puddle or if it is compacted by the trampling of cattle or heavy machinery, the infiltration rate will decrease. Thus the structure of soil can affect runoff and erosion risks.

Ploughing as well as digging with a fork, are themselves conservation measures because they produce suitable soil structure. The clods formed by cultivation give large – pore like spaces, which increase infiltration rate and retain large amounts of water, thus increasing the runoff and erosion, e.g. In Senegal the turning of bare soil by the hoe or plough decreased the erosion by 64 %(Fournier's tests).

Organic matter increases the aggregation of soil particles and makes the aggregates more water-stable. The reason is ionic bonds between clay particles and organic substance. As a result of this aggregation the infiltration and percolation rates will be increased thereby decreasing the runoff of water and its erosion. The porous organic matter decomposed or not increases the water holding capacity of the soil. High fertility results in good growth of crops and is the best insurance against raindrop erosion.

increases the water holding capacity of the soil. High fertility results in good growth of crops and is the best insurance against raindrop erosion.

The protection of the soil is proportional to the horizontal growth of the plants. An improved crop density can reduce the area of bare ground from 40% to 10% (C G Wenner, 1981), thus reducing the raindrop erosion by four times. Specific chemicals especially calcium from fertilizers, increase the shear strength of clay soils. Such a stabilization of the soils makes them more resistant to rain and erosion.

Crops: Early planting

This method is recommended for Machakos district, as much of the erosive rains come during the beginning of the rainy season. However, at the time cracks are still open, reducing runoff and erosion. An early planting during the rainy season will develop better plants and give protection against soil erosion e.g. the mean annual soil loss in an experimental field was three times greater after late planting compared to early planting.

7.1.2 Companion Crops.

This technology of inter-cropping is very common in the district and should be encouraged where possible. The Table 7.1 below shows the benefit of companion crops in decreasing annual runoff and soil loss due to erosion. The trials were carried out on a slope of 5% in South Africa. The soil losses would have been much larger on slopes more than 5% in areas of more intensive tropical rains.

Table 7.1 Effect of companion crop on soil loss

Treatments	**Annual Runoff in % of rainfall**	**Annual soil loss in tons/Acre**
Bare soil, not worked	32	11.5
Maize, not fertilized	10	3.6
Maize + Mineral fertilizer	9	3.1
Maize + Mineral fertilizer + companion crop	6	2.1

Source C G Wenner, 1981

7.1.3 Mulching

7.1.3.1 Normal mulching or Stubble mulching.

This is using dead plant residues as cover crop on the ground. Suitable mulches are banana-leaf mulch and mulch of grass. As for maize, the stalks can make seedbed and planting operations more difficult than without mulching. Mulching is indeed one of the most effective methods to minimize erosion and this is because,

- It decreases raindrop erosion, slows down the water flows and increases the infiltration rate, as the pores of the soil are not clogged.
- It encourages insects and worms to make holes into the ground, thus increasing the permeability of the soil to a large extend.
- Straw mulch can reduce the soil loss though erosion by 95% (Holtan and Kirkpatrick).
- Mulching can increase the crop yield by 27% according to an experiment in Machakos, Kenya. This is highly recommended provided the mulch is available.

7.1.3.2 Trash Farming

This is ploughing in of crop residues. It has positive effect to soil erosion and it is also highly recommended in the district.

7.1.4 Contour farming

This involves doing all the cultivation activities and planting along the contours. The effectiveness of contour furrows in collecting water is greater on gentle slopes than on a steep slope e.g. a channel on a 5% slope can hold more water than the same size of channel on a 30% slope. The decreased runoff in contour cultivation permits a better retention of the nutrients thus increasing the yield. This method is used all over Kenya and it is highly recommended for Machakos district.

7.1.5 Tied Ridging or Listing

Tied Ridging or basin listing is used to overcome the risk of erosion in East Africa. It can increase the yields in semi-arid areas but it should not be used where there is a risk of water logging i.e. in soils with a low permeability in areas with high rainfall. Instead of continuous basins, pitting is used in parts of the district with pits being 0.75 m deep. Tied ridging and pitting can easily retain the water from a 3-inch storm. Another advantage is that the ridges need not necessarily be cut accurately on the contour. This method is also highly recommended especially on the low-lying areas.

7.1.6 Strip cropping

Contour strip cropping promotes good soil structure and decreases erosion by water flows. Rain erosion is decreased on the alternating wide strips of grass, but still proceeds on the cropped strips. In Machakos district, strip cropping should be practiced more in the low lying Semi-Arid areas where the pastures are as large as the cropped land. The wide strips of pasture and crops are sometimes bordered by narrow grass strip terraces, or by channels diverting surplus water. The recommended maximum width of crop strips may be calculated as per table 7.2 below,

Table 7.2 Recommended maximum widths of crop strips

Slope	**Recommendation**
30 – 20%	10 m or closer if experience demands
20 – 12%	According to observations made in Kenya about 20 m
Less than 12%	A formula is used for the calculation of the width in feet, 168 – (7 x% slope), e.g. for a 10% slope, 168 – (7 x 10) ≐ 98 feet or 33m

C G Wenner, 1981

7.1.7 Pitting

These are small semi-circular pits dug to break the crusted soil surface. The pits are about 30 cm in diameter and 20 cm deep and the seeds are planted in the middle of the pits. The system developed and practiced at the Katumani Research Canter in the district has proved to be suitable to areas with average annual rainfall of about 500 mm.

7.2 Physical/Mechanical Measures

Physical soil conservation measures should be planned on the basis of watersheds e.g. valleys or parts of valleys. The directions of the potential overland flow should be identified. It is necessary to locate waterways for discharging water from terraces and cutoff drains if any. The methods below are recommended for use in the district.

7.2.1 Cutoff Drains

It is an open trench with an embankment on the lower side as shown in Fig 7.1. Cutoff drains protect cultivated areas from erosion by water flows. They mainly prevent large flows down the slope that create rill and gully erosion. They should be constructed only where the need is quite evident; i.e. the need is made obvious by erosion rills or if the farm needs protection from water flows coming from outside the farm. Sometimes it is possible to combine the construction of a cutoff drain with the construction of small dam in order to store the water. About 50% of the farmers especially on the slopes are using this method and it is highly recommended where there is a need.

