TECHNICAL HANDBOOK No. 22

RAINWATER HARVESTING FOR NATURAL RESOURCES MANAGEMENT

A planning guide for Tanzania

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A planning guide for Tanzania

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Top:	Commencement of runoff after the onset of rainfall (after: FAO (1994) p. 362)
Upper middle:	Runoff cascading through road culverts
Lower middle:	Livestock drinking water from a pond
Bottom:	Use of harvested water for the growing of rice

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Preface

Rainwater harvesting for crop production is a promising and generally appropriate way of upgrading rainfed agriculture in the semi-arid tropics. It is especially interesting given the fact that farmers experience crop yield reductions more often, due to poor rainfall distribution rather than inadequate total rainfall. Erratic and unreliable rains result in frequent dry spells which often result in serious reductions of crop yields. Farmers know this and adapt their investments in, for example fertilization, weeding and pest management accordingly. High risk for water stress leads to low incentives for investments. This means that water harvesting can function as an entry point for farming systems modernization in the semi-arid areas of East and Southern Africa.

This planning handbook for rainwater harvesting in Tanzania clearly shows the potential of applying rainwater harvesting on small-holder farms in semi-arid areas. It is an important handbook also, as it conforms with the decentralization process in Tanzania, by targeting planners at the district level. It is hoped that this planning handbook will provide planners with practical tips on how rainwater harvesting can form an integrated part of district development efforts. The book also gives practical guidelines in the planning steps required to incorporate rainwater harvesting in development plans, and shows how to implement them in the farmers' context.

Even though the handbook is written for Tanzanian conditions, RELMA believes it will be applicable in most semi-arid and dry sub-humid regions of East and Southern Africa.

Åke Barklund
Director, RELMA

Acronyms

AET	Actual Evapotranspiration
CA	Catchment Area
CB	Cultivated Basin
CBAR	Crop Basin Area Ratio
CV	Coefficient of Variation
DBMS	Database Management System
DoM	Department of Meteorology
DP	Deep Percolation
DSS	Decision Support System
DWSP	Domestic Water Supply Programme
EIA	Environmental Impact Assessment
ET	Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
GDP	Gross Domestic Product
GIS	Geo-referenced Information System
GPS	Global Positioning Systems
GTZ	German Technical Cooperation
HADO	Hifadhi Ardhi Dodoma
ICIMOD	International Centre for Integrated Mountain Development - Nepal
ICM	Integrated Catchment Management
IP	Internet Protocol
KEA	Kondoa Eroded Area
LAMP	Land Management Project
LU	Livestock Unit
MDC	Maswa District Council
MTNR	Ministry of Tourism and Natural Resources
NGO	Non Governmental Organizations
NPV	Net Present Value
PET	Potential Evapotranspiration
PPMB	Project Preparation and Marketing Bureau
RWH	Rainwater Harvesting
RELMA	Regional Land Management Unit
SDPMA	Smallholder Development Programme for Marginal Areas
SFD	Stream Flow Diversion
SWC	Soil and Water Conservation
TCP	Transmission Control Protocol
TLU	Tropical Livestock Unit
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
WMO	World Meteorological Organization
WPLL	Western Pare Lowlands
WUA	Water Users Associations
WWW	World Wide Web
ZOPP	Objective-Oriented Project Planning

Chapter 1

Introduction

Hatibu, N.

1.1 Importance of semi-arid areas of Tanzania

The most important characteristics of semi-arid areas are the factors, which limit availability of adequate soil-moisture for plant growth. These include; high daily and yearly temperatures, low humidity, intense sunlight and high winds.

These factors encourage very high rates of potential evapotranspiration in many parts of the country, to the extent that rainfall amounts exceed potential evapotranspiration only in very few and scattered days. The most critical factor that makes most of the country semi-arid is the dry spell which occurs during the growing season (Venalainen and Mhita, 1998; Nyenzi et al., 1997). These dry spells occur with significant variation from season to season in the same place and from place to place within the same season. In most cases therefore, a lot of rain is received at the wrong time and/or place.

There are districts in Tanzania where long-term average rainfall is more than 1000 mm per annum yet crop production is very low. This is because poor distribution of rainfall leads to water stress on plants during one or more stages of crop growth. Consequently, the plants may use all the rainwater but still produce low yields, especially if the water stress occurred during a critical growth stage. Thus, the productivity of rainfall, land and inputs become very low. The stress is not necessarily due only to shortage of water. It may also be due to too much water. A year with low amount of seasonal total rainfall may receive all the rain in only a few days and face periods of excessive soil-water and flooding. Average conditions are therefore not useful in designing strategies for rainwater management in semi-arid areas.

On the basis of variability of rainfall and the work by De Pauw (1984) and LRDC (1987), more than 50% of mainland Tanzania can be categorized as semi-arid. These areas receive less than 570 mm of rainfall in nine out of ten years with potential evapotranspiration exceeding rainfall during more than nine months of the year. The coefficients of variation of the seasonal rainfall range between 60 to 190% (Ngana, 1990).

On the other hand, the semi-arid areas are very important in Tanzania because of the following reasons:

- High rainfalls occur in mountainous areas where extensive mechanized agriculture is not possible.
- Most of the livestock and wildlife in Tanzania graze in the semi-arid areas.
- Areas such as Tabora and Shinyanga regions are highly populated.
- Rampant poverty in areas such as Lindi, Shinyanga and Dodoma regions.

Low and variable rainfall should therefore be managed in a way that will ensure adequate availability of soil-moisture and more effective use of rainfall by plants. This requires a consideration by all planners that rain is water and a vital resource. In the past, rain has not been treated as water and thus left to go to waste. Rainwater harvesting is aimed at managing rainwater from the moment it falls and ensuring that most of it is used productively, before it is returned to the atmosphere by evaporation.

There is hence a very strong relationship between semi-arid areas and poverty in Tanzania. Due to over-dependence on agriculture, the effort to eradicate poverty in the semi-arid areas should focus on substantially increasing the productivity of three critical resources. These are labour, rainwater and land in that order of priority.

1.2 Policies and strategies

A correct policy framework is necessary for dealing with the problems of the semi-arid areas. In the past, these problems were simply viewed as drought and erosion. The pursued policies, strategies and programmes therefore put a lot of emphasis, efforts and funds on drought-resistant crops and erosion control. Over-emphasis on erosion control led to strategies and programmes, which focused more on the land rather than the land users. These programmes were designed to stop soil erosion without due concern of the direct or opportunity benefits. Destocking, which was implemented by HADO as a way of conserving the Kondoa Eroded Area (KEA), is a good example (Mbegu and Mlenge 1983; Christiansson et al. 1983). Erosion control approaches of the past had focused more on the amount of soil lost rather than the effect of this loss on soil productivity (Stocking, 1988). This led to the promotion of strategies such as cut-off drains, which were mainly designed to dispose runoff and tree planting which most of the time decreased the amount of water available for crops due to high soil-water consumption by the trees. These approaches are inappropriate for the semi-arid areas where plants suffer more from water, rather than nutrient constraints.

It has now been realized that shortage of soil-water for plant use is the major problem, and it can be mitigated by approaches other than drought-resistant varieties. The management and effective use of rainwater is the key to the solution. However, farmers in many parts of the semi-arid areas are ahead of such policies and strategies. They have realized and adopted different land uses in various units of the landscape to over-exploit the valley bottoms where rainwater and soil nutrients accumulate. This lands are commonly referred to as 'Mashamba ya Mbugani'. This approach has led to the significant production of rice in semi-arid areas without any policy and technical support.

1.3 Rainwater harvesting

The concept of 'Mashamba ya Mbugani', practised by many farmers in the semi-arid areas of Tanzania, is a good starting point in conceptualizing the meaning of rainwater harvesting. In this case, the farmers grow high-water demanding crops such as vegetables, rice and maize in the lower parts of the landscape. This is to exploit the concentration of rainwater flowing into the valley bottoms from the surrounding high grounds. From the crop production point of view, rainwater harvesting can therefore be defined as the process of concentrating rainwater from a large land area into a small area so as to improve the soil-moisture regime. This definition is however limited as it only deals with the spatial nature of the intervention. In practice, this will not be adequate as the rainfall is not evenly distributed on a temporal basis.

To overcome the problem of poor distribution in time, it is necessary to collect rainwater when it rains and store it for use to meet the water needs in the preceding dry period. This view expands the meaning of rainwater harvesting. In the broadest sense, rainwater harvesting is defined as the process of concentrating, collecting and storing water for different uses at a later time in the same area where the rain falls, or in another area during the same or later time. The harvested rainwater can be used for many purposes. Many differing definitions of rainwater harvesting have been given in the literature (Gould & Nissen-Petersen, 1999; Oweis et al., 1999; Frasier, 1994; Reij et al., 1988; Pacey and Cullis, 1986; Boers and Ben-Asher, 1982; Hollick, 1982, Dutt et al., 1981; Fraiser, 1975).

Rainwater Harvesting, abbreviated as RWH, is justified by the nature of rainfall in semi-arid areas. If not managed, it quickly evaporates or runs as flash floods into saline sinks. Thus, the starting point of rainwater harvesting is to capture rainwater where it falls for purposes of meeting the water needs of that area. Any excess can then be transferred for use in downstream areas. In relation to rainwater harvesting for plant growth, capturing rain where it falls is called in-situ RWH. It is basically all the conventional approaches to soil and water conservation, designed to enhance infiltration of rainwater into the soil.

The next stage of rainwater harvesting is micro-catchment systems that involve two major components. These are the catchment area (CA) which generates runoff, and the cultivated basin (CB) where the runoff is concentrated, stored and productively used by plants. The parts are not so clearly distinct in the in-situ systems. Systems with large catchments are called macro-catchment RWH. These include intermediate components such as means for collecting, transferring and storing the runoff.

Rainwater harvesting for crop production is therefore a continuum that ranges from conventional soil and water conservation at one end and irrigation at the other. In this handbook, most soil and water conservation measures are described as forms of in-situ rainwater harvesting. The macro-catchment systems described in this handbook have some similarities with irrigation.

1.4 Planning

Planning for the exploitation of rainfall through rainwater harvesting is not an easy task. This is because rainwater falling in one part of the watershed may be demanded for different uses and/or users. These include groundwater recharge, feeding into rivers, dams, lakes and wetlands, and domestic water supply. Rainwater harvesting and other land uses in the sub-catchments may therefore have profound effects on the hydrology of the catchment.

In planning for different land uses and rainwater harvesting, it is important to value the rainwater in socio-economic terms. This can only be possible if the opportunity benefit or values from different uses of water are well understood. The planning must be integrated and should include the following steps:

- Plan initiation,
- Reconnaissance,
- Formulation and screening of project alternatives,
- Data collection and analysis, and
- Development of detailed plan.

The critical requirement in this process is the inventory of resources. Data is required to quantify the amount and both temporal and spatial variability of the rainfall and hydrology of the watershed. Guidelines are therefore discussed in this handbook on the database needs for good planning of programmes with RWH components.

Planning is a process that involves a team of many specialists. This is demonstrated in this handbook by showing the number of issues that need to be taken into consideration in making plans for RWH. The guides at the end of each chapter are therefore directed at different experts who can contribute to the process. They are not meant for a single "planner" or planning department. It is important to emphasize that no individual planner or planning department will be able to tackle all the issues necessary to complete a RWH planning or integration into wider development programmes. Planning is a team work dependent on data, analysis and expertise provided by many disciplines. The planning unit will therefore normally act as the facilitator. The actual planning process will involve a multi-disciplinary team of experts, in order to ensure that all relevant issues are taken into account.

1.5 Scope of this handbook

Effective utilization of water resources has been directly or indirectly recognized in several policies as one of the important factors in development and conservation of the environment. In the semi-arid areas of Tanzania, there is already a water crisis. The overall problem is water scarcity but flooding also creates problems during the rainy season. It is common to experience a situation where crops are destroyed by flooding at the beginning of the season, only to have the replanted crop destroyed by drought later in the season.

The problems of extreme stress caused by water scarcity or flooding are made more severe by the failure to more effectively exploit the direct rainfall. The fact that rain is water has not been built into the national natural-resources planning. Most of the rainwater is not being put into beneficial use. This handbook is mainly designed to guide development planners on how to design programmes that will obtain more water from the same rain that is currently being received in the semi-arid areas. The handbook is intended to provide a basic understanding of how to judge existing potential for rainwater harvesting under different conditions and for different uses. It is divided into three major parts.

Part I which consists of chapters two and three, has been designed to describe physical processes that determine the availability of rainwater and the water needs for different uses. The concept of water balance is discussed in chapter two to enable the planners judge the amount of rainwater that can be considered as wasted. The concept of wastage of rainwater is an important issue to be able to judge the amount of rainwater that is available for harvesting. This is a critical question that each planner must be able to answer. The different sub-sectors where RWH can play a major role are introduced and their water requirements discussed in chapter three.

Part II of the handbook deals with technical aspects of rainwater harvesting. It describes and discusses the factors that determine the potential for RWH as well as different techniques suitable for various uses. The techniques are however not described in detail as these can be found in numerous textbooks already published. In chapter five, the policy frameworks guiding different sub-sectors are briefly introduced to explore how RWH fits into national development policies and strategies.

Part III deals with the social, economic and planning aspects. Chapter six emphasizes the importance of ensuring social and economic viability and equity. Integration issues are also covered. Chapter seven focuses more on the planning approaches and stages. Chapter eight is designed to highlight the importance of information technologies in any form of planning. The purpose is to sensitize the planners that adoption of modern information technology is crucial to effective planning. The chapter is by no means meant to be a professional coverage of remote sensing, Geo-referenced Information System (GIS) and the Internet.

At the end of chapters three, four, five, six and eight, several case studies are presented to assist in putting the concepts into perspective of the real situation in Tanzania.

Brief guidelines on important issues for planners are also given in each chapter. These planning guides are not designed to provide “cookbook” instructions on important planning steps. The aim is to highlight on how materials contained in the chapter can be used to contribute to the planning process. The guidelines also point out examples of different knowledge and expertise which need to be brought together to contribute to the planning process.

PART ONE

Physical processes that determine the availability of rainwater and the water needs for different uses

Chapter 2

The wasted rainwater: whose point of view?

Mahoo, H.F., F.B. Rwehumbiza and N. Hatibu

Rainwater harvesting as explained in chapter one, is based on the premise that rainwater should first be used to meet the water needs of the local area where it falls. With this kind of thinking therefore, rainwater leaving an area where it falls before water needs of that area are satisfied, is regarded as wasted water. The measure of the amount that is wasted is in simple terms the difference between the rainfall water as recorded in the rain gauge and amount that is used to meet water needs of the area. The purpose of this chapter is therefore, to describe how to estimate the extent of partitioning rainfall into usage and wastage in a given area.

2.1 Hydrological cycle

The hydrological cycle represents different paths through which the water in nature circulates between the atmosphere, hydrosphere (water bodies) and lithosphere (the landmass and rock below the hydrosphere). It is a concept that considers the processes of motion, loss and recharge of the earth's water. The continuum of the water cycle may be divided into three principal stages namely; precipitation, evaporation, surface and sub-surface runoff (Figure 2.1).

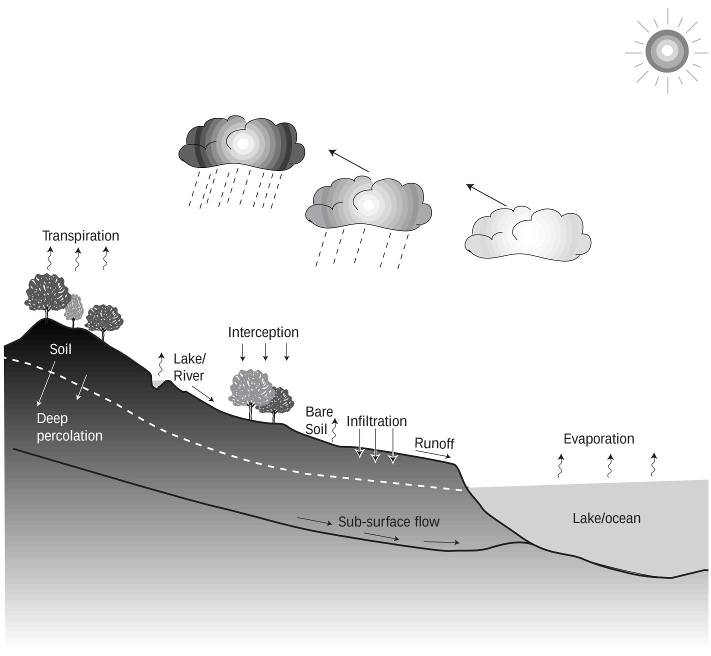

Figure 2.1 *Simplified presentation of the hydrological circle (modified from Gould & Nissen-Petersen, 1999).*

At each stage, the sequence of events involves transportation of water, temporary storage, and the change of state. Liquid changes into vapour and vice versa, or to solid and vice versa.

The quantities of water going through individual sequences can be evaluated by the following general hydrological equation:

$$I_n - O = \Delta W \quad \text{...} (2.1)$$

where:

I_n = *inflow of water to a given area during any given time period*

O = *outflow of water from the area during the selected time period, and*

ΔW = *changes in storage of the volume of water in the area during the time period.*

It should be recognized that the hydrological cycle has neither a beginning nor end, but the description starting with evaporation (Figure 2.1), is as follows:

- During evaporation, water on land, oceans and other open bodies is changed into vapour in the atmosphere. This process is driven by solar energy.
- As the vapour rises higher into the atmosphere, it is condensed into liquid form and finally falls back as rain or snow on land or oceans.
- The rainwater reaching the ocean would have completed the cycle at this point. However the portion falling on land follows several complex paths before being evaporated again.

From the preceding discussion, it is clear that the hydrological cycle is subject to various complicated processes of precipitation, evaporation, transpiration, interception, infiltration, percolation, storage and runoff. Some of these are further discussed in this chapter.

2.2 Catchment water balance

A catchment is a land area from which all rainfall would drain by gravity into a common outlet point. In hydrology, the boundary of a catchment is called the hydrological divide. This is the place in a landscape where rainfall will be partitioned into different catchments depending on which side of the divide the rain falls. The size of a catchment is a dynamic phenomenon that is determined by the position of the outlet point. If the outlet point is moved further down stream, the catchment size increases. When this point is finally located at the entrance to the ocean or inland water body, the catchment above that point is regarded as a drainage basin. Catchments and drainage basins do not normally follow village, district, regional or country borders. A basin is normally divided into several catchments that are in turn divided into several sub-catchments

(Figure 2.2). This section discusses the concept of water balance in relation to a given catchment.

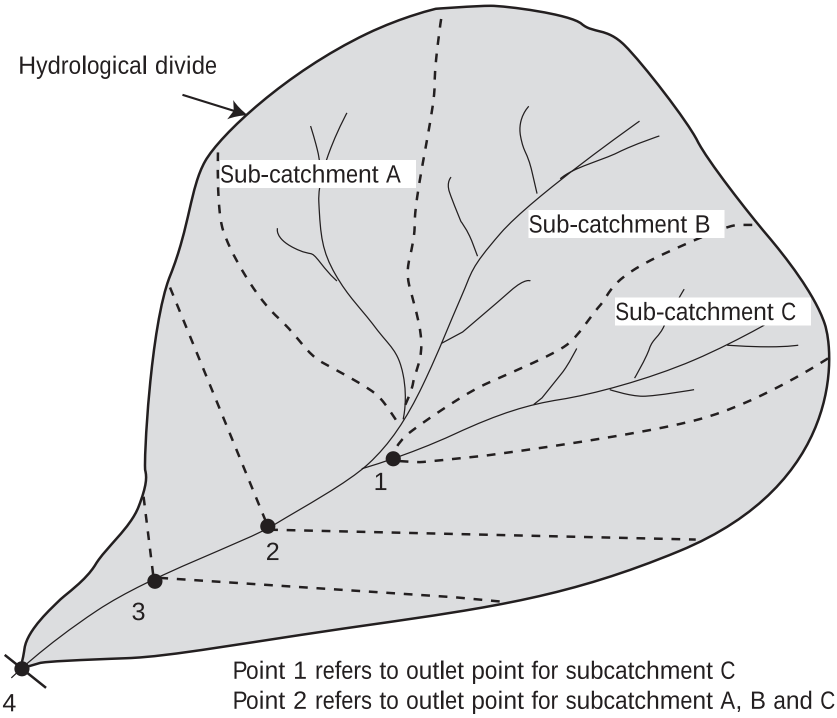

Figure 2.2 *An example of a river basin showing associated catchments.*

2.2.1 Rainfall amount and variability

In considering water balance for a given catchment or basin, rainfall is the primary source of water. The total amount of rainfall over a given period is expressed as the depth of water that would cover a horizontal plane as a result of collecting all the falling rainwater. This depth is generally expressed in millimetres and is measured using rain gauges. The mean of seasonal amount of rainfall received in representative semi-arid districts of Tanzania is shown in Table 2.1.

It must however be emphasized that the values given are long-term means. The rainfall amount varies greatly above and below these means as elaborated in Table 2.2. For the given seven stations, the mean coefficient of variation of the monthly rainfall total during the main season varies from 52% in January/February to 71% in April. The basic concept behind the coefficient of variation and its importance is illustrated in Box 2.1

Table 2.1 *Mean seasonal rainfall (mm) in selected representative districts in the semi- arid districts of Tanzania (after Ngana, 1991)*

	Month								
District	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Dodoma	3.5	19.9	111.6	135.6	109.8	113.4	56.1	3.9	553.8
Farkwa	14.9	39.7	118.0	125.7	108.1	105.4	90.3	18.4	620.5
Manyoni	5.0	51.5	116.9	141.7	107.9	116.4	71.8	17.4	628.6
Singida	7.4	43.0	129.8	138.6	120.7	118.4	71.4	12.8	642.1
Nzega	24.0	94.6	147.1	119.0	112.6	128.8	129.4	28.5	784.0
Lubanga	27.7	85.8	144.7	112.0	102.0	146.8	133.1	43.4	795.5
Maswa	29.7	99.4	133.9	107.6	109.3	128.8	144.9	47.6	801.2
Mean	16.0	62.0	128.9	125.7	110.0	122.5	99.6	24.6	689.3

Table 2.2 *The coefficient of variation (%) of the monthly rainfall (after Ngana, 1990)*

	Month								
District	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Seasonal
Dodoma	309	186	57	60	60	57	93	192	26
Farkwa	261	132	59	54	55	55	71	104	23
Manyoni	219	130	62	50	41	64	83	87	26
Singida	267	121	61	53	50	58	96	142	30
Nzega	116	75	47	48	49	43	57	125	24
Lubanga	124	82	46	48	55	50	48	112	24
Maswa	102	78	46	50	53	47	47	83	24
Mean	200	115	54	52	52	53	71	121	25

Table 2.2 also shows that the coefficient of variation for the seasonal rainfall ranges from 23% in Farkwa to 30% in Singida. These high coefficients of variation over the growing period imply a high uncertainty in crop yields. The variability of rainfall over seasons in the semi-arid areas is so high that average rainfall figures mean very little (Stewart, 1988).

Box 2.1 *Coefficient of variation (CV)*

The basic statistical measure of rainfall is concerned with average amounts for a specified time interval and the deviation of the individual value about the mean. In order to compare the deviations for places with different average values, it is necessary to express them as a percentage of the mean. The simple measure of relative variability (RV) is:

RV (%) = Mean Deviation (M.D)/ Mean (p) x 100

and M.D = $\sum | p_i - p |$

where $| p_i - p |$ denote the absolute value of p

p_i = rainfall amount in the i^{th} term

Usually, RV shows a marked tendency to increase sharply with low annual rainfall totals. A preferable measure is the coefficient of variation (CV) which is defined as:

CV (%) = Standard deviation (σ)/Mean x 100

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(p_i - \overline{p}\right)^2}{n}}$$

In the semi-arid areas, the higher CV values are observed during the onset of rains and during the cessation of the rains (Ngana, 1990)

The "notoriously" unreliable rainfall distribution in tropical drylands, forms the backbone of farmers' risk management strategies and incentives for investment in the land. The annual or seasonal variation of rainfall can typically range from as low as one third of the long term average to as high as approximately double the average. This means that a high rainfall year can have some six times higher rainfall than a dry year (Stewart, 1988). Statistically in a semi-arid region with annual rainfall between 600–900 mm, severe crop reductions might occur in 1–2 out of 5 years, resulting in total crop failure once every 10 years.

Intermittent droughts occurring within a cropping season are much more common than seasonal droughts, and do also result in serious crop yield reduction. Such droughts, defined here as dry spells, can have a short duration, often not persisting more than 2-4 weeks, and can, if hitting during sensitive growth phases like during flowering or grain filling, result in serious yield losses (Rockström and de Rouw, 1997).

Making plans which integrate RWH therefore require solutions to the difficult task of selecting the amount of rainfall to use as reference. The problem is elaborated further in section 4.5.

2.2.2 Partitioning of gross rainfall

The rainfall recorded by a raingauge can be referred to as gross rainfall. However, in a real situation, this amount is partitioned into several components before it reaches the ground where it can be managed and manipulated. Partitioning is the division of the total rainfall into throughfall, stemflow and interception.

Throughfall is the part of rainfall that reaches the ground directly or by dripping from leaves, twigs and branches. Stemflow is the part of rainfall that flows along the stems to reach the ground floor. It is usually an order of magnitude smaller than throughfall. Interception is that part of rainfall, which is intercepted by either vegetation or litter and evaporated directly back to the atmosphere. The amount which actually reaches the ground is called effective rainfall and is less than the gross amount recorded by the rain gauge, such that:

$$\textit{Effective Rainfall} = \textit{Gauge Rainfall} - \textit{Interception}$$

Interception is therefore the first component of rainwater that is wasted. This type of loss is affected by three major factors namely:

- Vegetation cover in a given area (canopy storage capacity),
- Amount and frequency of rainfall,
- Rate of evaporation.