7.2.2 Terraces

They are needed on slopes with erodible soils where contour farming, crop rotation and or strip cropping by themselves are not sufficient measures to prevent an undesirable loss of soil. Table 7.3 below gives different types of bench terraces. Figures in brackets represent upper slope limits possible under certain conditions.

Table 7.3 Bench terraces

Type of Terrace	Slope	Comments	Adaptability in the District
Excavated			
Ordinary	12(20) - 35%	Expensive & not	Not recommended for use
Modified	35 – 55%	Suitable for shallow Soils	
Developed			
Grass Strip	2 – 35(55)%	Cheap and easy to	Highly recommended and very
Fanya Juu	2 – 55%	construct	suitable to Kenyan conditions

7.2.2.1 Design of developed Terraces

The Vertical Interval (in feet), in parts of tropical Africa including Kenya,

VI ={ % Slope (above the terrace line)/ a} + b

Where, a and b are the rainfall and erodibilty of the soil respectively. In Kenya a is taken as 4 due to intense precipitation. For erodibility of the soil usually b is taken as 2 but can be varied,

VI ={[% Slope]/ 4 + 2} +-25%

Horizontal Interval (in units of VI)

HI = (VI x 100)/ % Slope

7.2.2.2 Formation of Bench Terraces

Fig 7.2 below shows the calculated soil loss for various percentages of slopes and for two extreme types of soil erodibility (sand and Loam). Though the slope is terraced, the soil losses are too large in loam soils on steep slopes (more than 5 tons/Acre /year). Therefore by itself would not be a sufficient method.

The percentage slope has to be decreased. Fig 7.3 shows how the percentage of slope has to be decreased to reduce the soil loss to an acceptable level of 5 tons/Acre/year. Once the percentage slope is determined then VI and HI can be calculated from formula.