The process of estimating the extent of this wastage is complicated but is known to vary between 13% to 24% for a forested catchment (Lawson et al., 1981). However, empirical equations have been established and quantitatively, interception (I) is the difference between rainfall (R) and the sum of the throughfall (T) and stemflow (S) (Lee, 1980)

$$I = R - T - S \qquad (2.2)$$

The rainfall that reaches the ground (i.e. effective rainfall) is further divided into several components. These include, direct evaporation from the ground, runoff, root zone recharge and deep percolation (Figure 2.3).

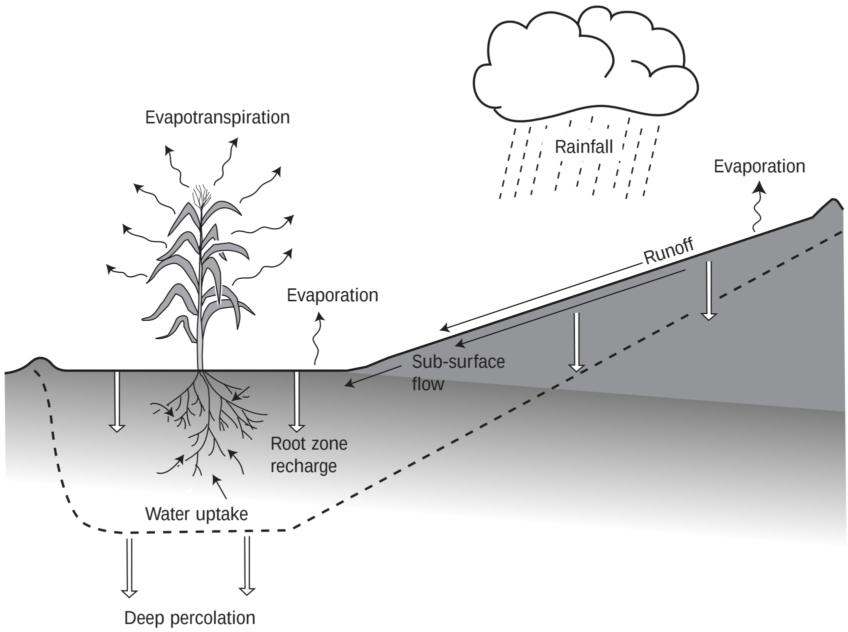

Figure 2.3 *Schematic representation of partitioning of effective rainfall.*

2.2.3 Evaporation: unseen loss of water

Evaporation is a process of changing water into a gaseous state. It requires a large amount of energy and humidity gradient. This is why evaporation rates are high in hot climates. Evaporation returns part of effective rainfall from the soil directly to the atmosphere before it is used for any purpose.

Evaporation occurs over a period of time ranging from a few minutes after a rainfall event to the whole season. Like rain, evaporation is expressed in millimetres and is normally measured using an evaporation pan. From whatever point of view, this component of rainwater is wasted. However, the magnitude of this loss is not quickly realised by many planners. As already mentioned in the previous section, the loss of water through evaporation takes place in the form of water vapour. Water vapour is not visible, therefore this constitutes an "unseen loss of water". Because of the nature of this loss, huge volumes of water are lost unnoticed in the river systems, reservoirs and other water conveyance channels. The magnitude of this loss is illustrated in the examples as given in Box 2.2.

The evaporation process is driven by heat and can therefore be reduced by controlling the amount of solar energy reaching the zone of evaporation. The process of evaporation from the soil after a rainfall event is divided into two stages:

Constant rate stage

This occurs when the soil surface is wet, at the rate necessary to meet the atmospheric demand. This is what is called rate of potential evaporation.

Falling rate stage

This stage occurs when the soil surface is dry and it is controlled by the hydraulic conductivity of the surface layer.

Box 2.2 *The extent of water lost through evaporation*

Consider a reservoir with a surface area	=	10 km^2
Evaporation in the viscinity of the reservoir	=	5 mm/day
The daily water loss	=	5×10^{-3} m x 10×10^6 m^2
	=	50,000 m^3

This amount of water is sufficient to supply the domestic water needs of a village of 300 households for about six years. This calculation is based on the illustration given in section 3.2.1

OR

Consider a reservoir with a surface area	=	2 km^2
Evaporation in the viscinity of the reservoir	=	5 mm/day
The daily water loss	=	5×10^{-3} m x 2×10^6 m^2
	=	10,000 m^3

This amount of water would supply an equivalent of 1000 mm of rain or irrigation water to a one-hectare farm. This means that water lost by evaporation from the surface of a small reservoir, in ONE DAY, is enough to supply irrigation water for one hectare for the whole year !!

2.2.4 Surface runoff

Runoff can be understood better when it is looked at from the point of view of water balance in a finite catchment area. Runoff is that component of rainwater which flows on the surface and out of the catchment area. Sometimes, surface flow may occur over only a short distance and the water infiltrates into the soil before it reaches the catchment outlet. This cannot be considered as runoff from the catchment but may well be runoff from the farmer's field. On the other hand, water infiltrating at a higher point may move as interflow, emerge before the outlet point and proceed to flow out of the catchment. This will contribute to the runoff from a given catchment. Runoff is generated when the intensity of the effective rainfall (i.e. rainfall reaching the ground) exceeds infiltration rate of a soil, and after surface puddles, ditches and other depressions (depression storage) have been filled.

From the point of view of water demands in a given catchment for productive activities, runoff will be regarded as wasted water. However, this may be effectively used down stream outside the catchment of interest. Thus, from the point of view of a much larger catchment, this water may not be considered as wasted.

2.2.5 Root zone recharge

The water that infiltrates into the soil is further divided into two components. The first drains under gravity into the subsoil and the second remains in the root zone after drainage has stopped. The latter component is referred to as root zone water recharge, which is water storage in the pore spaces of the soil. This water is available for productive use by plants through transpiration. However, under crop production systems, a component of this water may still be wasted if transpired by weeds. The maximum amount of water the root zone can retain is called field capacity (FC). If the root zone is not recharged beyond FC, then deep percolation (DP) cannot take place. To a farmer, it would be unwise to allow water losses through evaporation and surface runoff before the root zone is fully recharged. The volume of water stored in the root zone at FC is dependent on soil type, soil depth to the impermeable layer and rooting depth of the crop. For effective soil-water availability, it is important that the soil depth is larger than the root depth (Table 2.3).

Table 2.3 *Average rooting depth of the common crops (drawn from Doorenbos and Pruitt, 1977)*

Crop	Beans	Maize	Cotton	Groundnuts	Onions	Pineapple	Sorghum	Tomatoes
Root depth (m)	0.9	1.3	1.2	0.7	0.3	0.5	1.2	1.5

2.2.6 Deep percolation

Water that drains beyond the root zone is known as deep percolation. Again with respect to rainfed crop production, this water would be wasted. But if within the same catchment with shallow and deep wells, this water would still be useful when drawn from the wells. Sometimes deep percolation is encouraged for the purpose of flashing excess salts from the root zone. As mentioned earlier, deep percolation can only occur after the root zone is fully recharged.

2.2.7 The concept of "green" and "blue" water of the hydrological cycle

A distinction can be made between 'green' and 'blue' water flow in the hydrological cycle. The green water is the return flow to atmosphere as evapotranspiration (ET). It includes the productive part as transpiration (T) and non-productive part as direct evaporation (E) from the soil, lakes, oceans and from water intercepted by canopy surfaces (Rockström, 1997). Blue water flow includes the sum of surface runoff and ground water recharge. The 'green' and 'blue' water concept is illustrated in Figure 2.4.

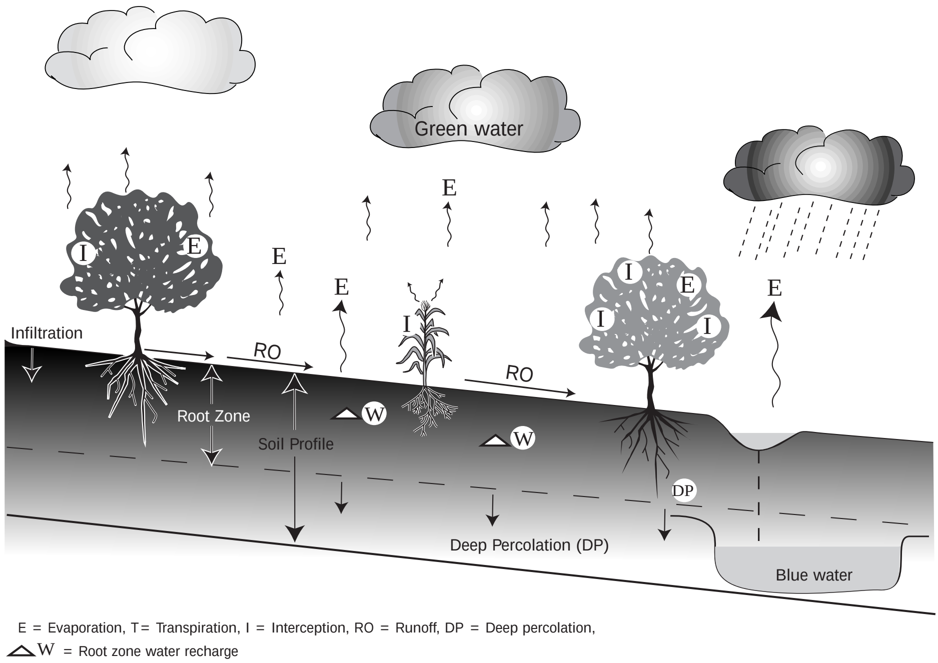

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Figure 2.4 *Rainfall components partitioning in a catchment, indicating the "green" and "blue" water flows.*

An important issue with respect to the partitioning between 'green' and 'blue' water flow, is the dynamic character of water flowing through the landscape. Blue water formed from rainfall partitioning in a crop field upstream of a watershed can for instance be converted into 'green' water flow in a forest further downstream. This means that in a catchment with different land uses such as crop land, forest and rangelands, there will certainly be a series of 'green' – 'blue' flow paths before the final 'blue' water flow is determined from measurements of surface and groundwater recharge at the outlet of the catchment.

2.2.8 The water balance equation

The rainfall components discussed in this section are schematically shown in Figure 2.4. For the purpose of undertaking water balance analysis, it is important to define a period of time. Figure 2.4 represent a situation that would exist a few days after a rainfall event. It is further assumed that the catchment is closed and the only water input is from direct rain. The water balance equation is simply as given:

$$R \text{ (as measured by a nearby raingauge)} = I + E + RO + \Delta W + DP$$

Interception (I) has already been defined but will not occur where there is no vegetation. Evaporation (E) is the sum of evaporation occurring from bare soil and that from open water in temporary depression storage. Runoff, root zone recharge, and deep percolation are clear from the earlier discussion. For the purpose of this analysis, actual transpiration and absorption by plants is accounted for within the root zone water recharge (W). An example of expected partitioning of rainfall in a catchment is given in Table 2.4.

In real life, the situation is more complex than what is presented here. The hydrological cycle is by no means a simple link, but a group of numerous processes that represent the different paths through which the water in nature circulates, as it is transformed. The evaporated moisture is lifted and carried in the atmosphere until it finally precipitates to the earth, either on land or in oceans. The precipitated water may be intercepted or transpired by plants, it may run over the ground surface and into streams, or may infiltrate into the ground. Much of the intercepted and transpired water and the surface runoff return to the atmosphere through evaporation. The infiltrated water may percolate to deeper zones to be stored as groundwater. This may later flow out as spring or seep into streams and finally evaporate into the atmosphere to complete the hydrological cycle.

Table 2.4 *Water balance (mm) for a cultivated catchment in Mbeya (modified from EAAFRO, 1979)*

Period	Rainfall	Runoff	∆W	Dp	Evaporation
20.10.58 – 10.10.59	1,320	329	+4	0	987
10.10.59 – 10.10.60	1,718	578	+6	+90	1,044
10.10.60 – 10.10.61	1,190	391	+18	-109	890
10.10.61 – 10.10.62	2,248	1,112	-27	+163	1,000
10.10.62 – 10.10.63	1,548	628	+14	-72	978
10.10.63 – 13.10.64	1,884	854	-3	+15	1,018
13.10.64 – 10.08.65	1,369	418	+25	-15	941
10.08.65 – 10.10.66	1,485	548	-22	-21	980
10.10.66 – 10.10.67	1,570	485	+18	-22	1,089
10.10.67 – 10.10.68	2,240	1,326	+24	+114	776
Mean, 1958–68	1,657	667	6	14	970
	±116	± 104	± 6	± 27	± 28

2.3 How much water is wasted?

The concept of wasted water has already been mentioned in the previous sections. Most of the time in semi-arid areas, a catchment will suffer water shortage as a result of wasting rainwater.

Wastage of rainwater is a relative term depending on the water needs of a given area. Rain falling in any area is demanded by stakeholders who often have differing and sometimes-conflicting needs. For example, a water engineer in charge of a town water supply from wells would want most of the water to contribute to groundwater recharge through deep percolation (Shindo, 1989, 1990, 1991). On the other hand, a farmer on the same catchment would want most of the water to recharge the root zone while a pastoralist would demand that the water flow into a reservoir for livestock drinking. These conflicting demands must be taken into consideration during the planning process so as to avoid conflicts.

Water considered "lost" at one point can therefore be gained elsewhere within the catchment. This is illustrated in Figure 2.5 where, for example, deep percolation losses from cropped fields, rivers and reservoir, recharge the ground water aquifer thus improving the yields of wells.

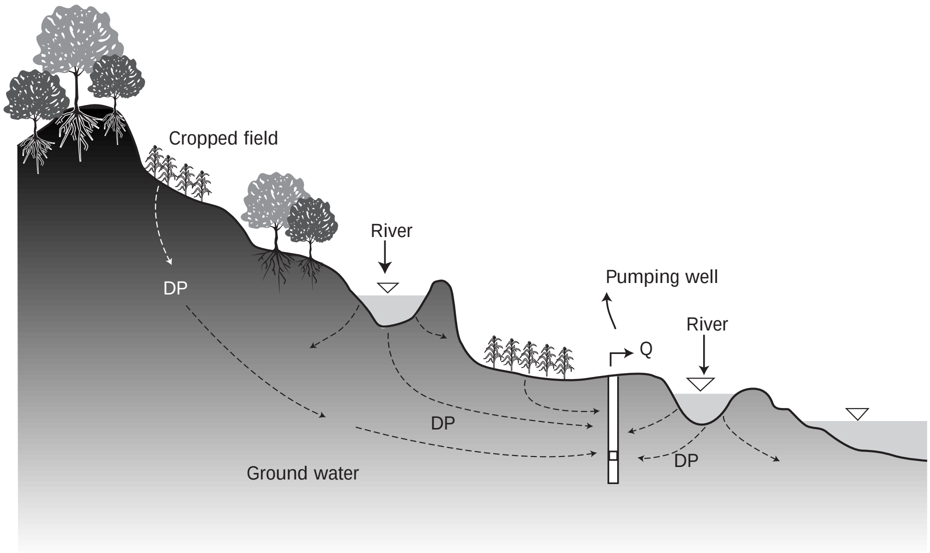

Figure 2.5 *Water loss at one point can be gained elsewhere within the catchment.*

The purpose of RWH is normally to minimise losses by capturing rainwater that may be wasted and putting that water into productive use. Runoff is one of the major ways by which water is lost from a given catchment. This is due to limited capacity of the soil to absorb and store all the rainwater from short but intense rainstorms. Such phenomenon is common in semi-arid areas. Numerous researches have been conducted to estimate this type of water wastage under different conditions as illustrated in Table 2.5. Thus, effective reduction of runoff losses requires the establishment of those conditions which minimise runoff as discussed further in section 5.1

Table 2.5 *Seasonal runoff losses from identical plots with different land use at Mpwapwa, 1946 – 1954, (modified from Christiansson, 1989)*

Season	Rainfall (mm)	Sorghum flat cultivated		Perennial grass *(Cynodon plecto-stachyus cenchrus ciliaris)*		Strip cropping (sorghum – grass)	
		mm	%	mm	%	mm	%
1946/47	780	70.2	9.0	9.4	1.2	30.4	3.9
1947/48	530	86.9	16.4	18.0	3.4	55.1	10.4
1948/49	650	141.7	21.8	47.5	7.3	124.8	19.2
1949/50	580	74.2	12.8	27.3	4.7	76.0	13.1
1950/51	670	178.9	26.7	35.5	5.3	103.2	15.4
1951/52	860	248.5	28.9	55.9	6.5	77.4	9.0
1952/53	410	54.5	13.3	18.1	3.9	32.1	6.9
1953/54	520	132.6	25.5	37.4	7.2	74.4	14.3
Average	690		19.3		4.9		11.6

Evaporation and transpiration are other ways through which water is lost from a given area. As already mentioned, if the transpiration is by productive plants, then it is not a loss. The two processes are however functions of the available water, ground cover and climatic conditions. When water is plentiful (i.e. during the rainy season), evapotranspiration occurs at a rate called potential evapotranspiration (PET). However, during the dry period, although the PET is higher, the actual evapotranspiration (AET) is lower and is a function of the available soil-moisture, vegetation type, cover and stage of growth.

The amount of water which flows into groundwater recharge can be estimated (only over a long period) by observing the rise of the water table. This may be difficult if the water table is very deep. The amount of rainwater that flows into groundwater recharge is dependent on the permeability of the soils where the rain falls as illustrated in Table 2.6. Permeability is the rate at which water can move through the soil profile. The seven-class permeability system of the USDA is widely used. Since permeability varies in different soil horizons, we have to specify the depth referred to, noting that the upper subsoil is usually chosen. A soil of high permeability could still restrict deep percolation if it is on top of an impermeable layer, like a hard pan.

Table 2.6 *Classes of soil permeability (after USDA, 1962)*

Class	Description of Rate	Rates of flow*
1	Very slow	Less than 1.25
2	Slow	1.25 – 5
3	Moderate	5 – 20
4	Moderately slow	20 – 65
5	Moderately rapid	65 – 125
6	Rapid	125 – 250
7	Very rapid	Over 250

* The rate of flow in millimetres per hour through saturated undistributed cores under a head of 12.5 mm of water

2.4 Planning guide

The purpose of this section is to provide a guide on how the materials presented in this chapter can be used in the planning process. One major step in the planning process of RWH is to establish a thorough understanding of the climatic characteristics of the target area. This guide therefore explains what is required to achieve this and once it has been achieved, how it can be linked to other components of the planning process.

Effective climatic characterisation requires:

i) Long term (not less than 30 years) of meteorological data series.
ii) That the meteorological stations should be adequately distributed such that;
   - for mountainous areas, at least one station per 25 km^2.
   - for flat terrain, at least one station per 100 km^2.
   - in forested areas, special measurements of the throughfall and stem flow should be done to enable estimation of interception losses.
iii) That if the distribution of recording stations is not adequate, stations are established and data collected for at least two years. Such data can be used in computer based statistical methods to simulate the long-term data series, using data from the nearest three stations with long-term records.
iv) That once the data has been accumulated, it should be checked for accuracy and gaps.
v) That to fully analyse the data and to get correct interpretation of parameters (e.g. evaporation from ground surface and evapotranspiration) experts are required. These will include meteorologists and hydrologists.
vi) The possibility to get already processed data for your target area from GIS databases, from different organisations (e.g. Department of Meteorology, University of Dar es Salaam, Sokoine University of Agriculture, Ministry of Water, and Projects) or even through the Internet (see chapter 8).

At the end of this exercise, a climatic database should be in place for the target area. It should be possible to query this database for the following information:

- Parameters representing measures of the central tendency of a statistical distribution which include: the mean, median and mode.
- Parameters representing variability such as: the mean deviation, the standard deviation, the variance, the range and the coefficient of variation.
- Parameters for determining data symmetry or asymmetry, which include: skewness and coefficient of skewness.
- Parameters determining data homogeneity such as trend, periodicity and consistency.

Further analyses should be done to establish the amounts and trends of water availability in the target area, from rainfall.

Chapter 3

Effective utilization of rainwater: more water from the same rain

Rwehumbiza, F.B., H.F. Mahoo and E. A. Lazaro

Agricultural production in Tanzania is 98% rainfed. However, much of the rainwater is either lost through evaporation or runoff as already explained in chapter 2. To raise crop productivity through rainwater, more water from the rains should soak into the soil than is currently the case. The same rain should give us more water through conservation and RWH. In this chapter, an attempt is made to describe how to estimate water requirements for different uses. These uses are divided into three major groups namely; vegetation, domestic and animal use and groundwater recharge.

3.1 Water requirement for plant growth

The discussion in section 2.2.6 has shown that a high proportion of rainwater infiltrating into the soil is consumed by vegetation through evapotranspiration. The growth and yield of any vegetation is related to the amount of water it transpires. When the crop is disease free, and enough water is available to fully meet the transpiration demand, the crop can grow and yield at its full potential. The rate of growth and yield is lowered by reduction of water available for transpiration and when this amount becomes too small, the plant wilts and dies. Transpiration is the process of water flow in a plant, entering by the roots and leaving by the stomata. Through this process, nutrients are also absorbed from the soil by the plants. It is very difficult to separate evaporation and transpiration in a vegetated field. It is for this reason that the composite term evapotranspiration has been adopted. It is however not a useful approach since evaporation is wasteful while transpiration is mostly useful. The rate of evapotranspiration is controlled by four main factors (Box 3.1). However, in semi-arid areas, the atmospheric demand is very high and therefore for most of the time, evapotranspiration is dependent only on the amount of water available in the soil.

Box 3.1 *Factors controlling rate of evapotranspiration*

- Amount of energy, since about 600 calories are required to evaporate 1 gram of water.
- Humidity gradient.
- Wind speed above the crop canopy.
- Amount of water in the soil. If water is not available no evapotranspiration will occur.

3.1.1 Water requirements for crops

Water used by crops is the leading economical use of rainwater falling throughout Tanzania. This section introduces the theory for estimating water requirements for crops. As for all types of vegetation, crop water use is measured in terms of evapotranspiration. The optimum evapotranspiration for a given crop is called crop potential evapotranspiration (ET_{crop}). This is defined as the evapotranspiration by a disease free crop, growing in large fields under non-restricting soil conditions including soil, water and fertility and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977).

Climate, crop type, and stage of growth therefore influences the potential water requirement by a crop. Potentially, more water is required by crops in environments which are sunny, hot, and windy with very low relative humidity than in cooler non-windy areas. Since weather conditions vary from day to day, so do the crop water needs. Potential water needs of crops are therefore calculated based on shorter periods like 5, 10 and 30 days rather than on seasonal or annual basis. Crops or cultivars that take long to mature require more water than small, early maturing ones (Table 3.1). Several databases are now available in the Internet, which can be used to estimate potential evapotranspiration for different crops and areas around the world. Ideas on how to use the Internet for this purpose are discussed in chapter 8.

Table 3.1 *Potential evapotranspiration for selected crops*

Crop	Growth Period (months)	ET_{crop} (mm/season)
Maize	3 – 4	500 – 800
Sorghum/millet	3 – 4	450 – 650
Soybean	4.5 – 5	600 – 1000
Sunflower	4 – 4.5	600 – 1000
Cotton	7 – 8	1050
Groundnuts	6 – 7	500 – 700
Beans	3 – 4	300 – 500
Rice	5 – 6	900 – 1200
Citrus	Perennial	900 – 1200

(Modified from Critchley and Siegert, 1991)

"ET_{crop}" is calculated as shown in equations 3.1 and 3.2.

$$ET_{crop} = ET_o \times k_c \times \text{number of days} \quad (3.1)$$

where:

ET_{crop} = potential evapotranspiration for a named crop over a specified duration.
ET_o, = reference crop evapotranspiration in mm.
k_c = crop coefficient which varies with crop development (Table 3.2).

In most areas of Tanzania, pan evaporation is the only available data. This data can be used to calculate ET_o . Therefore, to calculate ET_o from pan evaporation data, the formula to be used is:

$$ET_o = E_{Pan} \times K_p \quad (3.2)$$

where:

E_{Pan} = pan evapotranspiration over a specified period
K_p = pan coefficient (*taken as 0.7*)

To obtain crop water requirement over longer periods, water requirements calculated over shorter periods using relevant k_c values are added. In Table 3.2, monthly k_c values are used to calculate monthly ET_{crop}. Monthly ET_{crop} values are then added to obtain seasonal ET_{crop}.

Table 3.2 *Stagewise calculation of ET_{crop} from pan evaporation and relevant crop factors on monthly basis*

Month	Pan Evap (mm)	ETo (Eqn. 3.2)	Crop factors (k_c)			Crop water requirements (Equation 3.3)		
			Maize	Rice	Millet	Maize	Rice	Millet
October	328.5	230.0						
November	286.7	200.7	0.5		0.5	100.3		100.3
December	248.5	174.0	0.9	1.1	0.8	156.6	191.4	144.4
January	192.9	135.0	1.0	1.1	0.9	135.0	148.5	131.0
February	133.7	93.6	1.2	1.3	0.7	112.3	117.0	69.3
March	129.8	90.9	0.8	1.3	0.6	72.7	113.6	54.5
April	158.8	111.2	0.5	1.0	-	55.6	112.2	-
May	125.2	87.6		1.0	-	-	87.6	-
Seasonal						632.5	770.3	499.5

Rainfall and total crop water requirements for a given period are compared to assess the adequacy of rainfall (Table 3.3). During the months of October, November and December, the monthly rainfall does not exceed the monthly water requirement (ET_{crop}) for maize, sorghum and millet. The relatively high negative values between rainfall and ET_{crop} during the months of October and November indicate that the crop will suffer water shortage. It must be remembered that not all the rainfall actually reaches and stays in the root zone. Therefore, only part of the rainfall is actually available for transpiration. Thus the deficit in relation to optimal crop water requirement is much higher than that indicated by using the full amount of rainfall.

Seasonal rainfall amounts may exceed the seasonal crop water needs with the crop still performing poorly. The seasonal amounts tend to hide times of water surplus or deficit and especially when calculated on a monthly basis rather than on 5 or 10 day periods. Prolonged dry spells between rainfall events may lead to crop failure or poor harvest even when the total monthly or growing seasonal rainfall far exceeds crop water needs. Thus, rainfall distribution is more important than total rainfall.

Table 3.3 *Mean monthly rainfall compared with mean monthly crop water needs for maize, sorghum and millet at Hombolo, Dodoma*

Month	Monthly rainfall (R) (mm)	Water Requirements (ET_{crop})			Status (R-ET_{crop})		
		Maize	Rice	Millet	Maize	Rice	Millet
October	3.6		-			-	
November	32.6	100.3	-	100.3	-67.7	-	-67.7
December	106.7	156.6	191.4	144.4	-49.9	-84.7	-37.7
January	137.6	135.0	148.5	131.0	+2.6	-10.9	+6.6
February	125.3	112.3	117.0	69.3	+13.0	+8.3	+56.0
March	119.7	72.7	113.6	54.5	+47.0	+6.1	+65.2
April	57.1	55.6	111.2	-	+1.5	- 54.1	
May	5.4	-	87.6	-		- 82.2	
Seasonal	588.0	632.5	770.3	499.5	- 53.5	- 217.5	+22.4

Water deficit causes stress to the plants and depending on the stage of crop development, the intensity and duration of the water deficit, the following can occur:

- Sown seeds completely fail to germinate,
- Poor crop establishment (fewer seedlings),
- Plants become stunted,
- Disrupted development (phenological) cycles (e.g. premature tasseling in maize),
- Poor grain filling,
- Total crop failure at any stage if water deficit is very severe, and
- Poor quality of produce (e.g. shrivelled grains).

Interpretation of the difference between ET_{crop} and rainfall (R) given in Table 3.3 is only related to the situation when the crop is growing at full potential. This is often not the case due to other limitations such as soil fertility. In such situations the important parameter to consider is actual evapotranspiration. This is the actual quantity of water that is removed from the soil by the twin processes of evaporation and transpiration. The quantity is determined by the condition of the crop and available water or both. For example, a crop with poorly developed roots will not transpire water at maximum potential. Actual evapotranspiration is normally estimated as a percentage of the ET_{crop}, depending on the state of health of the crop under consideration.

Depth of the root-zone is a very important determinant of the amount of water and mineral nutrients available to a crop. Ideally, the root-zone should be the same as the potential depth of roots. This is rarely the case for two reasons: either the soil is not deep enough to allow the roots to grow to their full potential, or zones of compaction and relatively impervious horizons act as physical barriers to root penetration (Figure 3.1).

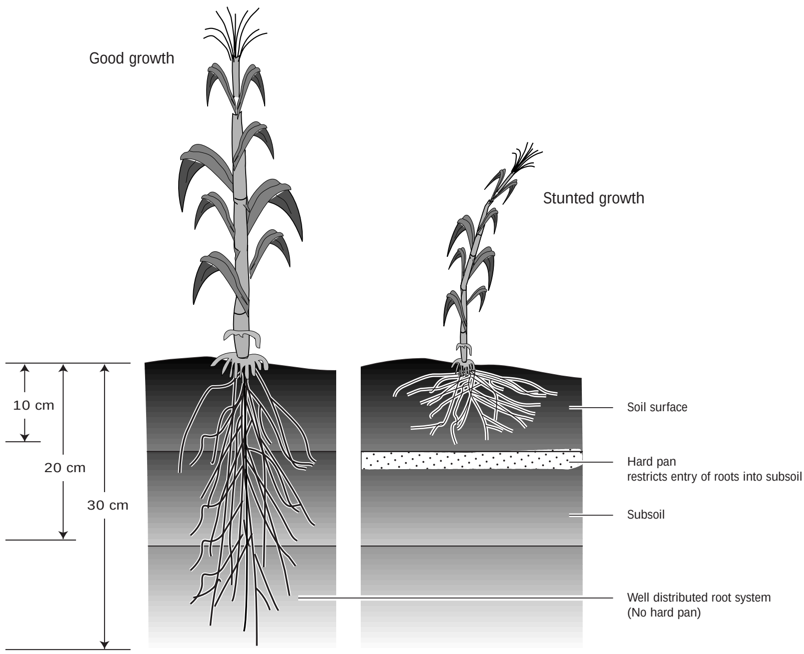

Figure 3.1 *Effect of hard pan on root growth and distribution*

Our discussion so far has expressed water requirement in units of depth (millimeters). However, to plan storage and pumping requirements for example, information is required in units of volume (litres or cubic meters). The formula for converting from one system to the other is given in equation. 3.3.

$$\text{Volume } (m^3) = \text{Area } (m^2) \times \text{Depth } (m) \quad \ldots\ldots 3.3$$

The area refers to the piece of land that is covered by the crop usually in square metres (1 ha = 10,000 m^2). The depth refers to the crop water requirement (normally given in mm). From Table 3.3, a sample calculation for water needs of a maize crop (1 ha) at Hombolo - Dodoma for a whole growing season is given below.

$$\text{Volume} = \text{Area } (10{,}000 m^2/ha) \times \text{Depth } (0.6325 m/season)$$
$$= 6325\ m^3\ ha^{-1}\ season^{-1}$$

3.1.2 Range development

Rangelands are lands on which the native vegetation types are predominantly grass, grass-like plants and shrubs suitable for grazing and browsing by domestic and wild herbivores. They include natural grasslands, savannah, shrublands as well as revegetated lands. Estimation of water requirements for rangelands are complicated by the fact that the vegetation consists of a wide range of plant species from grass, shrubs to trees.

An illustration of water requirements for grass is shown in Table 3.4. Most rangeland plants are perennials and water is required the whole year round. The table shows that there is water surplus only for three months (January – March). Vegetation tend to regenerate during this period and the landscape looks green. The situation changes between April and December when water deficit sets in. During this period, vegetation dries and most of the grasses and bushes die completely.

Overall, rainfall can supply only 588 mm of water against a requirement of 1426 mm, thus creating is deficit of 838 mm/year. This is the reason for the complete drying of most grass vegetation during the long dry season.

Table 3.4 *Crop water requirement for rangeland grass at Hombolo, Dodoma*

Month	Monthly ET_o grass (mm)	Monthly rainfall (mm)	Status (– = deficit) (+ = surplus)
October	230	4	- 226
November	200	33	- 168
December	174	107	- 67
January	135	138	+ 3
February	94	125	+ 32
March	91	120	+ 29
April	111	57	- 54
May	88	5	- 82
June	64	0	- 64
July	67	0	- 67
August	80	0	- 80
September	94	0	- 94
Total	1,428	589	

3.1.3 Forests and trees

The same principle of evapotranspiration applies to trees and forests when considering water requirements. From the rainfall consumption point of view, water demand by forests is higher due to interception which may be as high as 25% of the rainfall. In addition, evapotranspiration by trees is much higher than annual crops and may even be double the rate (Calder, 1994). For these reasons, trees and tree crops require higher volumes of water as compared to other crops and pasture.

Due to very high evapotranspiration capacity of trees, the rate of evapotranspiration is nearly entirely driven by the amount of water available in the root-zone and beyond. Because of deep roots, trees can suck from the ground water and thus the actual evapotranspiration during a hydrological year could be much larger than the rainfall. This is why there is a worldwide claim by local people that introduction of some tree species such as Eucalyptus has caused drying of wetlands and shallow wells. This ability for high actual evapotranspiration also explains the favoured characteristics of Eucalyptus; namely high growth rates. This is because as explained earlier, the rate of biomass yield of most plants is closely correlated to actual transpiration rate.

3.2 Water for domestic use and for animals

3.2.1 Domestic water needs

People normally give priority to domestic water supply, although pastoralists often gives higher priority to water for livestock. Water meant for other uses would therefore be diverted to domestic and livestock purposes where no alternative sources are available. In Dodoma region for example, many charco-dams meant for livestock water supplies are also used as sources of domestic water.

Calculation of domestic water requirements must take into account the daily water requirements per person for cooking and drinking, cleaning, dish washing, and laundry. Water required per person for drinking and cooking has a limited range of 2–5 litres per person per day, depending mainly on the climate and the standards of living. Water required for body cleaning depends mainly on the access to water and is a direct function of supply. In the semi-arid areas where water is not available near the homes, washing of the body may be accomplished by as little as two litres per person per day. Water for dish washing and cleaning of cooking utensils will also vary with the availability and access to water. This may range from two litres per person per day to as much as 50. In rural settings, women often walk to waterholes that may be as far as 10 km away to wash clothes. In water scarce regions, this may be done once a week consuming an average of 10 litres per person per week.

As an illustration, the total water demand for a rural family of seven in Dodoma during periods of little or no rainfall (June – November) is shown in Table 3.5. A sample calculation for the month of June is as shown in Box 3.2. Table 3.5 shows that the total domestic water requirements during the months of June to November is 13,359 litres or 13.4 m^3 which is equivalent to about 67 drums (200 litre capacity) of water. This is about 11 litres per person per day. The UN recommends 50 litres per person per day as indicative human water rights for all households needs.

Box 3.2 *Water demand for a rural family in a semi arid area*

7 people x 5 litres / person/ day x 30 days	=	1050 litres - Drinking and cooking
7 people x 2 litres / day x 30 days	=	420 litres - Body cleaning
7 people x 2 litres / day x 30 days	=	420 litres - Utensils washing
7 people x 10 / 7 litres / per day x 30 days	=	300 litres - Clothes washing

Table 3.5 *Domestic water requirements (in litres) during the dry months of June to November in Dodoma*

Month	Drinking and cooking	Body cleaning	Dish washing	Clothes washing	Total
June	1050	420	420	300	2190
July	1085	434	434	310	2263
August	1085	434	434	310	2263
September	1050	420	420	300	2190
October	1085	434	434	310	2263
November	1050	420	420	300	2190
Total	6405	2562	2562	1830	13359

3.2.2 Livestock and wildlife

The water requirements of livestock is the total quantity of water used by the animals for their metabolic processes as well as for regulating heat in their bodies. They vary according to a number of factors such as food intake, quality of the food and temperature. The voluntary water intake is the quantity of water that has to actually be supplied to animals. This corresponds to that part of the water requirement that cannot be provided by the moisture content of the forage. This is the parameter to be taken into account when planning a water supply system for animals.

For comparison purposes, the animals are usually expressed in terms of livestock unit (LU). For the tropical regions, a common unit normally used is the Tropical Livestock Unit (TLU), which is equivalent to an animal weighing 250 kg. The daily water requirement for different animals during the wet and dry seasons at an air temperature of 27° C are shown in Table 3.6.

Table 3.6 *Daily water requirements (in litres per day) of different animals during the wet and dry seasons, air temperature 27°C (after Finkel and Segerros, 1995)*

Season	Type of animal	TLU	Total water requirement (l/d)	Voluntary water (l/d)
Wet	Camel	1.6	50	15
	Cattle	0.7	27	10
	Sheep	0.1	5	2
	Goats	0.1	5	2
	Donkeys	0.4	15	5
Dry	Camel	1.6	50	50
	Cattle	0.7	27	27
	Sheep	0.1	5	5
	Goats	0.1	5	5
	Donkeys	0.4	16	16

3.3 Groundwater recharge

Groundwater refers to the water in saturated zones of geologic stratum normally called aquifers. It is one portion of the earth's hydrologic cycle as described in chapter 2. An aquifer is a combination of two Latin words *aqua* (water) and *ferre* (to bring). It is a geological layer that is porous and permeable and thus capable of holding and transmitting large quantities of water. The characteristics of the geological formation which allow for underground water retention are shown in Figure 3.2.

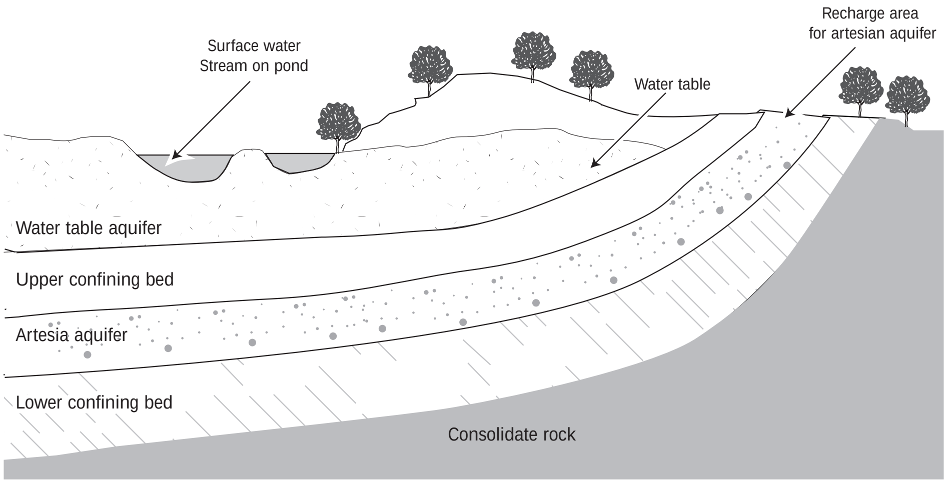

Figure 3.2 *Schematic representation of groundwater systems.*

Groundwater can be extracted through wells, but may also be accessed through naturally occurring springs or seeps. Wells are artificial excavations, usually dug, bored or drilled holes or tunnels, which penetrate aquifers and allow water to flow or be pumped to the land surface. A spring or a seep is a natural discharge point that occurs where an aquifer intersects the earth's surface.

In chapter two, it was explained that after infiltration has filled the root-zone to field capacity, the excess water flows downwards as deep percolation. The water that percolates becomes groundwater when it reaches the water table. Afterwards, it may seep into streams and lakes or may replenish the water in aquifers. Over a long period, water also moves from shallow to deep aquifers. The recharge is much higher in situations where artesian aquifer comes to the ground as shown in Figure 3.2. If rainwater collects in such areas, the rate of recharge of deep aquifer is much higher. This should be one of the conditions to be observed before installing deep wells. Due to the slow rate at which deep aquifers are recharged, pumping from deep wells often leads to overdrafts. This is the situation where the rate of water withdrawn by pumping exceeds recharge rates. The result of this is the contamination of the water with saline water found deep in the ground. Recent surveys indicate that 39% of 1181 shallow wells, and 78% of 76 boreholes in Shinyanga region are not functioning because of inadequate recharge of the groundwater (DWSP, 1995).

Groundwater recharge requirements are therefore determined by the discharge rates. It is important to establish a good knowledge of the amount of groundwater and the rate of recharge as a basis for planning the amount that can safely be withdrawn. If the withdrawal has to be large, then it is important to plan for artificial recharge.

The artificial recharge of groundwater is defined as one that augments the natural replenishment of groundwater storage by some method of construction, spreading of water or artificial changing of natural conditions. This can be implemented by using concentration basins (RWH), injection wells and wetlands.

In the semi-arid areas of Tanzania, most recharge mechanisms are either natural or incidental, where you may find losses or leakages from irrigation systems and flooding of low-lying areas. None of the groundwater schemes includes components of deliberate efforts to recharge the groundwater.

3.4 Water deficits and surplus

Water deficits and surpluses result into what is called drought and flooding cycles. The Disaster Management Department in the Prime Minister's office estimates that between 1872 and 1990, about 38% of all disasters in the country were caused by floods. During the same period, 33% of all types of disasters were caused by occurrences of drought. Thus, water problems (deficits and surplus) account for 71% of all disasters in the country (URT, 1998a). History shows that drought occurs in Tanzania every four years and that most frequently affected areas are central regions of Dodoma, Singida and Tabora. Some parts of Coast (Bagamoyo), Shinyanga, Mwanza and Mara are also victims of regular droughts. Flood prone regions are Tanga, Mbeya, Coast, Morogoro, Arusha, Rukwa, Iringa, Kigoma, Lindi and Ruvuma.

There can be a wide variation of water deficits and surpluses both within and between seasons as well as between places. A drought year whose total rain is well below a long-term average may still include periods of excessive rain and flooding, while a higher rainfall season may include periods of devastating dry spells.

3.4.1 Droughts

Many new programmes for water resources development are initiated following a drought. It is therefore important for planners to have a good understanding of the meaning and nature of droughts. There are hundreds of different definitions of drought depending on the purpose or locality. In relation to vegetation and thus agriculture, drought is conceptualized as a continuous period of time, including all the days which normally receive rainfall, with very low or no rainfall resulting in damage to crops or other vegetation. However, there are four recognized types of drought. These are meteorological, hydrological, agricultural and socio-economic.

Hydrological drought is said to occur when there is failure of rainfall either in amount or timing. It can for example be defined in terms of number of days with rainfall less than the expected normal. Meteorological droughts are often related to rainfall amounts much lower than average, on monthly or seasonal basis.

Agricultural drought links the meteorological drought to some significant agricultural impact. For example, the most important issue in agriculture is the amount of soil-water available to plants, in relation to evapotranspiration. Therefore, meteorological droughts occurring during early growth stages may not constitute an agricultural drought as the little amount of rain may adequately supply the water needed by the young plants.

Hydrological drought is said to occur when a meteorological drought leads to a significant drop or depletion of surface and sub-surface water. When a hydrological drought occurs, there is much wider socio-economic impact as it affects water supply, power generation and aquatic life. Because of the buffer provided by storage in the system, hydrological droughts occur several months after the meteorological and agricultural droughts. For a hydrological drought to occur, it often requires a series of seasons with serious meteorological droughts. On the other hand, hydrological droughts may be caused by changes in the land-use pattern in the catchment area. In addition, hydrological droughts often affect the downstream areas more severely than the area where it originates.

A drought is said to have socio-economic impact when the supply of socio-economic goods and services is below normal as a result of severe meteorological, agricultural and hydrological droughts.

3.4.2 Water surplus

Water surplus is in the form of a flood or water beyond the soil storage capacity that is lost as runoff. A flood is any relatively high flow that overtops the natural or artificial banks in any reach of a stream, sometimes resulting into damage of property and loss of life. One of the most important rainfall characteristics is its intensity. Rains with high intensities are referred to as storms. During such storms, large amounts of water that is too much for infiltration to cope with, are received in a short time thus causing runoff and at times devastating floods.

However, temporary floods need not be looked at negatively for in most cases, they are short lived. If not put into good use, flood water is soon lost and water deficit sets in. More often than not, the water deficit in a particular area may be as a result of low infiltration of rainwater where it falls, resulting into higher runoff losses which may cause flooding in another area. In dealing with excess water, consideration should therefore be given to the following:

- The same water could be required at the same place in the future.
- The same water could be required at another place now.
- The same water could be required at another place in the future.

3.5 Case study: Dar es Salaam water supply system: could RWH help?

The main source of water for the city of Dar es Salaam is the Ruvu River. Abstraction from this river contributes 97% of the current water supply to the city. The total catchment area above the upper Ruvu pumping station is 15,190 km^2. The monthly discharge of the river at this point varies between 42 to 550 million m^3. At the same time, it is estimated that by the year 2010, monthly water requirements for Dar es Salaam will only be 12.6 million m^3/month. Certainly, there should not be any water problems in the city!

The most important lessons coming from this analysis are that:

- Frequent shortages of water in Dar es Salaam can not be as a result of reduced water flow in the river. The shortages are therefore a result of inadequate management of the system. For example, it is estimated that current leakage losses amount to 53%.
- A very big percentage of the river flow reaches the sea unutilized. Even after allowing the minimum flow required for environmental purposes, the amount of "waste" is still very high.
- The "shortages" occurring frequently may only be for very few days and hence do not show in the monthly averages.

In 1997, a study was done on "the augmentation of Dar es Salaam Water Supply" (URT, 1997a). The study recommended three courses of action to deal with water shortages in Dar es Salaam. These included construction of reservoirs across small rivers, development of ground water sources and control of the leakages in the main pipe supply system from Ruvu River. It is interesting to note that rooftop water harvesting is not mentioned at all as an option.

Rooftop water harvesting would give the water supply one major benefit. The main supply from Ruvu River could be partially shut down during the rainy season. This will be beneficial because:

- It will provide time for maintenance of the system and thus control the leakage losses.
- It will reduce the energy required for pumping and treating water.

It is estimated that the mean annual rainfall for Dar es Salaam is 1095 mm. The highest monthly rainfalls are received in March, April and May. These three months account for 570 mm. The water demand in the city by the year 2010 is estimated at 420,000 m^3/day or 38 million m^3 over three months. Assume rooftop harvesting is used to supply 30% of the water during the rainy season and rainwater is harvested at 90% collection efficiency, then:

30% of the water demand	= 12.6 million m^3
Volume of rainwater to be harvested	= 14 million m^3
30% of the rainfall	= 171 mm
Rooftop area needed = $14 \times 10^6\ m^3 / 0.171\ m$	= 81,871,345 m^2
Assume catchment area of a typical residential house	= 120 m^2
The number of houses (residential houses equivalent) needed to have RWH systems	= 682,261

Therefore, the strategy will require installation of roof catchment system on about 700,000 residential houses equivalent units. This is quite possible because many new buildings have good gutter systems. However, the collected water is often directed into the drainage system instead of being stored for later use.

It is possible to envisage a design where the urban area is divided into blocks with underground tanks to collect water from all the roofs in the vicinity. This water can then be pumped at an appreciably low cost to overhead tanks, from where it can be fed into the houses through the conventional pipe system. The design will also provide increased covered storage capacity to supplement the reservoir systems, as a means for reducing water losses through evaporation.

3.6 Planning guide

The planning process for rainwater harvesting require a thorough understanding of the water requirements to meet current needs as well as the new needs to be created by the new project. The purpose of planning is to put measures in place to ensure that the total expected water needs can be met with available rainwater resources. To determine the rainwater requirements, the following are necessary:

- Versatile climatic characterization database of the target area, produced as already discussed in section 2.5.
- All measurements of current level of exploitation of the rainwater resources in the target area, in terms of :
  - beneficial uses,
  - efficiency of use, and
  - losses through evaporation or flow to saline sinks.

To achieve this, it is important to establish the different land uses and knowledge of the water-use parameters for the different uses (e.g. for crops, forests, livestock, domestic and rangeland). For this, expertise is required for example in agronomy, soil physics, hydrology and animal science.

The data needed for achieving this exercise is mainly available from specialized research institutes, such as universities. However, data can also be obtained from studies commissioned by government departments such as ministries of water, agriculture, natural resources, forestry, and environment. Development organizations such as FAO, World Bank and UNDP.

Further, FAO and other organizations are operating databases available through the Internet which provide useful estimation of water requirements for different areas around the world. Where possible, these should be accessed as a starting point.

PART TWO

Techniques and factors that determine the potential for RWH

Chapter 4

Technical integration of RWH into development plans: think globally, plan locally

Hatibu, N., G.J. Kajiru and E. M. Senkondo

In Tanzania, RWH is not given adequate consideration during the planning stages of many programs such as town plans, infrastructure, rural development, agriculture and most importantly, water resources. One reason for this is the low understanding of the key factors that determine technical viability of RWH under different situations. The objective of this chapter therefore is to assist planners in the identification of technical factors or issues for consideration in the process of integrating RWH into plans.

4.1 Factors affecting the availability of runoff

A good knowledge or estimation of the expected amount of runoff in a given area is important in planning RWH schemes. Unless a good assessment of the available runoff that can be harvested or conserved is made, it is difficult to even start considering RWH. The availability of runoff is determined by factors such as land surface, soil type and rainfall characteristics.

4.1.1 Land surface characteristics

With other factors remaining the same, the characteristics of land surface can indicate the extent of runoff that can be expected. A good RWH plan exploits naturally occurring runoff. However, it is not possible to find this kind of runoff in every location or for every type of RWH. The non-availability of naturally occurring runoff will increase the extent of manipulation necessary on the catchment and hence, cost of the scheme. The main factors affecting runoff generation are slope, length, vegetation cover and surface roughness of the catchment. Risk of erosion is also an important factor to be considered in choosing catchment areas.

(a) Slope

To obtain high runoff efficiency, the slope of a catchment should be as steep as possible. However, slopes of more than 5% are susceptible to high erosion rates. Where the catchment has slopes steeper than this, erosion control measures are therefore necessary. The catena sequence found in most semi-arid areas provide many parts with steep slopes that have been turned into natural catchments through erosion over many years. This is discussed further in section 4.1.4.

(b) Length

The length of a catchment has a most important effect on the determination of peak discharge, rise time, total runoff time and water harvesting potential. Runoff rates and peak runoff decrease with increasing catchment length. The reason is that both retention losses increase with the length of the catchment. If a catchment is very large, its surface runoff yield per unit area is reduced as shown in Figure 4.1.