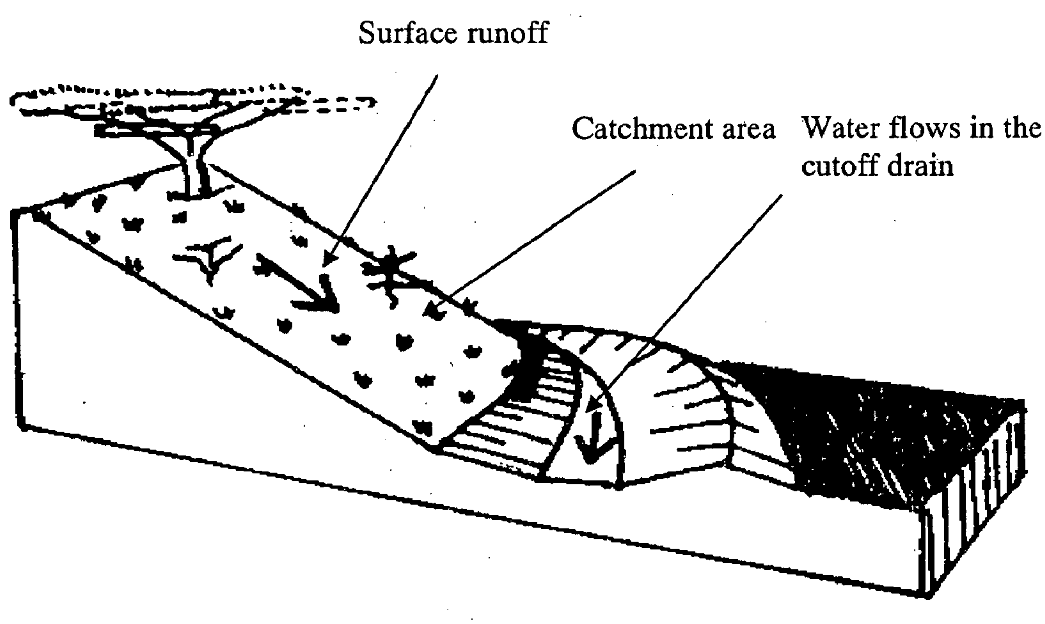


Fig 7.1 Cutoff Drain passing water from higher slopes

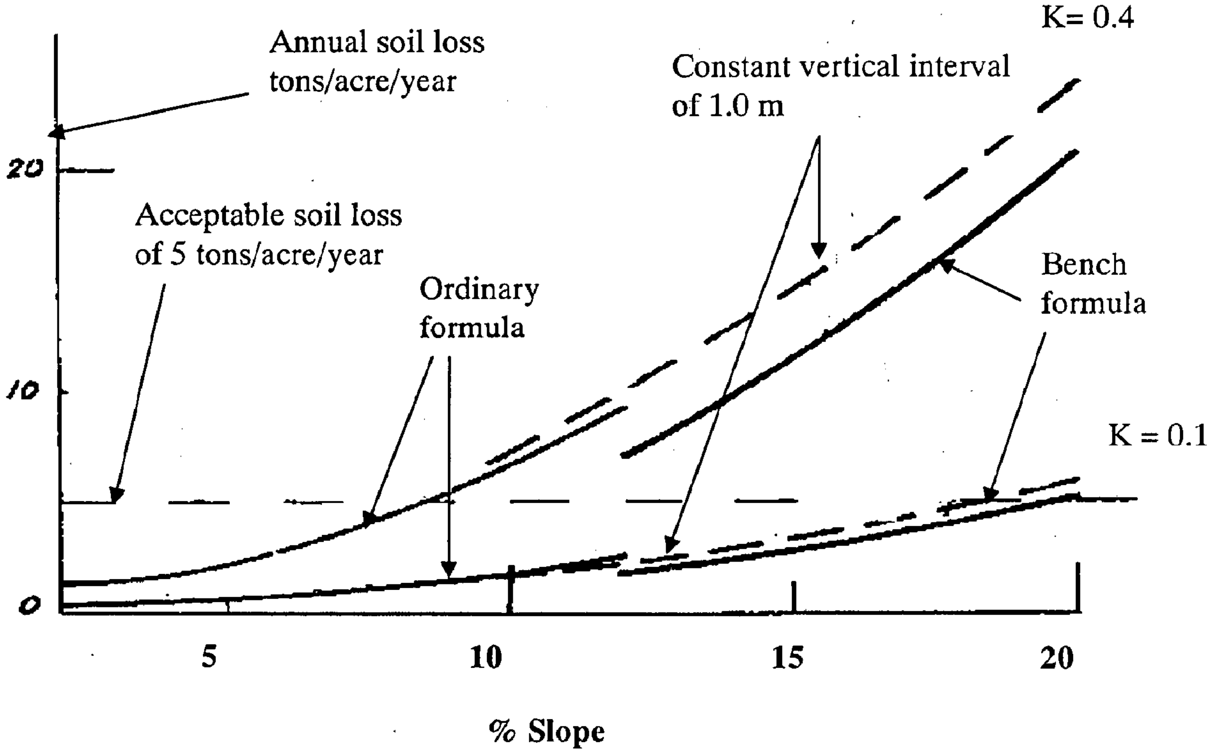


Fig 7.2 Soil loss from sana and loam for various slopes

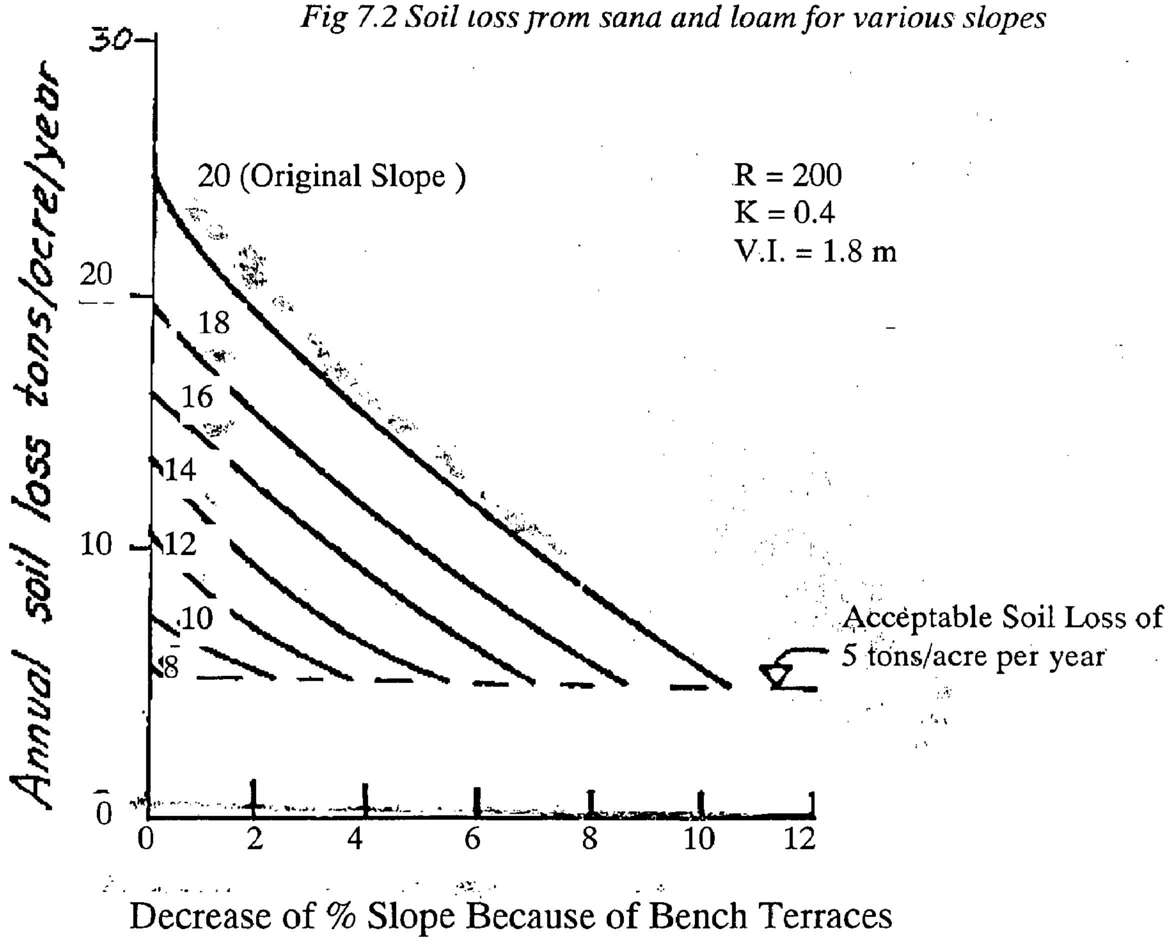


Fig 7.3 Slope reduction to acceptable loss of 5 tons/Acre/Year

Impact

The retention of moisture in bench terraces is especially important in dry areas. There are examples from Mitaboni Location in Machakos District (high potential area), where during dry years farmers with bench terraces got normal yields of maize and beans, but farmers without bench terraces did not get any yield at all. Farmers in medium potential areas of the district increased their yields of maize by 50% after introducing Fanya Juu Bench terraces.

7.2.3 Bunding

They are small earthen barriers provided in agricultural lands with slopes raging from 1 to 6 percent. They control the effective length of slope and thereby reduce the gain in velocity of runoff flow to avoid rill and gully erosion. The design is as explained in Chapter 2.

7.2.3.1 Contour Bunds

They are constructed along the contours in agricultural lands. Contour bunds are meant for storing rainwater received during a period of 24 hours at 10 years recurrence interval. The major considerations are maximum depth of water to be impounded. It is suitable for areas with slopes range of 1- 6 % and rainfall less than 600 mm. It is therefore recommended for arid parts of the district with suitable slope and terrain.

7.2.3.2 Graded Bunds

They are laid along predetermined longitudinal grade instead of along the contours. They are adopted in areas that have a slope of 1 – 6 % and annual rainfall exceeds 600mm. The average annual rainfall in Machakos District is 700 mm and they are highly applicable.

Principal of operation

They control the effective length of the slope and thereby reduce the gain in velocity of runoff flow to avoid rill and gully formation. To increase the time of concentration of the rain water where it falls and allowing more opportune time for rain water to be absorbed in the soil profile. Converting a long slope into several short ones so as to minimize the velocity and thereby reduce the erosive power of runoff water. To divert runoff water either for water harvesting or saving lower lands from excessive sand deposition or getting it severely eroded.