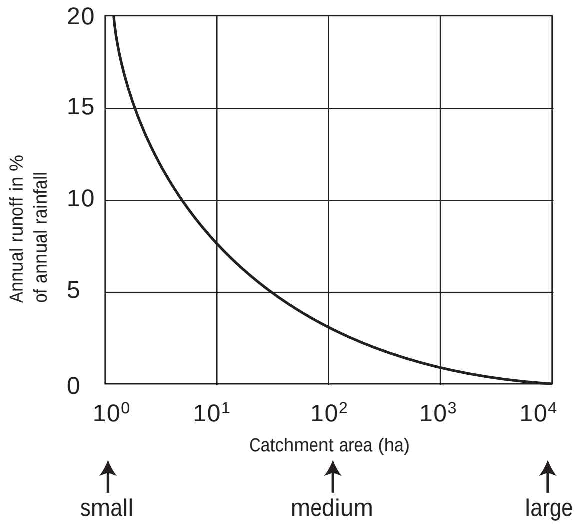

Figure 4.1 *Effect of catchment area on runoff yield (after Boers, 1994).*

(c) Vegetation

Vegetation cover is also very important to runoff and sub-surface flow from a given catchment. It has several effects on the effective rainfall and runoff. These include:

- Interception and thus evaporation from the canopy,
- Increased surface ponding and slowing down of water which assist infiltration and thus reduces runoff yield, and
- Increased hydraulic conductivity due to root channels which also leads to increased infiltration.

However, vegetation also consumes a lot of water through evapotranspiration as discussed in section 3.1 and thus reduces the total amount of runoff yielded by a catchment.

d) Surface roughness

A rough surface encourages infiltration and reduces the runoff yield from a given area. This is a consequence of depression storage that provides more time and opportunity for the infiltration of the rainwater. Areas with large portions of continuous hard surfaces will therefore have a very high runoff yield coefficient. To minimize costs, it is important that in planning RWH schemes, naturally occurring continuous hard surfaces should be exploited. The word ‘continuous’ is being emphasized because an area covered by many small stones has been shown to have lower runoff coefficient than a similar surface cleared of stones (Hudson, 1987). The hydrological explanation is that many discontinuous stones increase the roughness of the surface. This is despite the fact that the impermeable area covered by the aggregate is large.

It may sometimes be desirable to have a RWH scheme where the available catchment area does not have the desired surface characteristics. Such a situation will call for catchment surface treatment. Compaction of the land surface is one of the recommended and cheap methods for improving runoff yield, especially in relatively flat terrain. One example of compacted catchments is what is called 'Roaded Catchments'. The catchment surface is formed into ridges and troughs as shown in Figure 4.2. The furrows are linked to a drain that direct the water to cultivated fields or storage systems (Hollick, 1975). This system will be useful in rangelands where vast and gently sloping land can be treated to produce runoff at low cost. Other types of surface treatment include vegetation removal, surface cover, and chemical treatments.

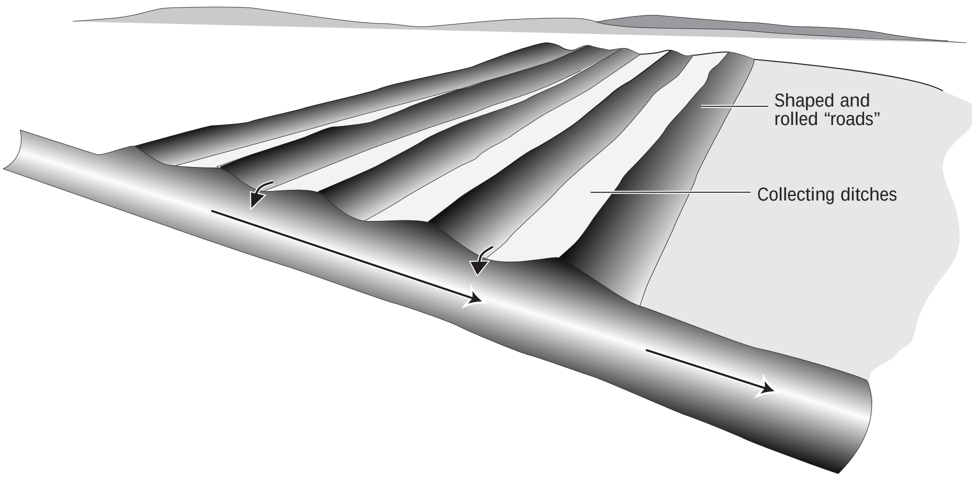

Figure 4.2 *Features of the roaded catchment (after Hudson, 1987).*

(e) Risk of erosion

Treated catchments are prone to soil erosion. It is recommended that RWH programmes should emphasize the effective harnessing and utilization of the runoff that is already occurring naturally. This is because most of the recommended methods for treating catchments, like removal of vegetation and stones, are measures which encourage erosion.

Should there be a necessity to clear an area for the purpose of enhancing runoff generation, then the catchment should be protected against erosion. One approach will be to divide the catchment into small sub-catchments using stone bunds. The water from each sub-catchment can then be conveyed to the catchment outlet using graded channels. The selected shape of the sub-catchments will depend on the land characteristics of the area. This approach will also lead to a high runoff from the total catchment because the short sub-catchments will produce more runoff per unit area. This approach is similar to the hillside conduit systems described in section 5.1.

4.1.2 Soil type

The nature of soil where the rain falls, is a very important determinant of how much runoff can be expected. The main controlling factors are infiltration rate, water holding capacity and hydraulic conductivity of the soil. Infiltration rate is the most important factor. It is normally affected by a combination of other soil characteristics such as:

- Soil texture, where clay tends to inhibit infiltration, while sandy or gravely soils encourage high rates of infiltration (Table 4.1).
- The presence of large openings in the soil, caused by tunnelling organisms or plant roots and cracking, increasing the rate of infiltration.
- The amount of water already in the soil profile, or antecedent soil moisture reduces the rate of infiltration because the soil has no capacity to store additional water.
- The water holding capacity and hydraulic conductivity are important because soils with high values of both will take in more water and thus assist in reducing runoff.

Table 4.1 *The effect of soil texture on infiltration rates (mm/hr)*

Soil texture	Ground cover	
	Bare	Forest
Sandy	20 – 25	40 – 50
Loam	10 – 15	20 – 30
Clay	0 – 5	5 – 10

4.1.3 Rainfall characteristics

The rate of infiltration and therefore runoff, is greatly affected by the rainstorm amount, intensity and distribution.

(i) Rainstorm amount

A rainstorm is defined as a single rainfall event occurring continuously over a specific catchment. A rainstorm amount is therefore the amount of rainwater resulting from a single rainfall event. This is normally measured in depth of water (mm) as explained in section 2.2.1. A high amount will quickly saturate the soil, with the excess being released as runoff.

(ii) Intensity

This is the ratio between the rainstorm amount and the duration of its occurrence. It is usually expressed in millimetres per hour (mm/hr), for a specific duration. It is important to specify the duration over which the intensity is calculated, since this varies with time and may be small at the start and high at the end of the rainstorm. Intensity values are therefore averages. The intensity of rainstorms often exceed the rate of infiltration of the soil, leading to high rates of runoff.

(iii) Distribution of rainstorms

The distribution of rainstorms influences the antecedent soil moisture in the catchment as follows:

- Rain falling with long dry spells between storms will have a low runoff yield. This is a situation where for example, one rainfall event occurs and seven or more days elapse before the next rainfall event. Under this situation, the catchment will dry up during the dry spell, hence making the soil able to absorb more of the rainfall received during the following storm. When the storms are close to each other with very few days between them, the catchment does not have enough time to dry and the soil will not be able to absorb the water from the next storm. This results in high runoff rate.
- On the other hand, depending on the soil type, dry spells may cause the soil surface to dry into a hard impermeable crust. This situation will lead to high runoff rate from the following rainfall event.

Where available, meteorological records can be used to establish a full description of rainfall characteristics in a given area. Data from recording rain gauges, which is necessary for estimating rainfall intensity, is however not collected regularly in Tanzania. Where it has been collected, it is often not analyzed.

4.1.4 Catena sequences

The term catena refers to a systematic arrangement of soil types along the slope of a landscape. The systematic nature of a catena provides a logical framework that can be used to assess the behaviour on a given catchment. Different soil types can be identified in the catena found in most of the semi-arid areas of Tanzania (Figure 4.3). There is a well-developed indigenous knowledge of the soil types on the catena in many parts of the country. For example, knowledge of the Sukuma people was popularized internationally by Milne (1947). The extent of coverage of different soils along the catena is shown in Table 4.2 for selected areas in the Lake Zone.

Table 4.2 *The extent of coverage of different soil types along the catena in three locations of the Lake Zone*

Name		**Area coverage (%)**		
Local	Scientific	Tabora	Ngudu	Misungwi
Luguru	Lithosols	6	6	8
Luseni	Arenosols	45	15	5
Ibushi	Calicisols	2	1	17
Itogolo	Planosols	6	60	45
Mbuga	Vertisols	30	18	25

a) Luguru

These are mostly exposed bare, rocky hilltops, dominated by granite boulders with interspersed gravely, loamy soil. This type of soil is a good source of runoff as infiltration is almost negligible.

b) Luseni

These are grey to reddish-brown, coarse sandy soils derived from granitic parent material. These soils occupy the upper and mid-slopes next to Luguru in the catena. Soil depth is variable and sand content in the topsoil generally exceeds 80%. Due to their coarse texture, permeability is high while water-holding capacity is 30 mm of water per metre of soil. These types of soil are not good for runoff generation.

c) Itogolo

These are hard pan soils occupying lower slopes next to Luseni on the catena. They are also derived from granitic parent materials but have fine texture than Luseni. Their important feature is a hard pan layer at about 30–50 cm depth which restricts percolation of water. This encourages rapid saturation of the topsoil leading to high rates of runoff. The soils have available water holding capacity ranging from 30–100 mm of water per metre depth of soil.

d) Mbuga

These are heavy, light grey to black cracking soils occupying the valley floors next to Itogolo soils. The majority of the fine fractions transported down slope are eventually deposited on the valley floor and in the depressions where they come to form dark coloured, clayey soils.

The catena, common in many parts of the semi-arid areas, is a naturally occurring RWH system. The Luguru part at the top generates runoff which flow through the Luseni and Itogolo parts picking soil nutrients before it is concentrated on the Mbuga. The Mbuga soils are therefore fertile and receive extra amounts of water. This natural RWH is well understood by farmers who grow high value crops in their fields located on Mbuga. The fields are popularly referred to as *mashamba ya mbugani*.

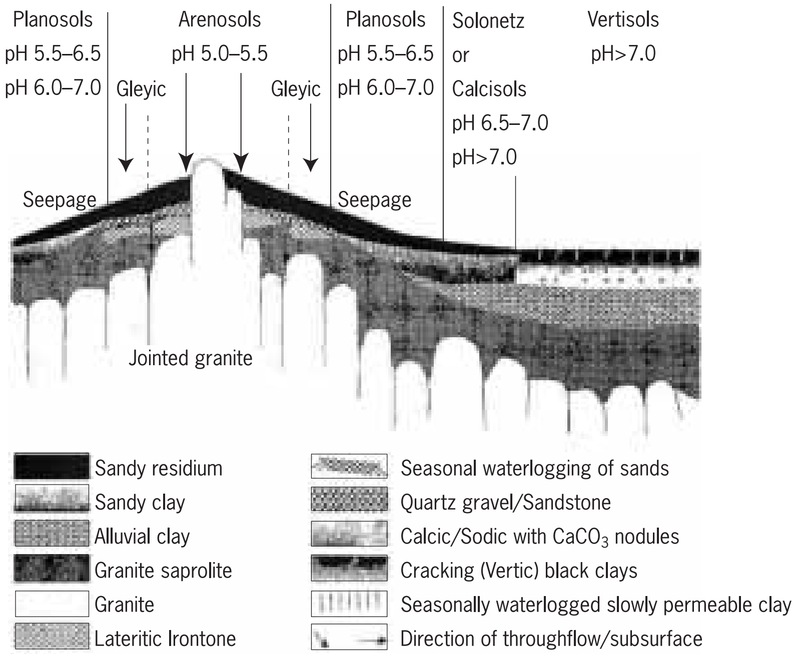

Figure 4.3 *Idealized catena sequence in Northwest Sukumaland of Tanzania (after Payton et al., 1998).*

4.2 Types of runoff

In RWH, the main interest is on the surface runoff which is the portion of rainfall that runs into rivers, and finally into lakes and oceans. The factors affecting the occurrence of runoff have already been discussed in the previous section. In this section, the common types of runoff (sheet, rill, gully and stream flow) are discussed. The terminology *sheet and rill flow* is normally used in discussing types of erosion. Sheet flow is said to occur when surface flow takes place in thin layers. This is the first step in any runoff generation. However, because land surface and soil characteristics are not uniform, this type of flow only occurs over a very short distance.

4.2.1 Rill flow

Sheet flow coalesces into rill flow in small but well-defined channels. Because these are small, they can be managed easily and the water can therefore be harvested at low cost. It is the most common type of runoff from micro-catchments. Very limited data is readily collected for estimating the amount of water available as rill flow. Therefore, if knowledge of the amount of rill flow is an important input to the plan being made, measurements will be necessary.

4.2.2 Gully flow

The next step in runoff generation is when the rill flows combine and concentrate into gully flow. Again the word gully is used more in connection with erosion. The main concern is the water flowing in the gullies that often flow as a flood wave for a short duration of time. This type is normally called runoff from macro or external catchment. The catchment size will vary between 0.1 ha to 200 ha, and the water flow is turbulent thus requiring control structures for it to be captured and used effectively.

At this stage, the amount of water is still within the area where the rain falls but will be flowing at a much higher speed which can potentially cause erosion. Harvesting of this water is also complicated by two of its characteristics:

- It is not easy to predict when flow will occur.
- The flow occurs over a very short duration.

4.2.3 Ephemeral stream flow

Runoff water in rills and gullies collects into stream flow. Most of the streams in semi-arid areas are ephemeral, thus flowing only during the rainy season. When it rains, the runoff response is very rapid and the water flows as a flood wave as it proceeds to its final destination. This water is often not captured for use and flows directly to oceans, lakes and other sinks, from where it is often not economical to recover it for beneficial use. For example, all rivers or streams in both Dodoma and Shinyanga regions fall under this category. However, literature identifies the Bubu River in Dodoma as permanent. This is not the case as the river remains dry for some part of the year as elaborated in Table 4.3. The data in the table shows the mean discharge of daily spot measurements.

Table 4.3 *Mean monthly discharge of selected rivers/streams in semi-arid Tanzania*

Month	Mean monthly discharge (m^3/s)			
	Bubu	**Kinyasungwe**	**Lupa**	**Mponde**
September	0.0	0.0	0.0	0.0
October	0.0	0.0	0.0	0.0
November	0.0	0.0	0.2	0.0
December	9.4	0.9	12.1	3.6
January	7.4	1.7	8.7	-
February	10.1	1.1	18.0	1.7
March	25.6	7.1	32.6	8.9
April	29.4	3.6	27.2	-
May	11.2	0.2	9.3	0.0
June	3.2	0.0	3.8	0.0
July	0.6	0.0	1.5	0.0
August	0.3	0.0	0.4	0.0

4.3 Integration of RWH with common infrastructure

Implementation of RWH schemes sometimes requires manipulation of catchments to enhance runoff generation. In addition, earth works are necessary for the purpose of concentrating and directing runoff to where it is required. At the same time, there are often artificial surfaces of common infrastructure, which generate substantial amounts of runoff. These include surfaces of paved highways, roads, pavements, airports, roofs and stock routes. Expensive drainage systems are often included to concentrate and dispose the runoff. It will therefore be cost effective to integrate any RWH plan with existing runoff generating infrastructure or vice versa.

4.3.1 Roads and railway drainage

There is a significant unutilized potential for integrating the road and railway infrastructure with RWH systems or vice versa. The nature of roads and railway lines is to act as cutoff bunds. These concentrate runoff and direct it into culverts or bridges (Figure 4.4). Currently the drainage systems are designed on the basis of 'save-the-road-and-let-it-flow' (Backman and Isaksson, 1994). There is no integrated management of the runoff after it has left the road or railway reserve area.

As a consequence, the concentrated runoff is left to cause gully erosion. A good example is the number of gullies which have been formed downstream of the culverts between Mwanga town and Kifaru along the Dar-es-Salaam – Arusha highway, in Mwanga District. There are only few cases where water from drainage systems is put to productive uses, for example, Lusilile project in Singida. [See case study 4.6.2]. The main reason for failure to use this resource is inadequate awareness among planners of both the common infrastructure as well as development, that water from the drainage system can be utilized in a much better way, instead of being allowed to cause soil erosion that is evident today. Integrating RWH with road and railway drainage will reduce erosion caused by water drained from the road and railway, as well as the cost of supplying water for different uses such as for domestic, livestock and crop production.

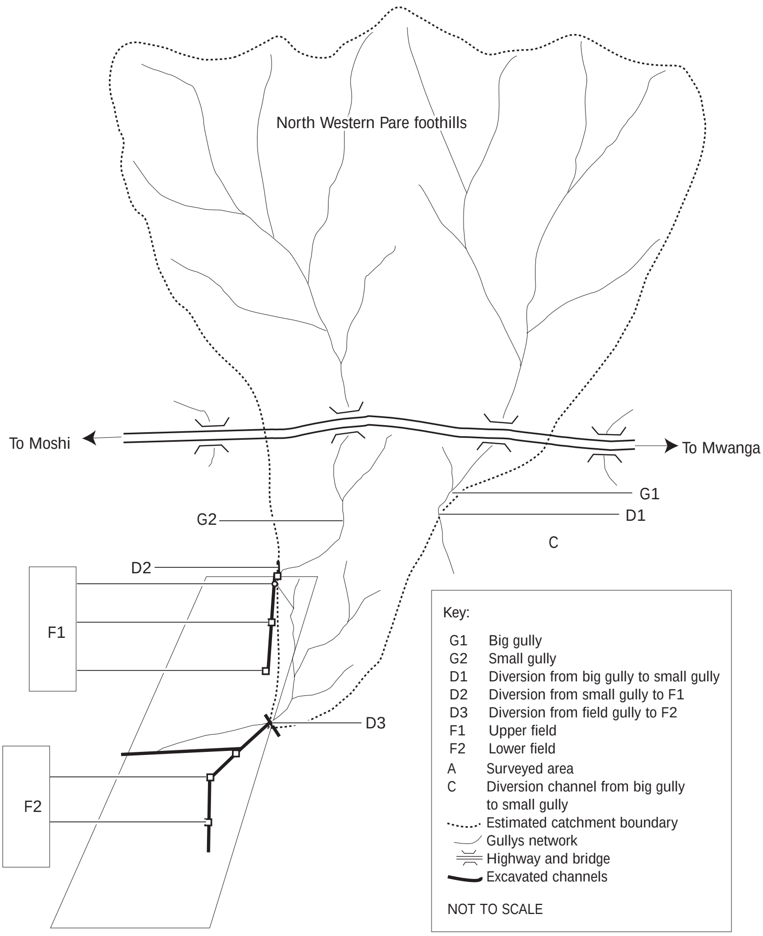

Figure 4.4 *Runoff concentration by a highway (after Bakari, 1999).*

4.3.2 Borrow pits

Construction of infrastructure is often accompanied by excavation for material such as stones, soil and sand. These excavations create pits in the ground commonly known as borrow pits. If appropriately located, the pits can serve as surface storage ponds for RWH. Although regulations governing road construction require that borrow pits should be filled, this is not always a common practice. Most borrow pits are left behind and can be used as storage reservoirs for rainwater. Water stored in borrow pits is used by local people residing along the highways. The water is used mainly for drinking, for livestock and sometimes for horticultural purposes.

Examples of borrow pits which store rainwater and are utilized are those along Morogoro – Dodoma, Dar es Salaam – Morogoro and Chalinze – Segera highways. These borrow pits are normally not planned for RWH purposes during road construction. However, if they become integrated into RWH plans, they will be a cost-effective way of supplying much needed water. The advantage of this integration in planning is that culverts, borrow pits and good catchment areas can be harmonized and become effective water harvesting programmes along the highways or railway lines.

4.3.3 Built-up areas

Built up areas consist mainly of buildings, pavements and any other structures which cover large land surfaces. These areas serve as catchments and often convert up to 90% of the rainfall into runoff. Tapping these sources of runoff can make available the water needed for many uses. Rooftop rainwater harvesting is the best known method of exploiting this source of water (Gould and Nissen-Petersen, 1999).

The opportunity to harvest rain in built-up areas is often wasted. For example, many institutions have installed elaborate gutters for collecting water from roofs, but then after investing so highly, the water is thrown away. This is a very good source of water that can be available with minimal extra investment. However, due to poor awareness that RWH is a viable alternative source of water, this opportunity is never exploited.

The provision for harvesting water from built up areas can be integrated into town plans. Towns often have very elaborate and expensive drainage systems for collecting and disposing valuable rainwater coupled with expensive piping systems for supplying the town with water from far away. It is true that RWH systems can not supply water throughout the year. But it is also true that if the town obtains 50% of its water from RWH for six months, then it will save 25% of its pumping cost per year (See case study 3.5).

4.4 Systems approach in RWH

RWH at any scale will affect the hydrology of a catchment. RWH components or full programmes should therefore be planned with a full accounting of the hydrology of the catchment. This requires a systems approach to the planning process. The starting point is the recognition that rain is water and that it has many different uses. Then the systems approach requires consideration of the whole catchment or basin broken down into separate components, which are then linked together in the plan. This approach is called *Integrated Catchment Management (ICM).*

A river basin can be divided into component catchments and sub-catchments as discussed in chapter 2. A rainwater harvesting project, however small, will therefore affect all other parts of the basin downstream. There is need to further establish a full description or modelling of the interactions between rainfall, evaporation, infiltration, deep percolation and runoff.

Stakeholders or users of the rainwater in a river basin are also an important part of the system, that forms a discrete sub-system with its own components. Thus, a consideration of the linkages of different stakeholders is an important aspect of the ICM approach. In one river basin, there may exist several users of water who will be directly or indirectly affected by a RWH project in an upstream part of the basin. This includes hydropower schemes, water supply systems, water disposal, and recreation and biodiversity habitats. The needs and opinions of all these users must be integrated into the planning process (see also section 7.2.2). This is because each use influences, or is affected by the extent and nature of the other uses. An effective plan is therefore the one which simultaneously considers all the uses as a system and elaborates the benefits and consequences of each use.

4.5 Data collection and appraisal of RWH potential

The information required for planning has got two components; namely, technical and social. While this section deals with the collection of technical data, the social aspect will be dealt with in chapter 6.

Technical assessments involve establishing databases on topography, soils, climate, water resources or hydrology, land use and resources. The climatic component has already been discussed in chapter 2. The approaches for obtaining and using this information are discussed in the following subsections.

4.5.1 Topographical mapping

In many parts of Tanzania, topographical maps in hard copies at a scale of 1:50,000 are available. However, the contour intervals are of 50 m and may be too wide apart for the purposes of detailed planning. These are good starting points for building topographical maps of the target area. Aerial photographs of the study area can be made or used to improve these maps.

Traditional approaches to mapping can be enhanced by Remote Sensing and Geo-referenced Information System, GIS (see also Chapter 8). In most cases, the exercise of remote sensing and establishment of GIS may have to be made within the project itself as this type of databases is not yet regularly available. However, several institutions and projects have undertaken Remote Sensing and established GIS databases for different places. These should also be identified and consulted at the initial stages of topographical mapping.

4.5.2 Soils

A good understanding of soils in the target area is required for effective planning of RWH programmes. Section 4.1 discusses how soil types affect runoff generation. Soil survey maps are the primary source of this information. These are available in two forms namely; general-purpose and special-purpose. General-purpose soil survey results into a pedological map which shows the distribution of soil units. These units are normally defined in terms of their morphology. The survey process also includes the description of physical, chemical and biological characteristics of these units. Special-purpose soil survey is carried out to describe and map the soil according to specific needs (Dent and Young, 1981). There are only few general-purpose soil survey maps in Tanzania. The most comprehensive being the soil, physiographic and agro-ecological zones map produced by de Pauw (1984). Most of the soil survey maps available are therefore of special-purpose nature.

The main sources of soil survey information includes:

- National Soil Service (NSS) based in Mlingano Tanga.
- Institute of Resources Assessment of the University of Dar es Salaam.
- Various development projects such as Hanang Wheat Complex (McKeague, 1988).

It is therefore unlikely that a soil-survey map and report will be readily available for the target area. However, it is possible to obtain initial maps by compiling from FAO world soil map, the agro-ecological zones map and various special-purpose maps from any previous projects. On the basis of the initial map, a new soil survey can be planned and implemented to fill the gaps or improve the scale and level of details where necessary.

4.5.3 Climate

Climatic data is the key to planning of any RWH programme or water resources management scheme. In Tanzania, climatic data is collected by the Department of Meteorology (DoM) through a network of stations located especially in the important institutions around the country. Climatic data are normally kept in tabular forms but digital versions have also been created. The Department of Meteorology should be contacted to obtain these data where available. Climatic zone maps can also be consulted to assist in making the first rough estimate of the climate of the target area.

It must be emphasized here that a detailed knowledge of rainfall pattern in the target area is important from the start of planning. Therefore, the available data from DoM will often require to be supplemented by more intense measurements in the target area. It is recommended that this should be done for a period of 2 – 3 years using stations about 2 km apart. This is because it has been shown that raingauge data represent only a small area surrounding the gauge. Efforts should be made to obtain full meteorological data where possible. If this is not possible then the most important basic parameters to be obtained are:

- Daily rainfall amount.
- Rainfall intensity.
- Average, minimum and maximum decadal, monthly and annual rainfall amounts.
- Open pan evaporation.

Modelling approaches are available for generating long-term data series from the short-term measurements using statistical correlation with the nearest station having long-term records.

4.5.4 Water resources and hydrology

Data on the hydrology, water resources and different demands for these resources, is the next most important planning data after climate. It is important to have adequate data for purposes of assessing the water balance of different components of the target area. The most important parameters are:

- Daily, decadal, monthly and annual runoff out of and into different homogeneous sub-catchments of the target area.
- Measurements of the sediment transport in the streams.
- Frequency of flooding and drought in different parts of the target area.

The hydrology section of the Ministry of Water has a network of hydrometric stations, mostly equipped with a staff gauge. The stations are normally found in major rivers and some RWH storage reservoirs. However, most stations have not been operational for long periods due to institutional failure. The available data can also be supplemented by data collected through research projects and during appraisal of past projects.

Like the case for meteorological data, it may be necessary to undertake specific hydrological measurements for 2 – 3 years in the target area. The obtained data can then be used to cross check and extrapolate the limited long-term data available from the Ministry of Water. For micro-catchment RWH systems, it may be necessary to install runoff plots to establish the runoff coefficients of the target area. The plots should be located in parts which are highly representative of the target area.

4.5.5 Land use

A correct mapping of the different land uses found in the target area is important in the planning process. Land use types have a wide scope varying from bare land, grass cover, forest cover, cultivated areas, built up areas and infrastructure. Accurate mapping, especially of those land uses with a high impact on surface hydrology is important in RWH planning.

There are only few maps of land use for whole catchments. However, it is possible to obtain maps from different sectoral departments showing the location, for example, of mining areas, forest reserves and game parks. By putting together these maps, an initial outline of the land-use pattern in the target area can be developed. The initial outline will form a basis for designing and implementing further data acquisition and mapping.

4.6 Case studies

4.6.1 Siltation of reservoirs in Dodoma

In the semi-arid areas of Tanzania, earth-dams were constructed in the 1930s to 1950s for the purpose of harvesting runoff to control flooding, for irrigation and for domestic and livestock use. These include Matumbulu, Mlowa Bwawani, Ikowa, Dabalo, Mwisanga, Hombolo, Kisaki, Lambo, Buigiri, Mkalama, Manda, Chamwela and Nondwa, all in Dodoma region. All are faced with two major problems:

- High rates of siltation.
- High water losses due to evaporation.

Studies carried out during late 1960s showed that the reservoirs suffer very high rates of siltation leading to 1 – 6% loss of the reservoir capacity per year (Table 4.4). All these reservoirs have lost their economic capacity. Further, nearly 70% of the water in the reservoirs was often lost through evaporation (Rapp et al., 1973). For this reason, the plan to supply Dodoma urban water needs from RWH reservoirs was abandoned in the early 1960s. Dodoma municipality now obtains most of its water from underground resources in the Makutopora depression.

Table 4.4 *Reservoir sedimentation in Dodoma (modified from Stromquist, 1981)*

Reservoir	Original capacity (m^3)	Year of construction	Average annual rate of capacity loss (%)	Estimate of economical life (years)
Ikowa	3,107,000	1957	3.0	30 – 40
Matumbulu	333,000	1962	2.5	35 – 45
Imagi	171,500	1934	0.8	120

Although these problems were identified more than 30 years ago, lessons have not unfortunately been converted into appropriate designs for reservoirs. Yanda (1996) reported the predicament of the Mwisaga reservoir commissioned in 1986 in Kondoa. By 1992, the reservoir had lost 25% of its capacity due to siltation, meaning that at that rate, the reservoir will be rendered uneconomical in 20 years.

Site selection and catchment management should therefore be carefully done when using surface dams for RWH. If it is not possible to change land use on the catchment such that erosion is controlled, surface dam technology should not be used. RWH should in this case be designed for purposes of recharging underground water resources. Further, where siltation has been controlled, it is important to include appropriate measures for controlling evaporation.

4.6.2 Integration of RWH with road and railway drainage system

The construction of roads and railways includes provision for drainage by culverts and/or bridges. These structures are primarily meant to protect the roads and railways from being damaged by water flow. However, concentrated runoff which passes through these structures can either be harmful or useful in the downstream areas depending on how the runoff is managed. This case study provides examples of both.

The situation along Tanga – Arusha highway in Mwanga district is a classic example of erosion hazards resulting from poorly managed runoff from culverts. In this area, there are 55 culverts with no management of runoff. As a result, very deep gullies have formed at the downstream part of every culvert. In some cases, even the road itself faces the risk of being damaged. In addition, attempts by some farmers to make use of the runoff have led to a more disastrous situation leading to destruction of farms by huge gullies due to poor design of diversion canals.

The Lusilile Irrigation Project (LIP) is an example depicting how concentrated runoff from railway culverts has been properly managed and put to economic use. Lusilile irrigation project is in Manyoni District, Singida region. This is one of the marginal areas of Tanzania receiving rainfall of less than 600 mm per year. As such, supplementary water for agriculture is necessary. LIP is one of the irrigation schemes constructed under the Smallholder Development Programme for Marginal Areas. It is located about 16 km from Kintinku railway station (Manyoni direction) and 536.7 km from Dar es Salaam railway station. The scheme has a total command area of 150 ha. The runoff is concentrated by two culverts. A series of canals were constructed including two main canals (350 m long), two secondary canals (3.6 km long), 28 tertiary canals (15.4 km long) and intake wells (SDPMA, 1998). These were meant to divert the water from culverts to the fields. It was estimated that 300 farmers would benefit from the project. However, by 1997/98 only about 145 farmers benefited from the project.

However, for those farmers who benefited from the project, the average yield of paddy rice (the main target crop) increased from 1 to 3.5 tonnes per ha. This is an indication of how the concentrated runoff from the drainage system of railways can be put to economical use. Despite the benefits, there existed some technical problems which reduced the expected benefits. It seems that the technical design was done based on inadequate database of runoff. As a result, some diversion canals were damaged during the El-Nino rains in 1997/98 season.

4.6.3 Use of borrow pits on the Morogoro-Dodoma highway

Borrow pits are common along most of the highways. A combination of the highway surface which serves as a catchment, the road drainage system and borrow pits could constitute a good RWH scheme.

This setup is an important source of water for many communities living along the Morogoro-Dodoma highway. On the Morogoro side of the highway, most of the settlements are by the pastoralist Maasai who established the permanent settlements after tarmac was put on the highway. There is strong evidence that these settlements are partly a result of water availability in the borrow pits. The settlements are spread over the first 70 km from the Msamvu roundabout in Morogoro. There are in total eight pits in which water collects. This is an average of one RWH scheme for every nine kilometres. On the Dodoma side, the pits are used for RWH over the entire stretch of 169 km from the Morogoro/Dodoma regional border to Dodoma Municipality. About 19 pits are used for RWH, which gives the same intensity of about one RWH scheme for every nine kilometres. The following are important observations about the system:

- The borrow pits were certainly not designed for RWH purposes. In fact the regulations of the Ministry of Works require that these should be filled up after the road construction project has been completed.
- Only three of the 27 pits have been modified or improved by the users. Therefore, the users are only opportunistically exploiting the pits perhaps without fully understanding the nature of their performance.
- The road surface is not adequately used as a catchment following the fact that, only one of the pits has been linked to a graded road drainage channel.
- The availability of water along the highway has been an important catalyst to several new permanent settlements by the Maasai.

This case study proves that borrow pits are being utilized successfully as a source of water in the semi-arid areas. The same trend has been observed in nearly all-new highways. These include highways such as Dar es Salaam – Chalinze; Chalinze – Arusha and Mwanza – Shinyanga. Efforts should be made to plan road and highway construction with RWH in mind. Thus, the criteria for choosing the location of borrow pits should include the possibility of future use as storage ponds for harvested water. The road drainage systems should as much as possible be linked to the borrow pits and other water harvesting schemes.

4.7 Planning guide

This guide establishes a checklist for ensuring that there is a good evaluation of the technical factors important in the planning process.

4.7.1 Undertake land resources appraisal

This requires access to existing topographic maps, aerial photographs, remote sensing data and soil survey maps of the target area. This information is available from the Land Survey and Mapping Unit of the Ministry of Lands, and various Remote-Sensing and GIS laboratories in the country.

The scale of maps to be used for this exercise is a critical parameter. For planning at district level, a scale of 1:50,000 is most appropriate. However, if the planning is being done for small sub-catchments, more detailed and larger scales are most suitable.

The available information should be analyzed and if possible built into a computer based GIS. The database can then be used to achieve the following:

- Land use characterization.
- Ecological characterization.
- Identification of catenary sequences and their frequency of occurrences in the target area.

- A scenario for optional allocation of land to meet specific needs e.g. catchment area for runoff generation.
- Land limitation such as areas of low fertility, areas with soil erosion and areas with high risk of flooding.

If the available data is not adequate, it may be necessary to undertake new surveys using conventional as well as participatory approaches. Survey of indigenous knowledge is emphasized as it is a quick way of obtaining an initial appreciation of the existing resources.

4.7.2 Critically assess the potential for RWH

i) The starting point is the identification and quantification of naturally occurring runoff and its current use, through processing and interpretations of hydrological data. The procedure described in section 2.5 for effective characterization of climatic conditions should be followed here to establish adequate hydrological information.

ii) Even when there is potential of harvesting runoff in the local area, that runoff may already be committed to other uses in the downstream areas. The potential for RWH in the local area should therefore be assessed in relation to other water uses in the catchment or basin as a whole. It is therefore important to consult development plans for other sectors, districts, programmes and projects. These will include the regional/basin water master plans and development plans of districts which are located in the downstream of the target area.

iii) Assessment of RWH potential is not complete without a thorough consideration of alternative sources of water to judge the best alternative. These will include RWH alone, a combination of RWH with other sources or another source other than RWH.

This should be done while keeping in mind the philosophy which says " plan how to use available water resources effectively rather than making plans and then starting to look for water".

4.7.3 Evaluate possibilities of integrating RWH into existing or planned infrastructure

- It is necessary to undertake a survey of infrastructural systems found in the target area. This can largely be accomplished by consulting documents and plans of national, district and private infrastructural programmes. Remote sensing can be used where data is not already available.
- Integration of existing and planned social and economic infrastructure require a good understanding of the regulations governing the design, construction and maintenance of the relevant infrastructure. Further, it is important to obtain the opinion and to sensitize relevant institutions and government departments.

4.7.4 Establish a GIS database

- Information collected as described in the previous sub-sections will be useful for the current or future projects if it is built into an existing GIS database or a newly established one (See section 8.2).

- If it is not possible to operate and run an independent GIS system, it will be beneficial to use an already established GIS from nearby universities or research institutions.

Chapter 5

The role of RWH in agriculture and natural resources management: from mitigating droughts to preventing floods

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The basic premise of RWH is to capture, use efficiently and conserve rainwater where it falls. The principal aim is to meet local water needs. Local water needs have a wide spectrum and in most cases domestic water supply will be most predominant. However, agriculture in its widest sense together with the natural vegetation are by far the largest consumers of rainwater. The purpose of this chapter is to raise the awareness of planners on how RWH can overcome water constraints in different sub-sectors of agriculture and management of natural resources. Relevant RWH techniques are also briefly described in relation to the different sub-sectors.

5.1 Rainfed crop production

5.1.1 Policy framework

The goal of Tanzania's overall agricultural policy is the improvement of the well being of the people whose principal occupation and way of life is based on agriculture. Nine specific objectives for pursuing this goal are identified as part of the Tanzania Agricultural and Livestock Policy of 1997 (URT, 1997b). One of the specific objectives is 'to promote integrated and sustainable use and management of natural resources such as land, soil, water and vegetation'.

The rainfed crops sub-sector is the largest and is estimated to account for 63% of the agricultural GDP (World Bank, 1994). Therefore, the goal and objectives of the agricultural sector policy will only be met by paying close attention to this sub-sector. Management of rainwater is perhaps the most important factor although it is given very little mention in the policy. On the other hand, six policy statements cover drought resistant crops and another set of six statements deal with "soil conservation and land-use planning", but water is not mentioned in any of them. It is suggested here that this shortfall should be recognized and rectified in future policy reviews.

The planners at district levels should critically assess the role of rainwater management in crop production improvement programmes. In most cases, soil-moisture constraints are the most important because of the overall soil-moisture shortage coupled with wide variations. These range from shortage of moisture (drought) to surplus (floods) between different periods of the same season or different parts of the same area. RWH can play a major role in mitigating these constraints.

Farmers in semi-arid areas of Tanzania normally lament that *"mvua moja tu, ningevuna"*. That is, the crop would have done very well if only it had received one extra rainstorm. Although this problem is caused partly by inadequacy of the amount, it is often more a result of the fact that, under traditional farming practices, over 50% of the rainwater is "lost" through evaporation, runoff and deep percolation (see also section 2.2.3).

The rainwater management techniques selected to overcome these constraints will depend on the crop, the soil where it is grown, the rainfall characteristics in the area and availability of runoff water from outside the cultivated area. Techniques that can be used are briefly described in this chapter. Readers are referred to technical books and manuals for more detailed description of these techniques (Critchley and Siegert, 1991; Reij et al., 1988; Fraiser, 1975; Dutt et al., 1981; Hollick, 1982).

5.1.2 Capture rain where it falls

Depending on the storage capacity available in the root zone, the first step in RWH is to capture and store rainwater in the soil profile. The next step of equal importance is to prevent or reduce water losses from the root zone. The third step is to implement cultural practices to ensure that crops make the most effective use of the scarce water. Techniques for achieving these have been developed and promoted extensively under the subject of Soil and Water Conservation (Hudson, 1981; GoK, 1997). Unfortunately, emphasis has more often been put on soil conservation at the expense of water management (Hudson, 1992). This trend has been observed in major SWC programmes such as HADO (Case study 5.10.1). Where water management is the main objective, most of the SWC measures can be considered to be in-situ RWH. Examples are given in the following sub-sections.

(a) Improving infiltration

The basic principle for improving infiltration is by loosening soil and creating roughness on the surface. Depending on the characteristics of both the soil and rainfall, the method includes ripping, deep chiseling, surface covers, contour ploughing, (tie-) ridging, and bed and furrow (Lal, 1976; Greenland, 1981). The Land Management Project (LAMP) has recently demonstrated the value of these approaches in improving crop production in Arusha region (Case Study 5.10.2).

(b) Reducing water losses from the root zone

The main source of water loss from the root zone is through evaporation from bare soil and transpiration by weeds. The aim should be to reduce these losses and allow most of the water in the root zone to be transpired by useful crops. There is a strong relationship between crop transpiration and dry matter production. Papendick and Campbell (1988) show that for every one millimeter of water transpired by crops, about 32 kg/ha of wheat dry matter can be produced. Evaporation is the largest source of water losses as described in section 2.2.3. On the basis of the nature of evaporation process, surface cover using mulches and crop canopy will reduce evaporation. However, most mulches will increase evaporation during dry spells by prolonging the first stage of evaporation. Tillage is also an effective way of controlling evaporation by disrupting capillary continuity.

Weeds transpire a substantial amount of water in competition with the desired crop. The best way to visualize this loss is to look at the biomass of weeds produced in a cropped field. This will be equivalent to the loss in the growth of the desired crop. Therefore, weed control is an important soil and water conservation measure. The weeds should be controlled when still very young, so as to effectively control the loss of water.

(c) Improving crop water-use and productivity

Several agronomic practices are used for ensuring that crops use soil-water effectively and productively. These include:

- Selection of crops and varieties having growth patterns which match the soil-water availability patterns of the given locality.
- The adjustment of sowing times so as to ensure that the periods of critical water requirement by plants coincide with the periods of adequate available soil-water.
- A judicious fertilizer use commensurate with the status of soil, nutrient needs of crops, plant population and an available soil-moisture.
- Crop rotation including fallowing for purpose of using the difference in crop characteristics to restore soil structure and fertility.
- Limited supplementary irrigation to carry the crop through a particularly damaging dry spell.

It is necessary to emphasize here that effective utilization of water is important. There are no benefits in investing in practices that make 1000 mm of soil water available, while the crop or variety requires only 500 mm for optimum performance. Equally important is the fact that making soil-water available when soil fertility is very low will result in the wastage of resources. Of course the reverse is also true, that is, applying fertilizers where the soil-moisture is limited. Thus although shortage of soil-moisture is often the important constraint, improvement of soil-water availability will at a certain stage lead to diminished rate of returns due to limitation of nutrients.

5.1.3 Runoff farming

This is the major component of RWH for crop production designed specifically to overcome the problem of low amount and/or poor distribution of rainfall. The collection and concentration takes place during the rainfall event. Since the quantity of water on the target area will exceed the infiltration capacity, ridging, bunding (boarders and dikes) or excavations are applied to provide adequate surface storage to enhance infiltration. This system requires the cropped area to have a high soil-water storage capacity. The most important methods used for runoff farming are briefly described below. The reader is refered to technical books for details (Pathak et al., 1985; Matlock and Dutt, 1986; Critehley and Siegert, 1991; FAO, 1994 and Reij et al., 1988).

(a) Strip catchment tillage

This technique, also known as contour strip cropping, involves alternating strips of crops with strips of grass or cover crops. Cultivation is usually restricted to the planted strips. The uncultivated strips release runoff into adjacent crop strips (Figure 5.1 a). The system is used on gentle slopes (up to 2%) with the strip width being adjusted to suit the gradient. The Catchment Area to Crop Basin Area Ratio (CBAR) is normally less than 2:1. The system is widely practised in many semi-arid areas, although farmers and extension workers may not recognize it as a RWH measure. It is suited to most crops and is easy to mechanize.

(b) Basin systems

This practice is commonly known as the “negarim” micro-catchment technique and is perhaps the best known RWH system. It is also known as the “meskat” system. In this system, each micro-catchment feeds runoff to a discrete cropped basin (Figure 5.1 b). The basin size is typically in the range 10 m^2 to 100 m^2 and is surrounded by an earth bund approximately 30 to 40 cm high. They are particularly well suited to tree crops, but other crops can be grown successfully under non-mechanized farming systems. There is a long tradition of using this system in arid regions (Evenari et al, 1971; Oweis and Taimeh, 1996). Many farmers recognize the natural redistribution of runoff that occurs in the farming landscape and adjust their management to reflect differences in soil-moisture availability.

(c) Semi circular hoops (half moons)

In this system, semicircular pits having radii of about 2 metres are dug and the excavated soil is used to construct a bund downstream of the pit (Figure 5.1 c). The bund height is about 25 cm after the soil has settled. These are normally applied at a rate of about 300 hoops per hectare giving a CBAR of 4:1. The hoops are arranged on lines along the contour and staggered down the slope. Crops are grown in the half circle where the water and nutrients accumulate.

(d) Conservation bench terrace

This method is also known as zingg terrace and is designed to use part of the land surface as a catchment to provide runoff onto level terraces on which crops are grown (Figure 5.1 d). The system works under conditions of gentle slope (< 6%), deep soil, large mechanized farming and CBAR of 1:1 to 2:1.

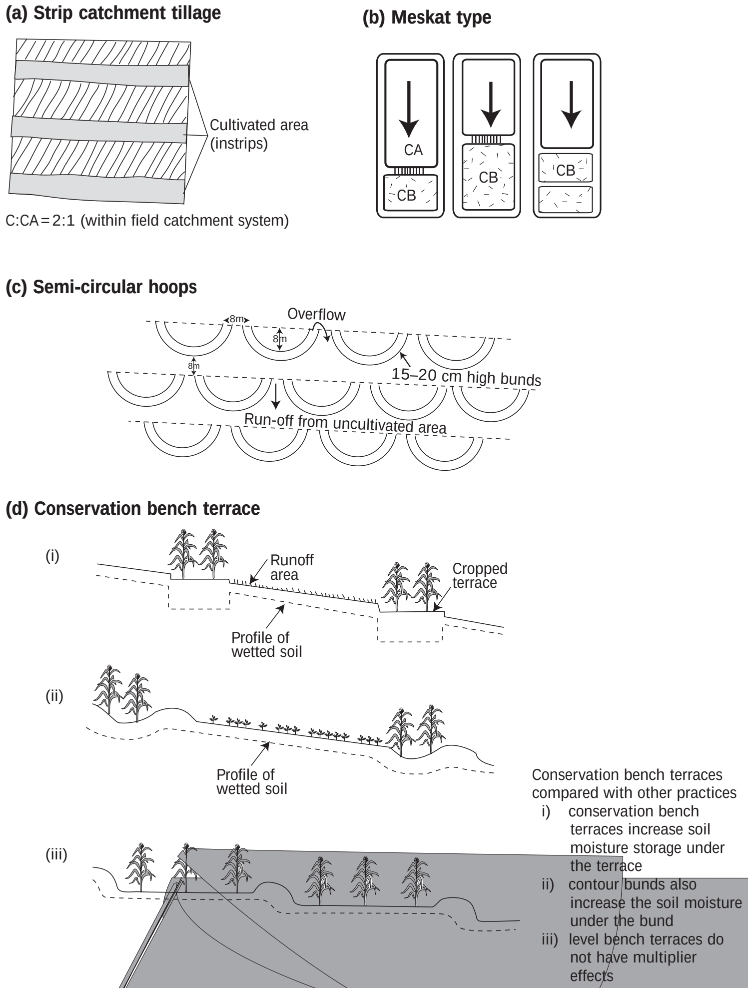

Figure 5.1 *Examp*

5.1.4 Flood

Due to the natur
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important compon
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(a) Cultivated reservoirs

In this system, the harvested water is diverted into cultivated basins where it is and stored. The cultivated reservoirs are constructed by digging the field to a depth of about 0.2 m and the scooped soil is used to build a bund around the field perimeter.

(c) Hillside conduit systems

This is a system for collecting runoff from the hilltops and using stone lined conduits to take the water quickly down to the farms. The main characteristic here is the manner of transferring the water, normally from small catchments. However, the water is used on cultivated reservoirs. The conduits are necessary for taking the water from the catchment down to the cultivated reservoirs with minimum loss by evaporation and seepage.

(d) Ephemeral stream diversion

These systems involve diverting water from an ephemeral stream and conveying it to a cropped area, where the distribution is achieved mainly in two ways. The first uses a cascade of open trapezoidal or semicircular bunds (Figure 5.3 a). Water fills the top basin and spills around the end of the bund into the next basin, sometimes known as the “caag” system. In the second system, the field is divided into closed basins and water is distributed either through a channel or in a basin-to-basin cascade using small spillways (Figure 5.3 b).

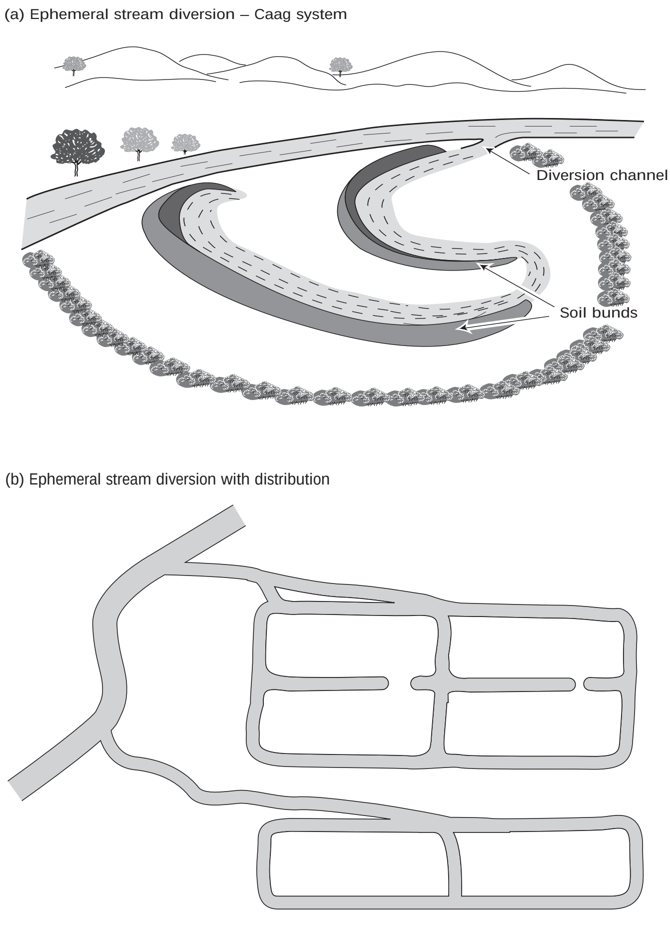

Figure 5.3 *Examples of stream flow diversion techniques.*

The diversion is achieved using structures such as earth bunds, stone walls or brushwood barriers. They are subject to frequent damage and are likely to be washed away by large floods. Attempts to improve such systems by building ”permanent” diversion structures such as concrete or stone-filled gabions have often encountered problems with flows bypassing the structure or with diversion of damaging flows during large floods, as discussed in case study 5.10.3.

5.2 Horticulture

5.2.1 Policy framework

The Agricultural and Livestock Policy of 1997 considers horticulture to include the production of fruits, vegetables, and flowers. The policy puts emphasis on the improvement of quality to meet the needs of export markets. The main focus of the policy is to achieve the following:

- Meet stringent product specifications which include size, colour, variety and other characteristics.
- Meet market requirements, which imply that supply must be regular and dependable.
- Meet shipping schedules, meaning that road transport must be efficient and dependable, and the availability of air or ship cargo space must be adequate and regular.
- Fast and efficient export procedure.

In order to achieve these, the policy aims to ‘enhance productivity of high-yielding and disease-resistant varieties and gives high priority to the strengthening of research, extension and small-scale irrigation’.

5.2.2 Relevance of RWH

In most semi-arid areas, adoption of different types of RWH has gone hand-in-hand with adoption of horticultural production. Apart from storage of water in charcos, reservoirs and cisterns, farmers also exploit the recession moisture by growing crops directly on ephemeral riverbeds or flooded valley bottoms. This is normally done towards the end of the dry season. It is the practice known as “vinyungu” in Southern Highlands of Tanzania. The vinyungu system is a dry season activity undertaken by farmers and it exploits both water and nutrients that accumulate in the riverbeds or valley-bottoms. It provides means for food security and income through sales of vegetables. RWH for horticulture production has been shown to be a very good entry point for the promotion of soil and water conservation practices. This is because in many semi-arid areas, there is a limitation of the sources of cash income. Vegetables often fetch good prices and thus provide good and quick returns on investment in RWH and SWC (Hatibu et al., 2000).