7.2.4 Check Dams

For control of gullies, the erosive velocities are reduced by flattering out the steep uniform gradient of the gully by constructing a series of checks that transform the longitudinal gradient into a series of steps with low risers and long flat treads. Temporary check dams will be provided only to provide protection until the vegetation becomes well established. The vertical interval between the check dams is equal to the height of the check dams. For stone check dams, it is usually one meter. Check dams can easily be applied in all gullies less than 2-meter depth and 5-meter width.

Heede and Mufich (1973) developed an equation to simplify the calculation of check dam spacing,

$X = H_E / K \tan S \cos S$,

Where

X = Spacing in meters,

H_E = Effective dam height (m) as a measure from gully bottom to spillway crest

S = Slope of the gully floor,

K = Constant, 0.3 when tan S is less than or equal to 0.2 and 0.5 when tan S is greater than 0.2.

Below (Table 7.4) are the guidelines on the spacing of the check dams under Kenyan conditions and the abbreviations a, b and c used in the table are as explained below.

(a) Wood and gabion constructions, (b) Stone wall with slopes 1:1, (c) higher than 1 m only in exceptional cases. Check dam construction should normally start in the lowest part of the gully and proceed upwards. Check dams can be constructed from any material available locally. They are used and are still very necessary in Machakos District. The types found are gabions, sisal, loose rocks, Tree branches, Sorghum stalks, etc.

Table 7.4 showing spacing in meters between check dams.

Gradient %	Height of check dam			
	0.3 m	0.6 m	0.9 m	1.2 m
2	15	30	45	60
4	15	30	45	60
6	7.5	15	23	30
8	5.2	10.3	15	20
10	4.0	7.7	11.5	15
12	3.2	6.3	9.3	12
14	2.7	5.3	7.8	10
16	2.3	4.6	(a) 6.7, (b) 7.4	a) 8.9, (b) 10.0
20	1.8	(a) 3.7, (b) 4.5	(a) 5.4, (b) 6.7	(a) 7.1,(b) 8.5
24	1.7	(a) 3.1, (b) 3.9	(a) 4.5, (b) 6.1	(a) 5.9, (b) 8.0
28	a) 1.4, (b) 1.7	(a) 2.7, (b) 3.4	(a) 3.7, (b) 4.5	(a) 3.7, (b) 4.5
32	(a) 1.2, (b) 1.6	(a) 2.3 (b) 3.2	(a) 3.3, (b) 4.6	(a) 4.3, (b) 6.0
36	(a) 1.1, (b) 1.5	(a) 2.1, (b) 2.9	(a) 3.0, (b) 4.4	(a) 3.9, (b) 5.7
40	(a) 1.0 (b) 1.3	(a) 1.9, (b) 2.9	(a) 2.7, (b) 4.2	(a) 3.5, (b) 5.5
44	(a) 0.9, (b) 1.2	(a) 1.7, (b) 2.8	(a) 2.4, (b) 4.0	(a) 3.1, (b) 5.2

Source: C G Wenner, 1981

7.2.5 Dug-out ponds/farm ponds

Where the topography does not lend itself to embankments construction, dugout or excavated ponds can be constructed in a relatively flat terrain. Dugout ponds are advantageous where evaporation losses are high and water is scarce.

As evaporation loses are quite high and due to scarcity of water in the watershed, the dug-out ponds are suitable for storage purposes. The low point of a natural depression is a good location for a dug-out pond. The ponds can be excavated and excavated material disposed as shown in fig. 7.4.

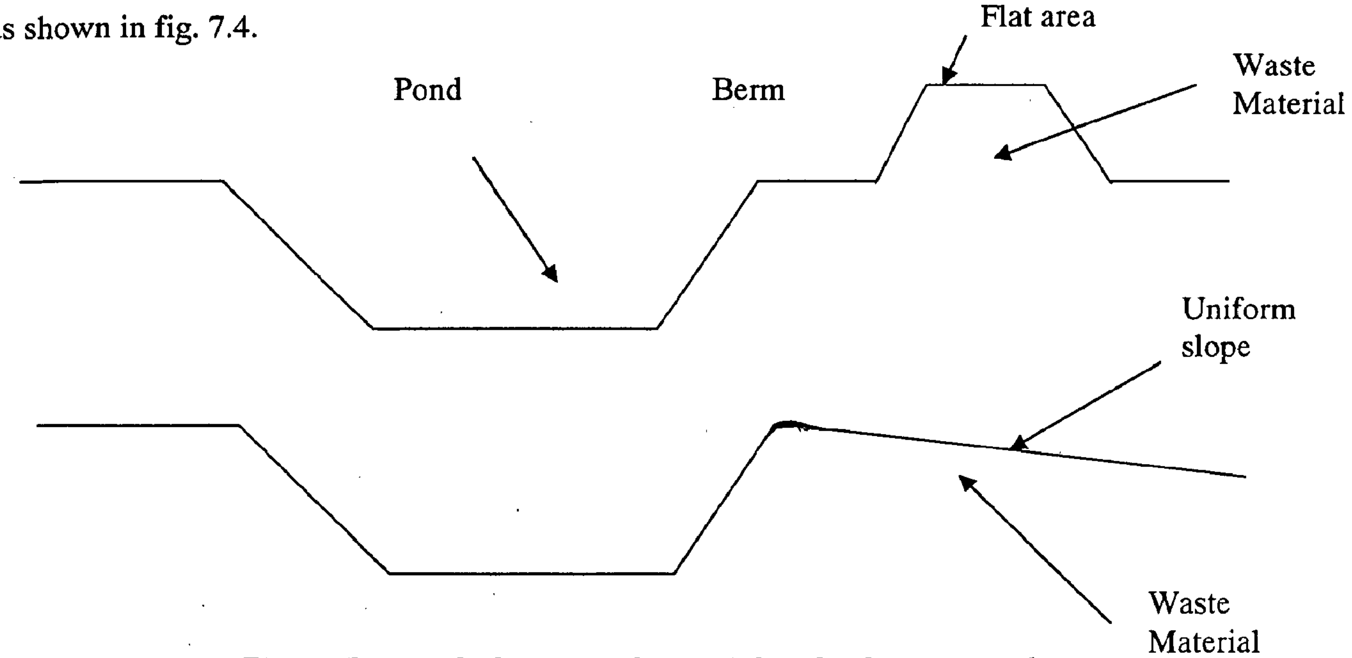


Fig 7.4 Disposal of excavated material in the dug-out pond.

(1) Estimation of volume of pond

The volume of the excavation required can be estimated with sufficient accuracy by primordial Formula:

$$V = \frac{(A+4B+C) \times D}{6}$$

Where,

V = Volume of excavation (m^3),

A = Area of excavation at the ground surface (m^2),

B = Area of excavation at the mid depth point (0.5D) (m^2),

C = Area of excavation at the bottom of pond (m^2),

D = Average depth of the pond (m).

(2) Pond capacity

Max. Pond Capacity = (AxPx0.3)/1000,

Where,

A = Calculated area (ha),

P = Annual total rainfall (mm) and

0.3 is the assumption that 30% of rainfall is converted into runoff.

The average area of the farms in the farmland is 5 ha while the average acreage in grassland is 100 ha. My proposal is to make dugout ponds in all the areas apart from the forests.

Farms: One pond is dug per 5 hectares, therefore the maximum capacity of the pond is

$$V = (AxPx0.3)/1000$$
$$= (5 \times 700 \times 0.3)/1000$$
$$= 1.05 \ m^3$$

The total area under crops is 312,292 ha, therefore the volume of water stored

$$= (321,292/5) \times 1.05$$
$$= 65,581.32 \ m^3 \qquad \text{(i)}$$

Pasture land: One pond is dug for every 100 hectares, therefore the maximum capacity of the pond is

$$V = (AxPx0.3)/1000$$
$$= (100 \times 700 \times 0.3)/1000$$
$$= 21 \ m^3$$

The total area under pasture is 313,576 ha and so the volume of water stored

$$= (313,576/100) \times 21$$
$$= 65,850.96 \ m^3 \qquad \text{(ii)}$$

The total water stored in the ponds is (from i and ii)

$$= 131,432.28 \ m^3$$

The total water in terms of depth can be calculated as Water volume/Area

$$= (131,432.28/55126.2) \times 1000 \ mm$$

$$= 2.28 \ mm$$

7.2.6 Contouring and terracing

Where contouring is not an enough measure, both contouring and terracing are combined. Table7.5 below gives the conditions of the runoff after the above watershed management measures are taken

Table 7.5 Runoff Curve Number values with watershed management,

Land Use	Area (ha)	Treatment/ Practices	Hydrologic condition	Curve Number
Maize	153,850	Contoured +Terraced	Good	80.0
Millet/Sorghum	7,655	Contoured +Terraced	Good	79.5
Root/Tuber crops	9,145	Contoured +Terraced	Good	77.0
Pulses	132,390	Contoured +Terraced	Good	77.0
Coffee/Fruit Trees	9,252	Contoured +Terraced	Good	70.0
Forest Land	2,241		Good	70.0
Pasture Land	313,567		Good	70.0

Total area = 628,100 ha,

Therefore the Weighted Curve Number (CN) after WSM will be,

CN = {(153850 x 80) + (7655 x 79.5) + (9145 x 77) + (132390 x 77) + (9252 x 70) + (2241 x 70) + (313567 x 70)}/628100

= 74.14

But CN = 25400/(254 + s)

Then, 74.14 = 25400/(254 + s)

S = 88.6 mm or 8.86 cm.

$Q_r = (P - 0.2s)^2/(P + 0.8\,s)$

$= (23.5 - 0.2 \times 8.86)^2/(23.5 + 0.8 \times 88.6)$

= 15.434 cm or 154.34 mm.

Water savings = 184.77 – 154.34 = 31.34 mm

The water savings in volumetric terms can calculated as

= Depth x Area

$= (31.34/1000) \times (628100 \times 10^4)$

= 196.847 Mcm for the entire district and

= 17.277 Mcm for the identified area.

7.2.6.1 Soil loss estimation with watershed management

Table 7.5 below gives the soil loss from the watershed after watershed management is carried out.

R = 200

K = 0.1

C = 0.7 (normal crop management factor for maize in Machakos district)

LS = Shown in the table as obtained from the Graph

P = Differs from slope to slope and it is shown in the table.

A = RKLSCP

Table 7.6: Estimation of soil lost after watershed management in tons/acre

% Slope	R	K	Ls	C	P	Tons/acre	Tons/ha
4	200	0.2	0.8	0.7	0.10	2.24	5.6
6	200	0.2	1.2	0.7	0.10	3.36	8.4
8	200	0.2	1.75	0.7	0.12	5.88	14.7
10	200	0.2	1.3	0.7	0.12	4.37	10.93
12	200	0.2	1.3	0.7	0.16	5.82	14.55
14	200	0.2	1.2	0.7	0.80	5.38	13.45
16	200	0.2	1.6	0.7	0.80	7.17	19.28
18	200	0.2	1.8	0.7	0.90	9.07	22.68
20	200	0.2	2.4	0.7	-	-	
						5.41	**13.23**

The soil loss after watershed management is done is 5.41 tons/acre (13.23 tons/ha), which is almost the same as the tolerable limit of 5 – 6 tons/acre (12.5 – 15 tons/ha) in the study area.

7.2.7 Earth Dams

They are very important for storing water and using it at a later date or allowing it to infiltrate slowly into the ground. Most of the dams are silted and need silt removal. They are very necessary in the district and due to the costs involved; the government needs to be involved seriously. They should be built wherever conditions allow. Seventeen positions shown in Fig.7.5 have been identified as the initial suitable positions for dams and the table 7.6 below gives the volumes of the dams and the cumulative volumes of the reservoirs. The use of dams to save the runoff remains the only feasible method to solve the water shortage problem in the district. A total volume of 428.838 Mcm/year can be stored in all the dams already identified and this water is more than twice the deficit of the water in the district by 2020. The construction can be done according to priority areas. The drier parts of the district should get the first priority.