Although moisture stored in the soil can be exploited for horticultural production, storage of water for irrigation is often necessary and an important component. The stored water can be pumped into overhead tanks for the purpose of feeding drip irrigation systems. In order to avoid clogging of the drip lines, it is important that water free of sediments is used. For this reason, RWH from erosion free-catchments, such as roofs, is preferred.

5.3 Livestock and wildlife

5.3.1 Policy framework

(a) Livestock

According to the 1994/95 agricultural census, the livestock sub-sector contributed about 18% of the national GDP out of which beef and dairy provided 40% and 30% respectively (URT, 1996a). The sub-sector as a whole contributed about 30% of the agricultural GDP. The livestock sub-sector is an important source of food in the form of meat, milk and eggs. Further to these, livestock provides manure, skin and hides, and draught power.

The Agricultural and Livestock Policy of 1997 has identified 22 major constraints facing the livestock sub-sector. Two of these are closely related to the role that can be played by RWH. These are:

- Annual and seasonal variations of forage supply and quality, and
- Inadequate seasonal and poorly developed water resources.

These two constraints are shown to be more important for beef production. They are listed as number one and two in a list of 18 constraints. To overcome these constraints, 20 strategies or policy statements are identified in the policy. One statement is directly related to RWH and it states that: 'The government will pay attention and institute specific measures to ensure that livestock have access to adequate water supply. In this regard, the Government will promote and support construction of charcos and/or dams to harvest rainwater which has proven a viable alternative to water distribution.'

Therefore, RWH has its strongest policy support in the livestock and especially beef sub-sector.

(b) Wildlife

Tanzania is a leading country in the world for its wildlife diversity and very high priority is given to the conservation of this world heritage. For example, more than 12% of the land area has been reserved for wildlife in the form of National Parks and Game Reserves. The reservations have very high scientific and heritage values and are also an important source of revenue. Wildlife contributes to revenue through hunting, photography and game viewing by tourists. In 1995, it was estimated that the revenues amounted to US $ 6.4 million (URT, 1996a).

The Wildlife Policy of 1998 states that "*wildlife is a natural resource of great biological, economical, environmental cleaning, climate ameliorating, water and soil conservation, and nutritional values that must be conserved*". Water supply for wildlife is therefore important although it is not directly identified in the strategies (URT, 1998 b).

Shortage of surface water and contamination of available resources have been identified as one of the major problems facing the wildlife sub-sector. The other problems include reduction of areas accessible to wildlife and blockage of migratory routes. Expansion of agricultural and pastoral production has been blamed for causing these problems. However, deeper analysis will show that the main cause may have been the pre-emptive decisions to put large areas under reserves without proper assessment of resource implications, especially in terms of land and water. There is therefore a wide scope for improvement. Rainwater harvesting will play a major role in the solutions to the identified problems.

5.3.2 Role of RWH

Different water requirements for livestock and wildlife have been discussed in chapter 3. During the dry season, which in most cases can be eight months every year, livestock may spend 50 – 70% of the time looking for water. This reduces the grazing time leading to reduced growth and productivity. Construction of small storage reservoirs to reduce the walking distance to a 5 km radius will optimize feeding time and hence livestock productivity.

Relevant RWH techniques for supplying water for livestock and wildlife require storage facilities. The installation of RWH systems for livestock water supply is very widely spread in Tanzania, but there is very little use of deliberate RWH for wild animals. In many parts of Shinyanga, Dodoma, Mwanza and Arusha regions, water storage structures of various sizes have been installed to supply livestock drinking water.

Majority of livestock and wildlife drinking water is obtained from large shallow depressions in which runoff water collects during the rainy season. However, most of these dry quickly soon after the end of the rain. Nevertheless, these are important sources of water for livestock and wildlife, which can also be improved through deepening to increase storage volume and also reduce loss by evaporation. This approach could provide RWH to livestock as well as wildlife. The amount of water involved is very high. For example, a depression which is 100 m long x 100 m wide x 0.1 m deep can collect about 1000 m^3 of water. Without proper management, the water will collect and evaporate several times during the rainy season.

Provision of water for livestock and wildlife has a higher potential for negative environmental impact than for the other uses. Once a water point has been made available, there is a high risk that both livestock and wild animals may overgraze the area close to this point. This in turn leads to high erosion rates, which contribute to the siltation of surface-water storage systems. It is therefore important that adequate land-use planning and stock carrying capacity assessments are carried out as part of planning RWH systems for livestock and wildlife. The water storage facilities and drinking points should be evenly distributed in the grazing area.

5.4 Rangelands

5.4.1 Policy framework

Rangelands in Tanzania include shrublands, grasslands and open woodlands that support domestic and wild animals. Rangelands are found in every district of the country. More than 35% of Tanzania land area can be categorized as rangelands. A high proportion of this land has been put into reserves as game areas and parks.

Rangelands have many uses and produce many benefits of value to the livestock keepers, districts, the nation and the international community. They provide a social, economic and environmental base for the livestock industry, crop production, water resources and tourism. These lands are the source of forage for livestock and provide essential habitat and feed for many species of wildlife. The social, economic and environmental values of these lands are many. Their development, management and conservation is of paramount importance.

The Agricultural and Livestock Policy of 1997 highlights among other things the following major problems in rangelands development:

- Poor management, use and conservation.
- Inadequate, seasonal and poorly developed water resources.
- Poor conservation of water catchment areas.
- Poor water use, management and maintenance.

The following strategies have been identified for overcoming these constraints:

- Collaboration with the Ministry of Water, donors, NGOs and beneficiaries and facilitation and support to development of low cost and sustainable rangelands water development and conservation of water catchment areas.
- Training (through extension service) of traditional livestock keepers on water use management and maintenance.
- Promotion of integrated and sustainable use of rangeland resources such as land, soil, water and vegetation in order to conserve the environment.

Therefore, the existing policy has to some extent identified RWH as an important factor in the development and conservation of the rangelands. The development and management of rangelands should aim at obtaining optimal goods and services for meeting needs while emphasizing on conservation.

5.4.2 Relationship between RWH and rangelands

There is a mutual relationship between rangelands and water resources. Rangelands are the most important catchments which provide for groundwater recharge and overland flow. Consequently, water, soil and vegetation should be maintained in conditions for the optimum yield of clean water. At the same time, water supply in the right quantity, quality and timing is crucial to management and conservation of rangelands. In both cases, several RWH approaches have a role to play as discussed below.

(i) In-situ RWH techniques

These techniques described in section 5.1.2 can be used in rangelands to slow down runoff or increase surface depression storage. Since these usually involve catching and holding water temporarily in furrows or depressions, this can be used to assist germination when reseeding to improve the herbage species composition, or to introduce new species. Examples of the techniques which are suitable for rangelands include; pitting and ripping practices such as micro-basins, tie ridging and strip catchment tillage.

(ii) Water spreading and inundation

Because rangelands are normally vast areas, one useful approach could be the construction of contour ridges using mechanical means. A medium size tractor can construct a kilometer of a ridge in an hour. Diversion systems are also important because certain parts of the land may be covered with stones and rocks. These parts produce runoff which needs to be captured and used appropriately.

The techniques for diverting floodwater from gullies and ephemeral streams into plains described in section 5.1.4 are also applicable to rangelands. The techniques should be used together with spreading and infiltration ridges and ditches to ensure even spread and absorption of water.

(iii) Controlling overgrazing

Overgrazing is one important cause of degradation of rangelands. With a good plan, the location of watering points can play a major role in spreading grazing areas and therefore contribute to the reduction of overgrazing.

5.5 Forestry

5.5.1 Policy framework

Forests and woodlands are estimated to cover 33.5 million hectares or nearly 40% of the land area of Tanzania (URT, 1998 c). Of this, 37% is estimated to be reserved land. Further, about 5% of the forests are in strategic water catchments. Savannah type (Miombo) woodlands, constitute the largest proportion of forests and woodlands in Tanzania.

Forests provide wood for fuel and a wide range of industrial purposes. It also provides non-wood products ranging from fruits, fodder and game, to honey and pharmaceuticals. Forests also provide services that include protecting soil from degradation and erosion, producing a continuous flow of clean water, reducing the danger of flooding, and sheltering crops and settlements.

The National Forestry Policy recognizes sustainability of water sources as one of the key prerequisites for local and national development in the forestry sector. It is for this reason that the policy statements include the following:

- *New catchment forest reserves for watershed management and soil conservation will be established in critical watershed areas.*
- *Water management and soil conservation will be included in the management plans for all protection and production of forests. Involvement of local communities and other stakeholders in watershed management and soil conservation will be encouraged through joint management agreements.*
- *Research and information dissemination will be strengthened in order to improve watershed management and soil conservation.*

5.5.2 RWH for tree establishment

In this section, various RWH techniques are discussed in relation to the management of forests. However, emphasis is on nursery establishment of single agroforestry fruit trees. The techniques include contour bunds, closed micro-catchment, semicircular bunds and macro-catchment RWH with storage. These are briefly discussed below.

(i) Contour bunds for a single tree

These are similar to the contour ridges for crop systems. The difference is that in the system for trees, the harvested water is collected in an infiltration pit.

(ii) Closed micro-catchments

These are square or diamond shaped basins surrounded by low earth bunds on all sides. These bunds or ridges keep rainfall and runoff in the mini-basins. Runoff water is channelled to the lowest point and stored in an infiltration pit where the tree is planted.

(iii) Semicircular bunds

These are earth bunds in the shape of semicircles with the tips of each on the contour. Here again, the runoff water is collected in an infiltration pit. It is possible to apply machinized construction.

(iv) Macro-catchment RWH with storage

Collection and storage of water from external catchment can be used as sources of water for raising tree seedlings. The collected and stored water can further be used for supplementary watering of seedlings from the rain once they are transplanted.

5.5.3 Role of forests in catchment water balance

Many studies have been done in the world to establish the hydrological behaviour of different vegetation cover. Some of the pioneering studies were recently reviewed by Batchelor et al., (1998) and Calder (1994 and 1998). In Tanzania, the most comprehensive studies are those which were done by East Africa Agricultural and Forestry Research Organization, in Mbeya between 1958 and 1968 (EAAFRO, 1979). The experiments produced unexpected results as indicated in Box 5.1.

Box 5.1

It became clear that the expected changes in the hydrological regime of the cultivated catchment were not taking place and that the total sediment loss from the catchment although considerable, was far less than anticipated…

(EAAFRO, 1979)

However, studies from other areas confirmed findings from Mbeya and it is now starting to become clear that forests and trees should be considered as consumers of water. This fact has started to be incorporated into Integrated Catchment Management (ICM) plans. For example, the review of Batchelor et al., (1998) summarized the findings from catchment studies as shown in Box 5.2.

Box 5.2

- Clear-cutting of forests increased both mean and peak flows by about 15%.
- Simulated leaf production and growth led to a reduction in streamflow by between 7–19%.
- Hard wood to pine conversion reduced runoff by 259 mm/year.
- It was estimated that as a result of commercial afforestation, the surface water resources of South Africa were reduced by 1,284 million m^3 per year in 1980 and further reduction down to 1,700 million m^3 per year was expected in the year 2010. This is about 32 % increase in water use attributed to afforestation.

(Batchelor *et al*., 1998)

The results cited above show that other land-use systems can make the land a better water catchment than when the land is under forest, provided these systems are properly managed. Findings of the catchment studies makes sense because transpiration by forests is much higher than other vegetation due to the deeper roots of trees (see section 3.1). Further, rain water that is intercepted and evaporated from forests is also much higher. It is not recommended here that deforestation should be done for purposes of increasing water yields from the catchments. The main point here is to caution the planners that forests are water consumers and should therefore be compared with other uses of rainwater during the planning process. The aim should be to plan for the most optimum productivity of transpired water and reduce losses of rainwater into saline sinks.

5.6 Land conservation and combating desertification

Most of the objectives of land conservation can be achieved through RWH. The message here is that in the semi-arid areas, RWH practices provide nearly all the benefits of soil erosion control but also add another important factor of conserving the scarce soil moisture.

The National Environmental Policy of 1977 (URT, 1997c) has identified six major environmental problems needing urgent attention. The first problem on the list is land degradation. The policy document attributes this problem to inadequate land and water management at various levels. Therefore, prevention and control of degradation of land, water, vegetation and air is one of the six objectives of the policy. In addition, the Agricultural and Livestock Policy focuses on:

- Soil and nutrients conservation.
- Land use planning.
- Husbandry practices.
- Rangelands development.

The two policy frameworks provide a basis under which RWH may be used to assist in meeting the objectives of land conservation. In the semi-arid areas, the ecological situation can be described as “dry with low nutrients”. In this case, the techniques for harvesting both soil nutrients and water, would be the most relevant SWC approaches. The classic approaches that are designed to divert runoff away from arable or rangelands, are therefore not appropriate.

There is no doubt that land degradation through erosion is an important problem in the semi-arid areas. However, the real problem is now considered to be the loss of productivity rather than that of soil alone (Stocking, 1988). This has led to current emphasis on land husbandry approaches under which soil-water management and its effective utilization by plants is given higher priority.

5.7 Controlling floods

5.7.1 The situation

Despite the overall low amount of rain in the semi-arid areas, it falls in intense storms that often lead to flooding. Flooding in Tanzania is therefore a seasonal phenomenon occurring in localized areas. Flooding is defined as a significant, sudden or gradual rise in water levels of rivers, lakes, streams and waterways, such that the excess overflows to surrounding areas. Consequently, rivers and lakes burst their banks causing damage to property, infrastructure, and crops. Flooding may sometimes lead to loss of human life. Ironically, most devastating floods are caused by heavy rains which occur after long periods of drought.

It is estimated that about 38% of the past disasters in Tanzania have been caused by floods (URT, 1998 a). The most recent flooding occurred during the 1997/98 El-nino rains. As a result of these floods, it was estimated that nearly US$ 200 million worth of damage to the infrastructure occurred. The catastrophic floods which affected the Southern Africa countries of Mozambique, Swaziland, Botswana, Zimbabwe and South Africa in 2000, remind us of the seriousness of this threat.

5.7.2 The role of RWH

The two basic approaches to flood control are based on RWH principles already described in this handbook. These approaches are:

- Maximum infiltration and holding of rainwater in the soil where it falls.
- Building dams and reservoirs to store peak floods.

In situ RWH harvesting techniques help to reduce the amount of water reaching waterways, streams, rivers and lakes, thus reducing the risk of flooding. Vegetation cover is particularly necessary to increase the rate of soaking. It is very difficult for water to infiltrate into bare ground. It is for this reason that a rainfall event occurring immediately after a long drought, causes flooding. When used to keep vegetation growing during the dry season, RWH will therefore contribute to flood control. Terracing, contour ploughing and other means of in-situ RWH will also reduce runoff amounts and flooding.

Reservoirs provide a large storage capacity in which floodwater can be impounded for gradual release. Most damaging floods result from busting of narrow rivers and streams that fail to accommodate rising floodwaters. The reservoirs help because the rate of rising of water level is very slow in a reservoir or lake, due to a relatively large surface area. Because many floods are just flash waves, all the floodwater can be stored in the reservoir and safely released before the arrival of the next flood wave. It must be emphasized that controlling floods by use of reservoirs will make more economic sense if the reservoir is also used for other purposes as discussed in section 5.9.

5.8 Groundwater recharge

The main reason for water shortage in Tanzania is that during the rainy season, rainwater is quickly lost by evaporation and runoff into saline sinks. Storage of water by different means is therefore necessary to meet water needs during the dry season. Rainwater harvesting combined with storage in shallow aquifers has a big role to play (see section 3.3 for details).

5.9 Storage of harvested water

The need for storage will in many cases be dictated by characteristics of both the runoff and the intended use of water. However, the most important limiting factor would be the cost. Viability of RWH schemes is in fact normally lowered if there is a need for large and long-term storage of water.

There are mainly three most important decisions that a planner will be faced with:

- Is storage necessary?
- What storage methods and size should be used?
- How should problems associated with storage systems be avoided?

5.9.1 When is storage necessary?

The intended use of harvested water is the most important determinant of whether storage is necessary or not. As already discussed in the previous section, RWH for flood control requires storage. If water is being harvested for purposes of supplying water for livestock or game, then it is necessary to have storage facilities. The next type of use where storage is necessary, is in vegetable production. Finally, storage, other than in the soil may be required for arable crops. In most cases, storage outside the growth medium is not necessary for land conservation, range development, forestry or ground water recharge.

Another determinant of the need for storage is the frequency of rainfall. If the rain is received over a very short period and rainstorms are interspersed by long dry spells, then storage of the harvested water becomes important even for trees and arable crops.

5.9.2 What storage methods should be used?

If it is necessary to store water then decisions will be required on suitable storage methods. The most common methods are briefly described in this sub-section.

(a) Excavated bunded basins (Majaluba)

Excavated bunded basins or *majaluba* is one of the methods of runoff utilization, management and storage for the production of paddy rice. *Majaluba* are constructed by digging to a depth of about 0.2 to 0.5 m and the scooped soil is used to build a bund around the field perimeter. Normally the bunds have a height of about 0.3 to 0.7 m above the ground. Farmers normally start with small sized *majaluba* of for example 10 m x 10 m finally culminating into large areas of about 1 ha. This system is widely used in all semi-arid areas of Mwanza, Shinyanga, Tabora, Singida and Dodoma regions, which have now become the most important producers of paddy rice, in Tanzania.

(b) Excavated pits or ponds

Excavated pits or ponds are sometimes called charco-dams and are constructed in relatively flat topography. They are used to a very large extent in Shinyanga region for supply of both livestock and domestic water. They are also found to a lesser extent in Dodoma, Arusha, Tabora, Singida and Mwanza regions. The design is simple and can be implemented at village level with minimum engineering input. For high efficiency in water collection, the pond should be sited at the lowest point of the topography. The point can be selected using contour maps of the area. If contour maps are not available, selection can be done by observing where water collects naturally (see also section 5.3).

(c) Sub-surface sand dams

Sand is a very good medium for storage of water. Therefore, where deep sand can be found, it is cost effective to consider the possibility of sub-surface sand dams for the storage of the harvested water. A sub-surface dam is a wall constructed across the stream to restrict sub-surface flow. It will be cost effective if the structure can be integrated with a drift for river crossing purposes. It should go down to the impervious layer below the sand. The water in the sand dam can be reserved for a long time due to low evaporative losses. Technical manuals are available explaining in detail how to construct this kind of dams (Nilsson, 1984; Nissen-Petersen and Lee, 1990)

(d) Low- earth-dams (Malambo)

This method of storage can be used in a more rolling topography. The water requirements together with the necessary allowance for expected losses will determine the size of the dam. The dam can be constructed to collect water from less than 20 km^2 for a steep catchment to 70 km^2 for flat catchment. The purpose of the dam should be clearly defined as the first step in planning. The following are the main questions to deal with that will define the purpose:

- Will the storage be required through out the year or only for few months?
- Who are the targeted stakeholders?
- Can the reservoir be anywhere?

Several earth dams have been constructed especially in Dodoma, Shinyanga and Pwani regions. This is therefore a common system of RWH in semi arid areas of Tanzania. Some of these are medium-scale reservoirs for the purposes of urban or irrigation water supply.

(e) Regulating reservoirs

When the soil is used as the storage medium, there are risks involved with directing runoff into crop fields. Many farmers have shown reluctance in adopting RWH because runoff amount and timing is difficult to predict. Farmers often make diversion channels to their fields, but when the flash floods arrive, they are sometimes too much leading to devastating damage of the fields. Using reservoirs to store and regulate the flash floods can minimize this problem.

A regulating reservoir is designed with a capacity to store the flash floods from a single day's rainfall. However, the reservoir is provided with a permanent water outlet that releases water at a flow rate of minimum risk to the spreading bunds installed in the fields. The stored water drains away continuously until the reservoir is dry in a day or two, ready to receive the next flash floods. An adequate spillway must be provided to guard against the collapse of the dam. It must be emphasized that should the dam collapse, the damage caused by the water will be far greater than whatever damage the original flash floods were capable of. Thus, this construction should be implemented with the necessary precautions. The paramount prerequisite is that qualified and experienced engineers should be in charge of the design and construction.

5.9.3 Problems associated with storage of water

Storage of water both in surface and sub-surface structures is associated with special problems. The most important problems are costs, siltation, evaporation and seepage losses, and health hazards. These must be addressed during the planning stage.

(a) Cost element

Storage will, if necessary, add to the cost of the scheme. Costs vary with the type and size of the storage structure. The main cost components are:

- Construction of the storage structure: part of capital or investment costs. For example a dam or reservoir will require earth movement. This is the key-determining factor of the cost.
- Regular operating, maintenance and repair costs of the storage structure, which include labour, spare parts, transport and desilting.

Before a decision to include storage reservoirs is made, it is important to assess availability of appropriate sites where the necessary earth movement will only be minimal. The proportion of total project costs due to storage is also variable and will depend among others, on type and size of storage structures.

(b) Siltation

Many earth dams in central Tanzania have been rendered useless by siltation. Silt accumulation in a reservoir leads to loss of storage capacity and reduction of useful lifetime of the reservoir. Siltation should be reduced to minimum possible levels because it is not economical to remove silt once it has accumulated. This is because the volume of silt to be removed will often exceed the volume of earth works necessary for the construction of a new dam. However, this is dependent on there being an alternative site nearby for a new dam. The main cause of this problem is erosion in the catchment area. It is necessary therefore to develop plans for managing the catchment area so as to ensure that runoff is produced with minimum erosion. The most important issues to be observed to achieve this, include:

- Choice of the catchment.
- Land use in the catchment.
- Silt traps in the water harvesting system.

It is important to make a good estimate of the sediment load in the water to be harvested. A factor called sediment trap efficiency of the reservoir can then be used to predict siltation rate. This data is necessary for designing dead storage and for estimating the life span of the reservoir.

(c) Evaporation

This is the most critical problem associated with surface storage of water. In the semi-arid areas of Tanzania, evaporation from the open water surface can reach 10 mm/day. This means that where the dry period with no rainfall is six months, about 1.8 m of water will be lost to evaporation. From the cost point of view, this will mean investing in nearly 2 m of the dam wall just to satisfy evaporation (See box 2.2).

Several methods for controlling evaporation have been developed. Reducing the surface area volume ratio by using deep storage reservoirs is a good method of reducing evaporation. This approach can be improved by dividing the reservoir into two or more compartments. During the dry season, water is only drawn from one compartment until it is depleted. If three compartments are for instance used, the evaporation rate will be reduced by 33%, and after depleting water from the second compartment, evaporation will be reduced by 66%.

Shading the water surface from wind and direct sun can also reduce evaporation. It is possible to reduce the rate of evaporation by 50% through a combination of wind breaking and shading. Bush rafts built using logs, tree branches and twigs are good covers (Figure 5.4). They are easy to make and will cost appreciably less as compared to other means such as netting.

d) Seepage

This is another common problem faced in storage systems. The main factors contributing to this problem are the soil type and the amount of compaction of the embankment. To reduce the extent of this problem, sites with sand and gravel should be avoided during site selection. Seepage can be reduced by compacting the reservoir floor by driving wheeled tractors several times over the surface or puddling by cattle while the soil is moist. Addition of clay soil or manure before puddling assists in significant reduction of seepage. Appropriate level of compaction of the dam wall is very important. Seepage through the wall increases the risk of breaking and failure of the wall.

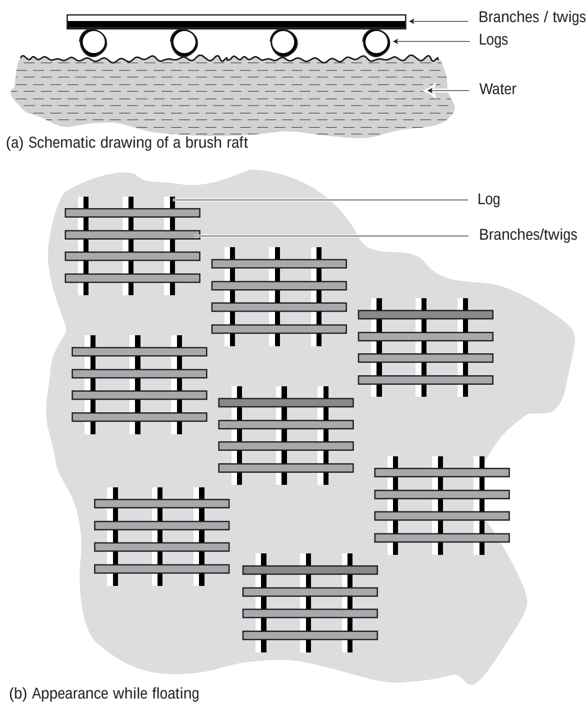

Figure 5.4 *Schematic drawing of evaporation control using brush rafts.*

(e) Health hazards

Storage of water is associated with health risks, such as spread of waterborne diseases or disease vectors and pollution. Creation of vector habitat and increased incidence of diseases is likely to occur following the construction of rainwater surface reservoirs.

The common diseases linked to the storage of water are malaria and schistosomiasis (bilharzia). A low flow regime in RWH may lead to ponding in the canal bed providing suitable sites for malaria vectors. Where water availability permit, periodic flashing has been successful in reducing the risk.

Reservoirs constructed for storing domestic water are also used by livestock or vice versa. There are possibilities for the livestock to contaminate the water by zoonotic diseases and dip chemicals. In addition, if high levels of nitrates are allowed in a reservoir used for drinking water, this may lead to human illness.

5.10 Case studies

5.10.1 Hifadhi Ardhi Dodoma

The Hifadhi Ardhi Dodoma (HADO) project was launched in 1973 by the Government of Tanzania with financial assistance from Sida. HADO was implemented in three geographically separate areas in Dodoma region; the Kondoa Eroded Area (KEA) in Kondoa District; Mpwapwa District; and from 1986, in Mvumi division of Dodoma rural district. Initially, conventional mechanical technology and methods such as graders and other machinery were used to construct soil bunds to stop erosion and plug gullies. However, the project activity with the most visible effect on landscape has been the enforcement of the expulsion of all livestock which was first instituted in the Kondoa Eroded Area in 1979. This activity facilitated the regeneration of seriously degraded rangelands. The other major project activities included direct and indirect support to reforestation and soil conservation.

The major part of HADO activities involved tree growing and physical soil conservation measures. Several hundred hectares of woodlots were established centrally by the project. During the final years, the project concentrated more on supplying seedlings from the project-operated nurseries. The HADO activities can be summarized as follows:

- Enforcement of complete de-stocking of livestock from KEA and other grazing by-laws to allow regeneration of vegetation.
- Erosion control through the construction of physical structures, especially cutoff drains and gully plugging – unfortunately using paid labour.
- Promotion of reforestation by operating tree nurseries, including planting and maintaining woodlots.
- Extension, education and training.

An evaluation of HADO undertaken in 1995 by Sida and the Ministry of Tourism and Natural Resources a, provided examples of some interesting weaknesses (MTNR/ Sida, 1995).

i) The objective and strategies of HADO were oriented towards land rather than the people in the project area.
ii) The work on croplands was focused on water runoff disposal and addressed important rainwater productivity aspects only in marginal ways.
iii) Key extension messages were rather traditional, for example improved seed and row planting. Soil-water management did not figure prominently among the messages.
iv) Many of the gully reclamation structures have failed due to poor construction or maintenance and gully development could be observed to still be continuing in many places.
v) To date, there has been very little follow-up to determine the survival rate of thousands of seedlings distributed free to villages, schools, other institutions and individuals.
vi) The emphasis on the “fanya chini” contour ridging may reflect the limited soil conservation training that the HADO staff, who all came from a traditional forestry background, have received.
vii) In Dodoma region, crop yields are reduced more by shortage of soil-moisture rather than by loss of soil. Hence, there should have been more emphasis within HADO on rainwater management within the croplands rather than erosion control.
viii) On-farm soil and water conservation measures promoted by the project over the last twenty years have done very little to increase land productivity within the crop lands.
ix) There is need for changing the strategy from a narrow focus on erosion control, to a broader “holistic” land husbandry approach.

This is an incredible verdict, especially given the fact that the review was commissioned by the main promoter, MTNR and the main funding agency, Sida. The HADO experience provides good lessons for planning land use and water resources programmes. These lessons are yet to be synthesized fully, but planners of RWH projects should make efforts to access and read the materials on HADO. One good lesson which can be drawn from the review conclusions given above is that HADO suffered from lack of clear and integrated policy direction. As a result, what should have been a multi-sectoral and multi-disciplinary project was dominated by only one sector. There is no evidence of a thorough planning stage, which took into consideration all the alternatives and screened them vigorously. In planning land resources programmes, the emphasis should be on enabling the people to manage soil, water and vegetation resources in ways which enhance conservation while increasing productivity.

5.10.2 Land Management Programme (LAMP)

The Land Management Programme (LAMP) works in three districts namely: Babati, Kiteto and Simanjiro, in Arusha region. These districts are characterized by a bi-modal rainfall pattern and may be grouped as semi-arid. The average annual rainfall for Babati, Kiteto and Simanjiro are 790, 609 and 487 mm respectively (Johnsson, 1996). Rainfall distribution is highly irregular. LAMP operates as a funding agency rather than a conventional development project, and is jointly undertaking between the governments of Sweden and Tanzania. The Babati District Council is the implementing agency with technical support from ORGUT. Activities under LAMP started in 1991. The LAMP support is guided by the overall objective of increased productivity in the use of natural resources in a sustainable way. The main thrusts under LAMP messages include dryland farming techniques which incorporates conservation tillage, soil fertility management (crop residues, FYM, rock phosphate), post harvest practices, agro forestry and improved livestock management (grazing, feeding/zero grazing).

By Tanzania standards, mechanization of agricultural activities in Babati is above average and has been so for over 30 years. Studies conducted in Babati by the Babati District Council (BDC, 1994) revealed the following statistics. There are 538 tractors and 276 trailers. In addition, there are planters and 544 tractor ploughs. Animal ox-drawn ploughs numbers about 6,000.

Land productivity has been declining and soil moisture deficit was identified as the cause. Conventional soil and water conservation techniques e.g. ridging did not solve the problem. Experts later found out that a plough pan had developed in most crop fields due to frequent ploughing and post harvest grazing. This restricted percolation and therefore stored profile moisture.

A survey in 1994/95 revealed that the compacted soils (plough pans) were a major cause of the low crop production in the Babati District and the other LAMP target areas. Neither rainwater nor roots could penetrate the soils. The conventional soil conservation measures, which could only reduce the symptoms, (runoff and the erosion) but did not eliminate the major cause, which was the compacted soils. It was evident that soil conservation measures must be complemented by a conservation tillage system, which could restore the damage soils caused by frequent ploughing and post-harvest grazing. Deep tillage with tine implements was tried with very positive results (tripling of yield compared to ploughing in 1995/96).

To illustrate the impact of the programme, maize production before and after LAMP activities is shown in Table 5.1. Maize is the dominating crop and covers 38% of the cropped land under LAMP. From Table 5.1, it is evident that there has been a substantial increase in the productivity as both crop yields (kg/ha) and rainwater utilization efficiency (kg/ha/mm rain) showed positive trends.

Table 5.1 *Maize performance in Babati District*

Season	Kg/ha	Kg/ha per mm of rain
1990/91	912	1.49
1991/92	1,141	1.80
1992/93	1,220	2.03
1993/94	1,200	2.37
1994/95	1,933	2.30
1995/96	2,000	3.13
1996/97	1,818	4.07

Since 1990/91 around 5,000 ha of land have been treated with some kind of soil conservation measures. There are both short-term and long-term benefits with the recommended soil conservation techniques promoted by LAMP. It is estimated that the average land with soil conservation treatments can produce 50% higher crop yields compared to just ploughed land without these treatments. Farmers claim that the reduction in rainwater runoff keeps applied seeds and FYM from being washed away. A major positive effect of soil conservation in Babati District is the slowing of the speed of the runoff water on the compacted soils. This reduces the erosion damage and improves rainwater utilization efficiency. It is estimated that the production increase from the soil and water conservation measures accounts for 3% of the total production of the four major crops.

5.10.3 Flood water harvesting in Smallholder Development Project for Marginal Areas (SDPMA)

SDPMA is one of the IFAD funded projects in Tanzania which became operational in 1990/91. The project aim is to improve household food security and income of smallholders in the drought prone regions of Dodoma, Singida, Tabora, Shinyanga, Arusha and Mwanza. The project has components:

- Smallholder irrigation development based on RWH,
- Strengthening extension services,
- Land survey and registration,
- Credit, and
- Project management.

In the first phase (1991 – 1997), the irrigation development component was designed to establish about 25 – 30 RWH irrigation based schemes. About 4,000 ha of marginal lands was planned to be developed for 8,000 farm families (Gallet et al, 1996).

The main activities included construction of:

- Diversion of small rivers or streams (catchment area of 500 km^2 to 2000 km^2) using gabbion or masonry weir,
- Main canals and distribution system,
- Flood protection embankments and drainage systems,

- Land levelling and demarcation of 0.5 ha plots for cultivation by individual farm families, and
- Access roads.

Several internal and review reports have been produced (Kajiru et al., 1998; SDPMA, 1998; SDPMA, 1996; URT, 1995 a; Gallet et al, 1995; Sebyiga et al, 1995).

The project was successful in installing flood diversion and distribution structures for 18 schemes compared to the target of 25. Because most of these schemes were being implemented in areas where RWH for paddy production was common, the rate of adoption was high. It is reported for example that tail-end plots have been developed in some schemes leading to an area coverage of 108%. It is noted that achievement of the programme includes increasing the yield of rice in RWH systems (majaluba) from 1 ton/ha to 4 tons/ha.

However, most of the structures were damaged during the El-Nino rains of 1997/98. The damage included:

- Washing away of canal embankments,
- Deposition of silt and mud along the canals,
- Destruction of intake and weir structures,
- Washing away of protection bunds and the entire canal sections,
- Destruction of intake resulting in the river changing its course, and
- Destruction of canal networks.

These are major lessons to be learned from what happened during El-Nino rains. Floodwater harvesting is a risky business especially where very limited or no data is available to make predictions of flood levels. Long-term water resource databases need to be analyzed and incorporated as part of the project plan.

Project implementation was delayed for a year because of delayed procurement. Time allowed for this activity was one year but it took two years. Due to this delay, tax regulations had changed leading to further delays. The project had to undergo long processes of applying for tax exemption which would otherwise have not been necessary. Planning for ample time to procure of equipment or machinery and disburse of funds is therefore very crucial.

The project was negatively affected by the focus on the “poorest of the poor”. This meant that the project did not initially target farmers already experienced in the production of rice, as these were not considered to be the “poorest of the poor”. In Bahi village, one of the target villages it was found that the majority of the targeted people did not cultivate the plots allocated to them (Hatibu et al., 1997).

5.11 Planning guide

5.11.1 Understand the overall policy framework

- This chapter has made it clear that RWH can play a very crucial role in water supply of nearly all sub-sectors of agriculture and natural resources management. However, the policy framework does not fully recognize the roles that RWH can play. The planners should therefore undertake an analysis of several related policies. This is in addition to dialoguing with policy makers to ensure that the RWH programme is fitted in existing policies.

- For the programme to be successful, it must be shown that it is the best approach to fulfilling elements of policy. Thus, the analysis of policies should produce cause-effect relationships to clearly show the linkages between RWH and key elements of relevant policies. This approach will increase confidence and support for the proposal to implement RWH.

- Sensitize policy makers and target beneficiaries at all levels to ensure adequate support. This should start by aiming to raise awareness that rain is water and the need to adjust policies and strategies around this philosophy. Aim for development of a supportive policy and political environment.

5.11.2 Select appropriate RWH techniques

- The main focus of rainwater harvesting should always be to utilize efficiently and effectively rainwater which would otherwise evaporate or flow into saline sinks. This should be the basis for selecting RWH techniques for a given location and purpose.

- Selection of the most appropriate techniques depends on prevailing conditions in the target area. The available data should be used together with modelling and GIS approaches to select the most appropriate techniques.

- Despite its many positive attribute, RWH is not a panacea for all the water problems in agriculture and management of natural resources. The technology is just one element of land and water resources management.

PART THREE

Information technology and socio-economic aspects in the planning of RWH

Chapter 6

Fitting RWH into the socio-economic environment: ensuring acceptability and sustainability

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In planning for rainwater harvesting systems, it is not enough to just consider the technical aspects but also the socio-economic environment. The most important components of socio-economic environment are: policy and legal frameworks, local institutions, equity aspects and cost and benefit relationships. The objective of this chapter is to guide planners in the identification and integration of these socio-economic factors into development and production plans incorporating RWH.

6.1 Policy and legal framework

In planning and designing RWH, consideration should be placed on the existing policies and laws that govern various land-use practices such as reserved lands, agriculture and infrastructure. Policies of different sectors where RWH has a role to play have already been discussed in chapter 5.

In this section, policy and legal frameworks which governs the land tenure, water rights and public infrastructure are discussed in relation to RWH.

6.1.1 Land tenure

Land tenure is an important consideration in RWH planning, mainly because it plays a critical role in investments that are related to land use and natural resources management practices. Land tenure is a system of land ownership or acquisition governed by the land laws, land policies and customary land ownership systems that are prevailing. Land tenure is therefore related to rights of occupancy as described in section 6.1.2. In Tanzania, the National Land Policy of 1995, the Land Act of 1999 and various customary land tenure systems (URT, 1999; URT, 1995 b) specifically govern tenure. The policy points to the need for having a clear land tenure system as an important factor ensuring both optimal and sustainable use of lands.

Since RWH involves long-term investment, long term and secure tenure system is desirable. According to the land policy, all land in Tanzania is public and vested in the President as trustee on behalf of all citizens. The land categories as identified in the policy and the act are general, reserved and village, as elaborated below. The President may, by the provision of the land act and the order published in the government gazette, transfer or exchange land from one category to another.

a) General land

This refers to public land that has not been allocated to either reserves or villages. It includes unoccupied or unused village lands. The Commissioner for Lands, on behalf of the President does the allocation of this land according to other categories. This is a potential land category for RWH investments.

b) Reserved land

According to the Land Act of 1999, reserved land is the land reserved, designated or set-aside under different legal provisions. These include:

- Forest Ordinance (Cap 389)
- National Parks Ordinance (Cap 412)
- Ngorongoro Conservation Area Ordinance (Cap 413)
- Wildlife Conservation Act, 1974
- The Marine Park and Reserve Act of 1994
- Town and Country Planning Ordinance (Cap 378)
- Public Recreation Ground Ordinance (Cap 320)
- Highway Ordinance (Cap 167)
- Land Acquisition Act, of 1967

The reserved lands can be integrated into RWH systems as catchment to produce runoff. Examples include forests, national parks, wildlife reserves, towns and built-up areas, public recreation grounds and roads infrastructure. During the planning stage, reserved lands could deliberately be those in higher grounds to facilitate runoff.

Reserved lands can also be integrated as area of use in RWH systems. Here too, example include RWH for forest, wildlife and domestic use. However, it is important to note that the reserved lands are governed by different legislations, and therefore require careful integration to RWH systems.

c) Village land

This is under the jurisdiction of the village councils. Village land will continue to be vulnerable to change of hands including land transfers through, for example; allocation by village councils, land transfer by the state and villagers giving land rights to others through selling. Where surveys have been done, the Commissioner of Lands issues certificates of occupancy. The certificate gives the village council land management and administrative powers. According to the land law, the certificates of customary rights of occupancy will be equal to statutory rights of occupancy in law.

In planning RWH systems for rural areas, village land will be the most important category to consider. There are several by-laws at district and village levels which govern the use of such land. These should be studied and taken into account during planning.

For example, the Same District Council by-laws on prevention of soil erosion and water conservation (1986), stipulates that:

- No person shall cultivate, cut any tree, grass or graze animals on any prohibited area.

- Any person who cultivates on any preserved or restricted area shall obtain a written permit and comply with the conditions endorsed on the permit issued.
- Any person cultivating on any restricted area which is a slope or valley, shall for the purpose of preventing soil erosion and conservation of water, cultivate and maintain terraces and shall erect hedges if he is required to do so by an agricultural or authorized officer.

6.1.2 Right of land occupation

According to the Land Act of 1999, there are two types of land occupancy; a granted right of occupancy and the right derivative of a granted right of occupancy called derivative right. A granted right of occupancy shall be:

- granted by the president,
- in general or reserved land,
- of land which has been surveyed,
- required to be registered under the land registration ordinance to be valid, subject to provision of that law and the Land Act, 1999,
- for a period of up to but not exceeding 99 years,
- at a premium,
- for an annual rent that may be raised from time to time,
- subject to any prescribed conditions,
- capable of being the subject of dispositions,
- liable, subject to the provisions of this act, to revocation, and
- liable, subject to prompt payment of full compensation, to compulsory acquisition by the state for public purposes.

Derivative rights refer to a residential licence, conferring upon the licensee the right to occupy land in non-harzadous, urban or peri-urban areas for a period of time for which the residential licence has been granted.

6.1.3 Water resources

The water policy of 1991 as amended in 1996 and the Water Act of 1974 as amended in 1977 and 1981 govern water resources. The policy recognizes rainfall as one source of water. The policy further acknowledges that most rainwater is lost uncollected, which could have been used effectively to provide services to the people. The policy further recognizes that RWH is one way of improving both domestic and livestock water supply (URT, 1991; URT, 1981; URT, 1974).

The water policy put the following emphasis on RWH:

- Construction of small and large reservoirs in semi-arid areas,
- The use of rooftop RWH,
- Provision of technical knowledge to the public on the use of small and large reservoirs, and
- Strengthening rainfall data collection.

Water rights for different uses are explained in the Water Utilization Act of 1974 (as amended in 1981). The most important features are that;

- all water is vested to the United Republic.
- the water officer may grant the right for any person to divert, dam, store, abstract and use water from such sources, in such quantity, for such period, whether definite or indefinite and for such purpose as may be specified in the water right, subject to such terms and conditions as he may deem fit.

6.2 Local institutions

The identification of institutions should be done with the objective of understanding their roles with respect to RWH. Institutions can form a useful entry point for a project and can be very instrumental in advocacy of RWH. They can also be used in the implementation of the plans. For example, these institutions can participate in construction and management of RWH structures, which are labour intensive, but for the benefit of the community. The kind of questions which the planner needs to ask are; will the existing institutions hinder or promote RWH? Will there be a need for special institutions to promote RWH?

Four main categories of institutions can be identified:

- Local government.
- Central government.
- Community-based organizations.
- Non-governmental organizations.

6.2.1 Local governments

These are formal institutions which were established following the Local Governments (District Authorities) Act of 1982 (URT, 1982). These institutions include district governments, ward development councils, and village councils. They are important institutions in providing respective guidance on local by-laws and management of the projects.

6.2.2 Central government institutions

Central government institutions are all those that operate as state organs. Examples are courts and public schools. They are important in providing respective policy guidelines and management of projects.

6.2.3 Community-based organizations (CBOs)

These are formal and informal organizations which are formed through the community initiatives. The formal organizations are normally registered under the co-operatives regulations or laws and have constitutions. Informal organizations includes labour-sharing groups, women groups and youth groups. These groups do not often have constitutions and are not registered.

6.2.4 Non-governmental organizations (NGOs)

These are institutions which are usually registered through the Ministry of Internal Affairs. They include international and local organizations. The mode of operation of NGO's is often based on participatory approaches. NGOs normally have a good and deep insight on the local conditions as well as needs and aspirations of their target beneficiaries. It is therefore important to identify such institutions and collaborate with them during the planning process.

6.3 Equity

Equity is a term used here to refer to fairness especially in distribution of resources and benefits from economic activities. It is important to include equity issues in planning of projects so that;

- The introduction of a new project should not create inequality, for example in ownership of resources.
- If inequality already exists in a given area, the plan should aim at correcting it.

The inequality can be between individuals in society, between men and women or between leaders and the rest of the society. While including equity issues, planners should also take into consideration, optimal utilization of resources, especially water. In many areas, farmers use water for rice cultivation in a catena. The farmers construct the rice bunds (majaluba) across the catena, at the top, middle and bottomlands. However, the soil at the top of the catena is not favourable for rice production as that at the bottom. Thus despite equitable distribution of water among themselves, rice production at the top is lower than at the bottom. This results on average, into lower rice yields. Thus although water distribution is equitable, it is not used optimally.

The planners therefore aim at finding a balance between equitable distribution and optimal utilization. Equity in this section is discussed in terms of income levels, gender relations, upstream and down stream relationships and tree–crop–livestock interactions.

6.3.1 Income sources

The introduction of RWH in an area will change both income sources and levels. The income will change as a result of adopting different farm enterprises as well as income emanating from increased services such as processing and marketing. The plan of RWH should provide guidance to ensure that there is fairness in the distribution of increased income.

6.3.2 Gender relations

Gender refers to the qualitative and independent character of women and men's positions in the society. Gender relations are constituted in terms of the relations of power and dominance that structure the life chances of women and men. The essence of considering gender relations in planning is to:

- determine the division of labour between women and men,
- assess the impact of this division of labour on time allocation for different economic activities, and
- assess the ownership and control of resources between women and men.

Introduction of RWH can result in labour input differential between men and women. The identification of such differences will guide the planner in the design of RWH without creating imbalances. It will be useful in the identification of the providers of labour, potential beneficiaries and owners of the project.

6.3.3 Upstream–downstream relationships

RWH depends on slope differentials in water flow. The water usually flows by gravity from steep to relatively gentle slopes. The longer the distance between the steep and gentle slope area, the more the need for consideration of equity aspects. Such equity is in terms of the use of water harvested in the relative up-stream and down-stream parts of the target area. The upstream farmers may be using more water and deny the downstream farmers. On other hand, upstream farmers may fail to control water flow thereby destroying farms of the downstream farmers. All these aspects should be very well understood during the planning stage so that they can be controlled effectively.

6.3.4 Tree–crop and livestock relationships

Crop producers, livestock keepers and tree growers co-exist and sometimes are the same people. Conflicts are likely to occur between livestock keepers and agricultural crop producers, with the former destroying RWH structures on crop fields. RWH programmes should take into consideration the interests, needs and rights of all groups. This is because water is an important resource for trees, crops and livestock. Care must therefore be taken to have a fair distribution.

6.4 Cost and benefit relationships

Costs and benefits relationship is important in the adoption of improved RWH techniques. Decision of farmers to adopt RWH like any other investment decisions on the farm, is driven by profit motive. Assuming that farmers have enough information regarding RWH, then the objective of the farmers will either be to maximize profit or minimize cost. Profits or minimum costs can be arrived at if details of costs and benefits are known.

6.4.1 Components of costs

Two main types of costs need to be considered when planning for RWH projects or schemes. These are investment and operating costs. It is also important to estimate the cost of water and the full contributions made by various partners to the development of a RWH project.

The most useful way of looking at components of costs in RWH is to focus on;

- the cost of catchment area such as cost of collecting, concentrating and delivering the rain water to intended users and cost of treating the catchment if necessary.
- the value of water considering alternative uses. For example:
  - if the catchment is a bare rock and cannot be put into alternative use, then the cost of this catchment is zero.
  - if water causes erosion downstream, the use of RWH to control the water is an environmental benefit downstream.
  - if water has an alternative use downstream, then the value of use downstream is the opportunity cost of water when it is harvested up-stream.

Another cost component which needs attention is the external cost which occurs beyond the project area. This is explained in section 6.4.3.

6.4.2 Benefit components

There are two ways of considering benefits, namely; direct and indirect components. Direct benefits are those occurring as a result of project activities. For instance, in RWH, direct benefits involve benefits as a result of increased production due to presence of a RWH scheme.

Increased production as a result of effective and efficient use of RWH need support of appropriate infrastructure such as markets, roads and transport and storage or processing facilities. It is therefore important to take into consideration the availability of these factors when planning for RWH.

6.4.3 Externalities

Apart from direct costs and benefits described above, there are external costs and benefits commonly referred to as externalities or indirect costs and benefits. These are cost and benefits which occur beyond the projects forecast. These have repercussions in the choice of alternatives, because one with very high direct benefits might have higher and significant external costs to the society compared to direct costs.

In RWH systems, the intended benefits upstream may be to increase crop production, but in doing so, the erosion and flood hazards are reduced downstream. The external benefit will be the control of erosion and floods hazards downstream. Likewise, there may be external costs if the RWH upstream increases siltation or reduces water availability in down stream reservoirs. The external cost will be the cost of desilting the reservoirs or the decreased crop output as a result of reduced water flow to downstream farms.

Based on the above, it is important for planners to consider both direct and indirect costs and benefits that will occur as a result of a new project. External costs of a RWH project or irrigation are sometimes related to the environmental destruction and health hazards. (See section 5.9).

6.4.4 Decision criteria

The costs and benefits identified above can be used in two alternative ways. First, the costs of various alternatives are compared and the cost effective alternative is selected. Secondly, the cost of alternatives can be compared with the benefits in a cost benefit analysis.

Cost-benefit analysis usually ends up with a decision criteria, namely Net Present Value (NPV). NPV is the sum of the discounted net benefits of a given investment alternative. Since a series of benefits and costs occur in the future, like plans made today and executed in the future, comparisons may only be valid if the costs and benefits are converted into the present value using discounting procedure (See case study 6.5.3). A positive NPV indicates that the alternative is profitable and can be executed. In case of different alternatives, the alternative with the highest NPV is usually selected.

Another decision criteria that can be calculated in the cost benefit framework is the cost benefit ratio. This is the ratio of the discounted costs to the discounted benefits. The lower the ratio, the more preferred is the alternative.

6.5 Case studies

6.5.1 Importance of institutions

Maswa District Council (MDC) in Shinyanga region established a project to improve rain water harvesting schemes for supplementary irrigation of paddy rice. The project targeted five villages: Lali, Bukangilija, Sayusayu, Malampaka and Budekwa. An appraisal of these Schemes (Hatibu, 1999) indicated that weak institutional support was one of the factors affecting their performance. The main institutions involved in the project were; the MDC ward development committees, village councils and farmer groups. The following points describe the status of the schemes in relation to the institutions:

The performance of farmers' groups was found to be poor or very poor. This was reported to be the result of MDC's over-emphasis on the technical and completely ignoring the social aspects of the schemes. Farmers were expected to form and operationalize Water Users Associations (WUA) to manage and maintain the canals. However, very little professional assistance on how to form and operate associations was provided to the villagers.

Similarly, village councils were not adequately involved in the projects. There was therefore no evidence of acceptability of the scheme by the whole village rather than a small group of people calling themselves 'Kamati ya Mtaro'. None of the several committees (Kamati ya Mtaro) was elected by a stakeholders or villagers meeting. The involvement of the village council was important since the diversion of water had an implication on other users.

The associations showed most of the following weaknesses;

- the associations did not have a written constitution and/or by-laws,
- most of them had not held general meetings and produced minutes,
- only two had opened a bank account,
- contributions were very low and slow,
- the committees were mostly self appointed, and
- the committee members did not receive adequate training.