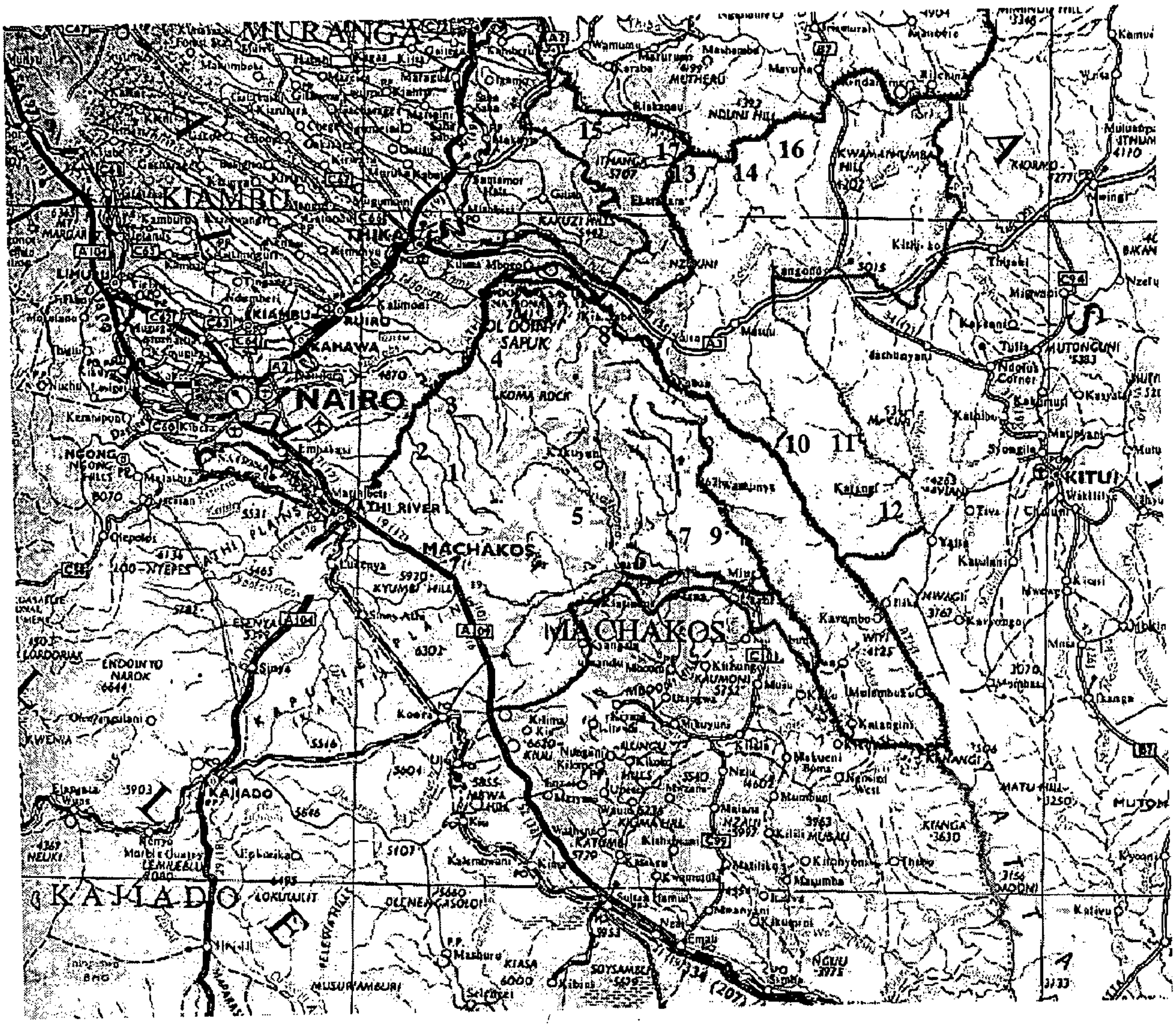


Fig 7.5 Dam locations in the watershed

Total water saved due to watershed management practices

Table 7.7 shows the measures taken to manage the watershed and the water saved due the practices. The total amount of water saved from the measures below is 101.715 mm

Table 7.7 Depth of water saved after watershed management practice

Measure taken	Volume of water (ha-m)	Height of water in mm
Terracing + contouring	1,727.655	31.340
Dug-out ponds	13.143	2.280
Dams	42,883.813	777.921
Total	**44,624.611**	**780.021**

Table 7.8 Volumes of the structures

Structure	Area (ha)	Volume (ha-m)	Volume Mcm)	Cumulative Volume (Mcm)
1	6093.18	1121.145	11.212	11.212
2	6093.18	1121.145	11.212	22.424
3	7616.48	1401.432	14.014	36.438
4	6093.18	1121.145	11.212	47.650
5	12186.36	2242.290	22.423	70.073
6	39605.68	7287.445	72.874	142.947
7	18279.55	3363.437	33.634	176.581
8	9139.77	1681.718	16.817	193.398
9	21326.14	3924.010	39.240	232.638
10	21326.14	3924.010	39.240	271.878
11	24372.73	4484.582	44.846	316.724
12	15232.95	2802.863	28.029	344.753
13	7616.48	1401.432	14.014	358.767
14	10663.07	1962.005	19.620	378.387
15	12186.36	2242.290	22.423	400.81
16	9139.77	1681.718	16.817	417.627
17	6093.18	1121.145	11.211	428.838
	233064.2	**42883.813**	**428.838**	

7.2.6.2 Level of irrigation

The level of irrigation without any watershed practice is 31.95%. The same after watershed management practice is as below,

$$\text{The level of irrigation is given} = \frac{\text{Water Applied during Irrigation}}{\text{Total Water demand (Agricultural)}} \times 100$$

The Average agricultural demand in the district is 258.589 Mcm/year or 469.090 mm

Actual water applied for irrigation = 82.615 Mcm/year or 162.63 mm

Water saved by Watershed management =780.021 mm

Therefore the total water available after treatment

= 162.63 mm + 780.02mm

= 942.65 mm

So with this availability the maximum level of irrigation that can be achieved is

= (924.65/469.09) x 100 (by depth)

= 203% or

By volume, the total water available after treatment is

= 446.813 + 82.615 Mcm

= 528.836 Mcm

Therefore the maximum level of irrigation attainable is

= (528.836/258.589) x 100

= 205%

7.3 Agro-Forestry/Afforestation

7.3.1 General

This is a productive system combining crops and /or cattle with the planting of trees. Trees are important in soil conservation and in rehabilitation of eroded areas.

Gunnar Poulsen, 1977 states that trees help to maintain a favorable climate, prevent or reduce wind and water erosion, provide favorable conditions for the cycling of soil nutrients, add humus and nitrogen to the soil – thereby improving both structure and fertility – produce buds, leaves and fruits that are consumed by livestock and humans, provide the ideal environment for wildlife, carry the flowers that are the main source of honey in the district – apart from yielding the usual forest products : Timber and Ecudates.

Growing of certain trees and ground crops together can be the best means of preserving the fertility and structure of the soil. For example a farmer in Mitaboni location in Machakos District has peach trees along the edges of his bench terraces. The annual sales value of the peaches from the terrace edges is greater than that of maize on the bench terraces. The farmer says the yield of the maize under the peach trees is higher than that on the bench terraces without trees. He thinks the reason is that the soil below the tree is more fertile. Trees suitable for agriculture can be grouped in the following ways:

(1) Timber and fuel trees.

(a) Fruit trees and bananas

(b) Fruit bearing trees e.g. Citrus and mangoes

(c) Nut – bearing e.g. Macandamia and cashew – nut.

(d) Oil producing e.g. coconut

(e) Tree Legumes e.g. Luceana and algarroba

Fodder trees e.g. Acacia Albida and Algarroba.

7.3.2 When to recommend trees

(1) When parts of farm are not suitable for crop production

Even shallow and poor soils can carry a luxuriant forest. The reason being that trees have a network of roots which absorb the nutrients from the ground well.

Harcharick and kunkle, FAO points out that Natural Savanna and woodland produce timber at the rate of 0.5 – 2 m^3/acre/year, but planted trees can produce firewood and timber at the rate 10 times greater. Spacing of trees for *erosion control* should be closer and not wider than 2 x2 m. A spacing as close as 1 x 1 m can be used

(2) Rehabilitation of eroded land including gullies

Trees reduce soil erosion on the slopes and stabilize the slopes.

(a) They prevent raindrop erosion,

(b) Their canopies and the litter produced on the ground can trap up to 20 mm of continuous rainfall and solifluction

(c) In the ground below the forest, the rates of infiltration and percolation are much greater than in cultivated ground.

Pereira, 1973 – Tree belts along the contour occupying only 6% of a hill area can halve the overland flow, and 30% - 40% covered by forest belts can absorb the entire overland flow meaning that it is not always necessary to do afforestation all over the hill

(3) On river banks to prevent soil erosion

Bushes and tall grass reduce the velocity of water over flooded ground and roots systems protect the bank from erosion.

(4) Along the Cut-off drains and terraces

The usual way is to plant on the upper side of the grass strip on embankment. In dry areas trees and preferably bananas can be planted in pits below the bank of the terrace. On steep slopes i.e. between 25% and 55% modified bench terraces can be used for trees.

(5) Semi – Areas

Trees are needed for the following purposes

Minimizing wind and raindrop erosion.

Increasing fertility by bringing up nutrients from great root depths hence "Nutrient Pumps" and returning them to the ground as litter.

Preserving the vegetation cover through shade, which will help to maintain a better microclimate, thus permitting humus generation instead of humus reduction.

Restoring hydrological conditions.

Providing fuel wood and timber

Charreau and Vidal, 1987, found that the seed and protein yields of millet when grown under trees are increased by 50 – 300%.

Leucaena Leucocephala and Prosopis Juliflora can also be used for rehabilitation of desert-affected areas. On grassland in an arid Arizona (annual rainfall 330 mm) the ground under the canopies of prosopis trees had dense stands of perennial grasses (24% covered, Biomass 1,146 kg/ha compared with the areas outside canopies; 4% covered, Biomass 239 kg/ha). This method is very suitable for the semi-arid parts of Machakos District. In general Agroforestry and Afforestation are recommended in the district as much as possible and with the recommended tree varieties so as to rip maximum benefits.

7.4 Sustainable Watershed Management

7.4.1 General

To succeed, watershed management has to be participatory. This is one of the lessons coming out of decades of failure of centrally planned watershed development projects through which local people have been either coerced or paid to undertake terracing, bunding, destocking and other technical measures that external experts believed would cure watershed degradation (Shah - 1999, Rhodes - 1988, IBD - 1998) which could not make the watershed development more successful and sustainable.

Success will likely require that all stakeholders in watershed management including users, policy makers, researchers and others recognize that participation is not simply another way to deliver the same technological solutions. Participation implies that the stakeholders will work together to set criteria for sustainable management, identify priority constraints, evaluate possible solutions, recommend technologies and policies and monitor and evaluate impacts.

7.4.2 Importance of participatory Watershed Management

Early watershed management programs in East Africa and South Asia were promoted by a very narrow range of technical solutions such as terracing and contour bunding to control soil erosion. Two key assumptions appear to underlie the design of such programs,

(1) that soil conservation practices were universally applicable, that what works in one place will work in another,

(2) that local farmer are unaware of erosion and ignorant of its causes and consequences (Pretty and Shah 1999).

Both assumptions turned out to be false and the program technologies were frequently both ecologically and economically incompatible with local farming systems. Moreover being imposed on the people as the way to prevent erosion, they came to replace rather than supplement local methods of soil and water management. The desire to work collectively is lacking and in most cases there is no further maintenance once the government hand is withdrawn. Training the staff involved and the farmers on both the technical and organizational matters should be o priority area.

7.4.3 Participation

It is becoming more widely accepted that unless people are actively involved in the development projects that are aimed to help them, the projects are doomed to failure. It is important that the beneficiaries participate in every stage of the project. When the project is being planned, the people should be consulted, and their priorities and needs assessed. During the construction phase the people again should be involved in supplying labor and also helping with field layouts after being trained. Systems proposed should be simple enough for the people to implement and to maintain. To encourage adoption, apart from incentives in the form of tools for example, there is a need for motivational campaigns, demonstrations, training and extension work.

7.4.4 Gender and equity

If watershed management is intended to improve the lot of farmers in the poorer, drier areas, it is important to consider the possible effects on gender and equity. In other words, will the introduction of water harvesting be particularly advantageous to one group of people, and exclude others? Perhaps water harvesting will give undue help to one sex, or to the relatively richer landowners in some situations. These are points projects should bear in mind during the design stage. There is little point in providing assistance that only benefits the relatively wealthier groups.

7.4.5 The project and the people

The experience of projects related to watershed management has shown that there is no substitute for dialogue with the farmers/villagers, and a continued close relationship throughout. Projects should always aim to learn from the people of the target area, in particular about local traditional technology. It is essential that project authorities keep in mind the importance of people's priorities and participation. It is important that the benefits of the new systems should be apparent to the farmer as early as possible. For new techniques there is often a need for demonstration before people will understand and envisage their effectiveness. Motivation and promotion of awareness among the people with regard to the project objectives and how to achieve them are very important issues. It is sad but true that very often the people simply do not understand what a project is trying to achieve, or even what the meaning of the various structures is.

7.4.6 Watershed Management project approach

There are two basically different approaches with regard to watershed management projects.

(1) The Demonstration, Training and Extension Approach:

The technology introduced by the project should be relatively simple, and costs per hectare low. The intention is to promote systems that can be taken up and implemented by the people themselves, with a minimum of support. The philosophy behind this approach is that the people themselves must be the prime movers in the development of their own fields and local environment.

(2) The Implementation Approach:

In this approach the technology may be simple or complex, but it is implemented by the project itself. Machinery is often used, but some projects employ paid (or otherwise rewarded) labor. Costs are often relatively high. The intention is that the project will quickly and efficiently rehabilitate land for the people. The philosophy is that the people are simply unable to undertake the extent of work required using their own resources and therefore they require considerable or complete support to implement the project.

Experience shows that it is the first approach that offers the most hope for sustainability once the project has come to an end. Nevertheless there are situations where the introduction of appropriate machinery or support of some labor can be justified.

7.4.7 Subsidies and incentives

Many watershed management projects provide subsidies or incentives for construction. The following points should be considered:

- help and assistance should only be considered as stimuli to the programme; too big a subsidy to begin with can cripple future expansion and deter participation.
- it is important that in all cases the beneficiaries should make at least some voluntary contribution towards construction. The level of contribution should rise when incentives are provided.
- food-for-work is common in projects in drought-prone areas. It is not easy to manage food distribution and development work at the same time. Generally other incentives, such as tools for work, are preferable.
- incentives/subsidies should not be used for maintenance: this should be the responsibility of the beneficiaries.

7.4.8 Monitoring, evaluation and reporting

Monitoring, evaluation and reporting are often weak spots in watershed management projects. Too many projects fail to collect data at even the most basic level. For example crop yields and tree heights are often just estimated. It is also very rare to find any information on the frequency or depth of water harvested. Without a basic monitoring system, projects are starving themselves of data for evaluation.

Without clearly written reports, widely circulated, projects are denying to provide others with important information.

Initially the local people in Machakos District were not fully involved in the watershed management project willingly. They were enticed by giving them tools etc. When the project fund ended, it was not possible to sustain some of the projects already started. The local people should be involved from beginning to the end. All the factors discussed above should be implemented or taken into account for the success of any particular project. Women groups commonly referred to as "Mwethya" groups are very active in the district and a lot can be achieved through them. It is easy to pass the knowledge or ideas to men through women groups since men are not well organized so in general people participation is very highly recommended.

7.4.9 Closing of project report.

Closing report for specific project estimates should be compiled. It includes all the aspects of financial nature of the project. This will enhance transparency and accountability in the project implementation.

7.5.0 Completion of project report

A report detailing the achievements and the failures during the project implementation should also be compiled. Experience gained in the project will be useful in similar projects in the future.

CONCLUSIONS

In the present study, a watershed management approach is applied in Machakos District of Kenya. The district is facing water crisis, which is expected to increase if no measures are taken. In the present study, data colleted for the district and analysis is made. Based on the analysis and in light of the conditions and possibilities of watershed management in Kenya, following are the salient features of the study.

i. The rainfall ranges from 500 mm to 1300 mm annually within a topographic range of 700 m to 1700 m above the sea level.

ii. The mean annual temperatures range from 12^0 C to 25^0 C with an average rainfall of 700 mm. The average annual evapotranspiration is 1630.20 mm.

iii. The total water demand by 2002 is 295.239 Mcm/year and the amount available is 205.905 Mcm/year giving a deficit of 89.65 Mcm/year (162.63 mm).

iv. The water deficit is expected to grow to 195.320 Mcm /year by the year 2020 if no measures are taken to reverse the situation

v. The total average annual runoff in the catchment is estimated as 183.5 mm using the water balance method, and 184.77 mm using the Hydrological Soil Cover Complex Method

vi. The tolerable mean annual soil loss in the district is between 12.5 to 15 tons/ha/year

vii. Soil loss from in the district especially on the highlands is which is very much higher than the tolerable limit and therefore soil control measures must be applied.

viii. The soil loss is expected to go down to 13.53 tons /ha/year when using the recommended soil conservation measures.

ix. The total amount of water saved by watershed management measures is 446.221 Mcm and about 780.021 mm by depth.

x. The land treatments already available in the district have been discussed together with their merits and demerits and their levels of adoptability

xi. The yield of some crops increased when grown with some trees. Agro-forestry should be encouraged as much as possible. It has been shown that planted trees can produce firewood and timber at the rate 10 times greater than natural savanna and woodland

xii. Tree belts along the contour occupying only 6% of a hill area can halve the overland flow, and 30% - 40% covered by forest belts can absorb the entire overland flow meaning that it is not always necessary to do afforestation all over the hill.

xiii. For success of watershed management projects, participatory approach is very crucial. The following aspects must be analyzed critically and implemented appropriately. They are participation, gender and equity, the people involved, the project approach, demonstration, training and extension, implementation approach, subsidies and incentives, monitoring and evaluation.

xiv. Level of public satisfaction and proper documentation of specific project for using the experience of the ground realities during implementation of other similar projects.

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