The existing weak institutional set-up led to several problems. These included:

- Poor integration of the water diversion schemes with other uses of the water resources in the ephemeral streams. For example, most of the water diversion structures were damaged or rendered useless as a result of the practice of planting crops in the riverbeds, as well as the extraction of water for domestic or livestock use. These practices create flow obstruction which causes frequent shifting of the stream course.
- Uncontrolled cultivation of the catchment area without conservation measures led to high sediment concentration in the runoff water, causing damage to the RWH schemes by scouring structures and highly silting canals and paddy fields.
- Poor integration with roads and stock routes resulting in no provision of safe drainage of water across the main road near the scheme. During the 1997/98, the main parts of the road were washed away.
- Poor performance of the RWH schemes, as a consequence of the problems above.

6.5.2 Equity issues

Management of water from ephemeral streams and springs for the purpose of supplementary irrigation in the Western Pare Lowlands (WPLL), provides a good example of up-stream and down-stream equity relationships. This case study was done in Mgwasi village within Same District in the WPLL.

The WPLL are located within semi-arid plains and mountain sides, stretching south-eastwards from Kifaru to Hedaru. The area is divided into three physiographic units. These are:

- Plains lying between the foot slopes of the Pare mountains and the edge of Pangani River,
- Mid slopes with gently undulating rolling plains, and
- High altitudes with steep slopes and mountain tops.

The rainfall distribution is bimodal with the seasons occurring in November – January and March – May. The average annual rainfall is 400 – 600 mm. Mgwasi village lies between latitude 4° 15' to 4° 21' S and longitudes 37° 48' to 37° 53' E on the Dar es Salaam – Arusha highway.

In the higher altitude areas and mountain tops, rainfall is relatively higher. These areas are therefore sources of runoff and spring water, which is used for supplementary irrigation and domestic water supply during the rainy season and to a small extent during the dry season.

An indigenous irrigation system has been developed in the village for the purpose of extending planting season into the dry period. This has created a third season outside the regular two seasons. This season is called 'Champombe' or 'Chamazi' which literally means a growing season dependent on stream or stored water (mazi or mpombe) rather than direct rainfall. The system consists of three major components, namely:

- The river or stream.
- Water storage ponds.
- Water distribution canals.

The village has four storage ponds and most of the water is used for supplementary irrigation of maize. Farmers explained that it is not possible to harvest a crop of maize without supplementary irrigation using either RWH of flood water or spring water.

The available water is however not generally adequate to meet the demand. As a result, those farming in the higher altitude areas tended to abstract nearly all the available amount. This created inequality and friction with the farmers in the downstream plains. To solve this problem, the farmers negotiated and agreed on a time-based approach in the sharing of water. The plan allowed upstream farmers to draw water directly from the streams during the day for irrigating their fields. At night, the water is directed into the storage ponds. Downstream farmers use the stored water in the next day. This way, the available water resources are distributed equitably between up-stream and down-stream users. Canal committees have been established to supervise the distribution of water among these farmers.

6.5.3 Cost and benefit analysis based on paddy and maize production in Dodoma

The case study area is located in Hombolo village of Dodoma region in central Tanzania. Dodoma region is well known for its poor soils and erratic rainfall causing low and uncertain crop yields. The case study area lies between an altitude ranging from 850 to 875 m above sea level. The global position of the area is at latitude 35° 55' E and longitude 5° 55' S. The land form includes isolated hills, inselbergs and hill chains dominated by peneplains. Soil and landscape is in the form of catenary sequence with four distinct components, which are hilltops, foot slopes, peneplains and river valley bottoms. Many farmers exploit the valley bottoms and plains where runoff collects by growing high-water-demanding crops. Crop fields in these areas are called "mashamba ya mbugani" which literally means distant fields, and are very common. These are mainly used to grow maize. In addition, these areas are also attractive to many farmers due to their fertility enrichment from the upslope areas where nutrients originate and are transported and deposited in these plains during seasonal flooding. As a consequence, some farmers concentrate the runoff and lead it into bunded fields (or majaluba) for growing paddy rice. In some villages, there is a high demand for low-lying areas which receive runoff, to an extent that there is marketing and renting of these valuable pieces of land.

In this case study, cost-benefit analysis is used to compare the profitability of paddy rice grown in majaluba versus maize grown in distant fields. Financial Net Present Value (NPV) criterion is used to compare the profitability of paddy and maize in smallholder agriculture.

The cost of construction of majaluba is amortised over a period of 10 years. Annual maintenance cost of 10% of the original labour cost is assumed. In a real situation, farmers make continuous modifications of the jaluba. In year one, investment is made by constructing the structure and the benefits are realized in the same year. Costs and prices used are constant 1994 market prices to take care of inflation in subsequent years.

In calculating the NPV, 10% was used as the opportunity cost of capital (discounting rate). However since interest rates offered by the commercial banks at that time (1994) were about 24%, this rate was also used as an alternative financial opportunity available to farmers.

Table 6.1 *Costs and benefits for paddy production*

Cost/benefit	Years					
	1	2	3	…	9	10
				Tshs		
A) Costs						
Investment cost: 320 man-days @ Tshs 267	85,440	0	0	-do-	0	0
Land preparation: 20 man-days @ Tshs 267	5,340	5,340	5,340	-do-	5,340	5,340
Maintenance cost: (10% of investment cost)	0	8,544	8,544	-do-	8,544	8,544
Planting: 9 man-days @ Tshs 267	2,403	2,403	2,403	-do-	2,403	2,403
Weeding and thinning: 17 man-days @ Tshs 267	4,539	4,539	4,539	-do-	4,539	4,539
Harvesting, threshing and winnowing	16,020	16,020	16,020	-do-	16,020	16,020
Seeds and fertilizer costs	2,857	2,857	2,857	-do-	2,857	2,857
Total costs (not discounted)	116,599	39,693	39,693	-do-	39,693	39,693
B) Benefits						
Selling paddy rice at Tshs 9,000/bag	64,800	64,800	64,800	-do-	64,800	64,800

For maize production, there is no substantial investment in land preparation. Simple gross margins could therefore have been used. However, because the interest is to make a decision about the profitability between paddy and maize, projections have to be made on maize to reflect a 10-year period. Table 6.1 shows costs and benefit projections for paddy rice grown in the majaluba system while Table 6.2 shows the discounted NPV for paddy.

Calculations of NPV for maize grown in distant fields are shown in Table 6.3. Since the same costs and benefits occur in each year, annuity factors both at 10% and 24% were used to discount the net benefits.

Table 6.2 *Discounted net benefits for paddy production (Tshs)*

Year	Benefits	Costs	Net benefits	Discounted 10%	Net benefits 24%
1	64,800.00	116,599.00	-51,799.00	-47,085.30	-41,750.00
2	64,800.00	39,693.00	25,107.00	20,738.40	16,319.60
3	64,800.00	39,693.00	25,107.00	18,855.40	13,156.10
4	64,800.00	39,693.00	25,107.00	17,148.10	10,620.30
5	64,800.00	39,693.00	25,107.00	15,591.40	8,561.50
6	64,800.00	39,693.00	25,107.00	14,160.30	6,904.40
7	64,800.00	39,693.00	25,107.00	12,879.90	5,573.80
8	64,800.00	39,693.00	25,107.00	11,725.00	4,494.20
9	64,800.00	39,693.00	25,107.00	10,645.40	3,615.40
10	64,800.00	39,693.00	25,107.00	9,691.30	2,912.40
NPV				84,349.90	30,407.70

Decision criterion is based on the alternative that has high NPV. From the results, it can be concluded that both paddy and maize are financially profitable enterprises since they have positive NPV. In both discount rates however, the returns from paddy production are higher than those from maize (Tables 6.2 and 6.3). Using the decision criterion (and other available information), the planner can be in a position to make recommendations on the above scenarios. Based on the analysis and assumptions made, the planner is expected to choose the alternative with high NPV. In this case, paddy rice production using majaluba system is preferred.

Table 6.3 *Costs and benefits for maize production*

Cost/benefit	Years				
	1	2	….	9	10
			Tshs		
A) Costs					
Land preparation: 1 man-day	267	267	-do-	267	267
Planting: 2 man-day + Tshs 1000 for communal labour	1,534	1,534	-do-	1,534	1,534
3 Weeding: 25 man-days + Tshs 7,300 for communal labour	13,975	13,975	-do-	13,975	13,975
Harvesting and threshing: 7 man-days + Tshs 2450 for communal labour	4,319	4,319	-do-	4,319	4,319
Transport	3,000	3,000	-do-	3,000	3,000
Total cost of production	23,095	23,095	-do-	23,095	23,095
B) Benefits					
Selling maize: 4 bags/acre @ Tshs 7,500	30,000	30,000	-do-	30,000	30,000
Net benefits (benefits–costs)	6,905	6,905	-do-	6,905	6,905
NPV at 10% (annuity factor 6.145)[1]					42,431
NPV at 24% (Annuity factor 3.682)[1]					25,424

[1] Since costs and benefits are constants throughout the period, annuity factors are used to discount them, rather than using the procedure described in section 6.2. Annuity factor are those factors that are used to discount streams of costs and benefits which are constant throughout the life of the project.

6.5.4 Ilobashi reservoir project, Shinyanga Rural District

Ilobashi village is located in Shinyanga Rural District, some 30 km to the south of Shinyanga township. The majority of the villagers are crop producers. The main crops include rice, sorghum (Serena), maize and cotton. The village has about 270 families. The crop production pattern and practices by the villagers are basically traditional and dependent on rainfall. Like in other dry areas, the yields are low following low and erratic rainfall. The majority of farmers combine livestock production as a major part of their overall farming operations.

For the production of paddy rice, the villagers practice water harvesting by employing stream flow diversion (SFD) techniques. Runoff is normally diverted from the seasonal Mhumba river which passes through the village. The water is channelled and directed to the bunded fields where rice is planted.

The Ilobashi reservoir project was conceived in 1994 by a group of people under the name of Green Shinyanga Group (GSG) and was based in Shinyanga township. This group comprised mainly of government workers and private business people. According to the villagers, the GSG was interested in acquiring land for paddy production. It is no wonder that Ilobashi village was chosen because of its easy accessibility from the town. In 1994, the GSG managed to secure funds from a donor for the implementation of the Ilobashi reservoir project. The project itself was aimed at harvesting and storing water in a reservoir for domestic purposes, irrigation and livestock use. Villages which were planned to benefit included Ilobashi, Masengwe, and Ikonda.

Implementation of the project started by GSG going to the village in 1994 to 'sell' the project to the villagers, and enquire from them whether they will accept it or not. As usual, the villagers 'passively' accepted the project, and later a committee was selected, although the villagers learnt that the committee was not representative and it had to be reselected. Construction of the dam started in 1994. GSG provided construction equipment like a D4 bulldozer and vehicles, while the villagers provided labour in collecting sand and stones. During the period 1994 to 1996, floods destroyed the dam wall three times even before completion. The villagers attributed the damages to lack of a spillway, poor compaction of the dam wall and lack of technical know-how on the GSG site supervisors. The project was abandoned by GSG in 1996 on the pretext that there were no more funds to repair and complete the project.

From this case study, the following lessons can be drawn:

- The project as conceived by GSG had no technical backing in terms of surveys, designs and construction. In addition, no climatic data, like rainfall, was analyzed to estimate the runoff. This lack of planning was the main reason for the frequent damages of the dam wall and the ultimate abandonment of the project.
- GSG did not fully involve villagers as stakeholders in decision making.
- Lastly, GSG seems to have died with the project. Therefore, NGOs formed for the purpose of pursuing only one project are not reliable agents of sustainable development.

6.6 Planning guide

Planners should identify socio-economic issues with respect to RWH and integrate them into plans. The most important issues include:

- Laws and policies governing land, water and infrastructure. These can be obtained from the respective ministries.
- District Councils' by-laws, for example by-laws governing land tenure, water rights and public infrastructure. These can be obtained from respective departments within the district councils e.g. health, agriculture, forestry, water and education.
- Customary laws existing both at ward and village level. These laws are normally not written. They can be obtained from local and village leaders through social appraisal of the target area.
- Inventory of priorities of institutions to be involved in the project. For example, District Councils, Ward Development Committees, Village Councils, NGOs and community-based organizations. This inventory can be obtained from the District Executive Director and through social appraisal of the target area.
- Gender relations in the target area. This include analysis of how resources like land and income, are owned and controlled and labour divided between men and women. These relationships can be identified through key informant surveys and social appraisal.
- Categories of water users. For example, individual crop producers, livestock keepers and domestic supply schemes.
- Identification of potential conflicts between upstream and downstream users. This is best done through social appraisals.
- Benefits accrued from RWH investment. These include assessment of alternative investment options. The best way to do this is to undertake a feasibility study to identify the costs and benefits associated with alternative investments.

Chapter 7

Planning programmes and projects with RWH components: optimizing benefits from available water

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The planning process involves the allocation of scarce resources between various uses in a way that best satisfies defined objectives. Planning requires collection and analysis of information on the present situation and uses the output to predict the future situation with or without the programme or project. Different individuals, groups and institutions are likely to be affected in several ways and all will have their own priorities. If the programme fails to satisfy these stakeholders' objectives, it is likely that the programme will not be successful. Failure to recognize this reality is one of the reasons for the poor results of many development programmes and projects in Tanzania and other similar countries (Kikula et al., 1999). Programmes and projects with a particular focus on rainwater harvesting have suffered this fate along side other development initiatives. Failure of RWH structures such as Ilobashi dam in Shinyanga (case study No. 6.5.4), is due to weaknesses in both the technologies themselves and the approaches adopted for the programme planning and implementation.

Project planning is generally divided into three stages; namely reconnaissance, pre-feasibility and feasibility. In this book, the planning process has been divided into five major stages. These include:

- Plan initiation.
- Reconnaissance.
- Formulation and screening of project alternatives.
- Data collection and analysis.
- Development of detailed plan.

In addressing these important steps of planning, the chapter draws from a report published in 1987 by the United Nations Educational, Scientific and Cultural Organization, on "The process of water resources project planning" (UNESCO, 1987).

Water resources issues in general, and RWH in particular, touch on the interests of many people and institutions. A RWH project will often affect many outside the project target area or population. For these reasons, it is important to adopt participatory planning approaches at every stage so as to ensure that all the stakeholders are involved and their interests taken into consideration.

7.1 Stage one: Plan initiation

In this stage, the first important aspect is to establish the nature of the problem. The second aspect to be considered is identification of the stakeholders. The third is to undertake a problem analysis whereby stakeholders determine the cause-effect relationships of the problem.

7.1.1 Nature of the problem

Normally a programme is initiated in response to existing or anticipated needs. For example, there could be a need to optimize the exploitation of rainfall or to control flooding. Assessment will first question if there is evidence of sub-optimal exploitation of rainfall. If yes, what are the factors that contribute to the problem?

The identification of needs is a prerequisite to problem formulation. Projects have often been designed on the basis of poorly defined needs. This makes the project a failure before it even starts.

The nature of needs can best be done by the stakeholders. However, experts should provide necessary information for analyzing the real nature of these needs. In addition, participatory ranking approaches can be used to prioritize the needs, so as to deal with those which will either bring the maximum benefits or mitigate the most serious threats.

7.1.2 Identification of stakeholders

A stakeholder is any individual, group or institution who:

- Has needs which require access or control of the water resource.
- Will be affected (negatively, directly or indirectly) by the use or control of the resources by another individual or group.
- Has environmental, ethical, cultural or scientific interests in the nature of utilization, conservation and preservation of the resources.

For a plan to be successful, it must constitute a negotiated agreement which is acceptable to all the stakeholders (FAO and UNEP, 1997).

Different stakeholders have their own particular goals and work under different circumstances. During the identification process, it is necessary therefore to classify stakeholders into homogeneous target groups. This classification is best done through a participatory process whereby participants identify the criteria for classification. The purpose of classifying this heterogeneous population into target groups is to strike a balance between proposing solutions for every stakeholder and proposing one set of solutions for the whole community.

In the analysis, the aim should be to determine a few key characteristics, say 3-5, that differentiate these groups. A workable approach is to follow stepwise differentiation as depicted in Figure 7.1. The stakeholders can first be grouped according to the natural circumstances facing them. In the given example, the grouping is done by dividing those residing or using resources within the target area and those outside and to the downstream of the target area. Those within are further divided into two groups; those residing or using resources in the higher altitude and sloping land and those in the flat bottom lands. A different approach, for example, between windward and leeward side, could be used with the same results. The group can then be further sub-divided according to socio-economic circumstances. A deep differentiation can be made in relation to the difference in needs.

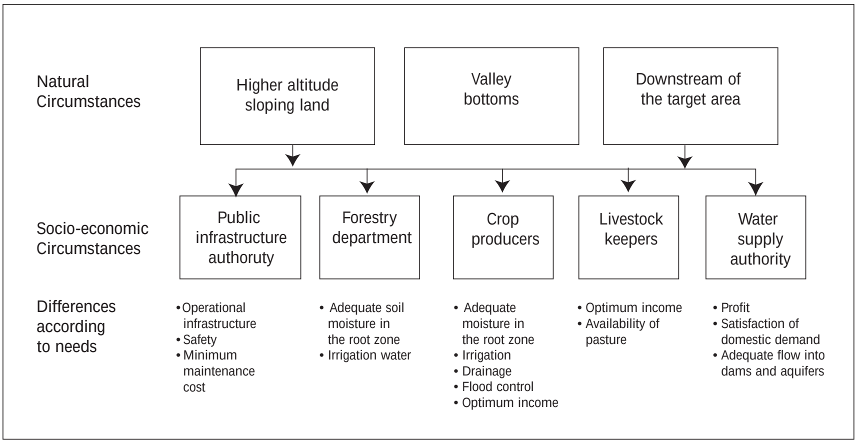

Figure 7.1 *Stepwise differentiation of stakeholders.*

7.1.3 Problem analysis

Problem analysis is best done as an informal group activity, which follows a structured sequence of 'why' questions in order to better understand the interrelated nature of local problems and their root causes. This can be used as a wide-ranging analysis of problems affecting the community, but in our case we are concerned with using the method to explore the 'core problem' related to water resources. Given that different stakeholders have different motivations and interests, it is important that all the stakeholders are adequately represented in the group undertaking the analysis.

The recommended approach is the widely employed 'Objective-Oriented Project Planning' generally known as the Logical Framework Approach or sometimes as ZOPP analysis (GTZ, 1991).

Details of the method can be found in various manuals (GTZ, 1991). The advantages of using the method are the following:

- It ensures that fundamental questions are asked and weaknesses analyzed.
- It guides systematic and logical analysis of the inter-related key elements.
- It facilitates common understanding and better communication between planners and other stakeholders.

To obtain balanced results, the analysis should be facilitated by an independent moderator. The aim is to identify factors contributing to the core problem and to represent them logically in a problem tree as shown in Figure 7.2.

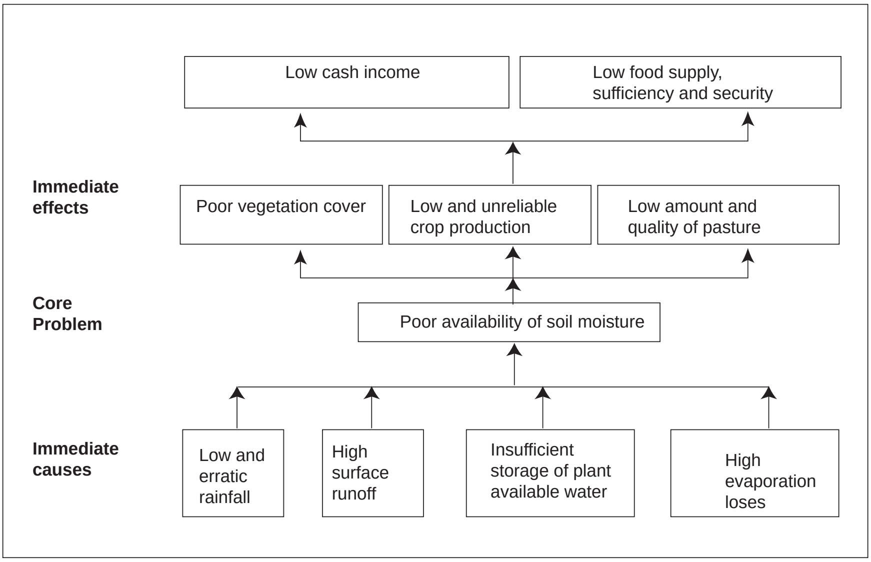

Figure 7.2 *An example of a problem-tree.*

The core problem is placed at the centre of the tree. The substantial and direct causes of the problem are placed parallel on the line underneath it. The substantial and direct effects are placed parallel on the line above it. Causes and effects are further developed along the same principle to form the problem tree. The analysis is concluded when the stakeholders are satisfied that all essential elements have been included in the network in order to explain the main cause-effect relationships.

In the example given in Figure 7.2, the core problem is poor availability of soil moisture and four types of causes to the problem. The immediate causes will also be a result of other problems as elaborated below:

Overall inadequacy of rainfall or inappropriate distribution with respect to crop production.

High evaporation losses in the form of;

- insufficient rainfall (relative to evaporative demand) for adequate crop development during the major part of crop growth period, or
- total rainfall exceeds evaporative demand over the growing season, but yields are diminished due to unpredictable dry spells.

High surface runoff normally due to low rate of infiltration as a result of;

- relatively impermeable soil surface, or
- low percolation rate through compacted or impermeable subsurface layers.

Insufficient storage of plant-available-water due to:

- limited water storage within root zone owing to soil type (i.e. low available water capacity), and/or
- limited water storage owing to a shallow soil or compacted layer limiting rooting depth.

7.1.4 Preliminary statement of the goal and purpose

Stage 1 should end with a conclusion of either continuing with the project or not. If it is decided to develop a project, then the outcome of stage one will be a preliminary statement of goal and purpose. Identification of goal and purpose follows from the problem analysis and starts with a transformation of the problem tree into a tree of objectives (i.e. future solutions to the problems) (Figure 7.3). This is achieved by re-formulating the problem statements into positive desirable conditions. However, not all problems can be realistically or expediently tackled by the project. These should be deleted from the tree of objectives. In the example given, very little can realistically be done to the problem of low and erratic rainfall. It is therefore not appearing in the tree of objectives.

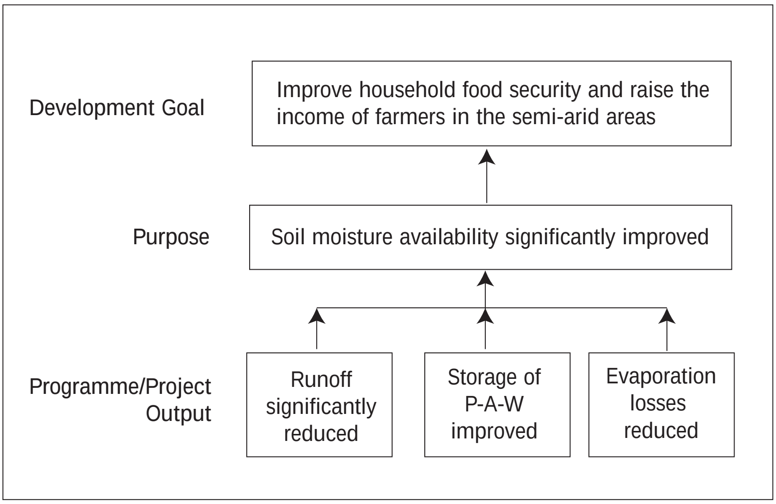

Figure 7.3 *An example of objectives tree.*

7.2 Stage two: Reconnaissance

Once the purpose of the project has been agreed upon, funds can be committed to determine its feasibility. This is done through a reconnaissance study implemented by a team composed of multi-disciplinary experts in the various aspects of the problem. The team accesses information existing about the target area and stakeholders. If the existing information is found to be inadequate, the team may decide to conduct some fresh surveys and/or studies to collect additional or new information. The analysis of the assembled information is used to decide and ascertain whether it is desirable to continue with further development of the project.

In the example given in section 7.1, the design of measures to promote improved capture and use of rainfall must start from an adequate understanding of the rainfall regime based on analysis of available rainfall data. It cannot be the objective of the project to bring about a change in the prevailing rainfall regime. On the other hand, problems arising from restricted water entry or storage can be addressed directly and must be correctly diagnosed by reference to soil characteristics.

The outcome of this stage will be a pre-feasibility report recommending further development or cancellation of the project. This report will also suggest the type of further investigations required to build the database for further project development.

7.3 Stage three: Formulation and screening of alternatives

7.3.1 Purpose

At this point, it is important to determine the focus of project interventions which requires a systematic approach to:

- Identify alternatives through a broad range of options derived from local experience (indigenous knowledge) and experience from elsewhere (expert knowledge e.g. research or other RWH projects).
- Screen alternatives by ex ante evaluation of options using a set of criteria, which reflect the essential qualities an intervention should have in order to meet stakeholders' needs.

The purpose is to agree on the strategy and focus on interventions which will bring about maximum impact. The process of objective analysis described in the previous section will generate several branches of intervention necessary to solve the problem. This will provide the basis for generating project alternatives. These alternatives normally combine several branches into strategies like training and water storage.

By defining the criteria for screening, we aim to avoid an arbitrary selection which does not match stakeholders needs. These criteria (see Box 7.1) may be devised through a participatory process involving a panel comprising planners, researchers, and other interested groups. However, it is arguable that the most appropriate team of 'experts' in this case would be drawn entirely from the stakeholders.

Box 7.1 *List of criteria for screening project alternatives*

1. Feasibility under given socio-economic circumstances, for example:
   - Correspondence with stakeholders' skills
   - Sufficiency of stakeholders resources
2. Correspondence with stakeholders goals and preferences, for example:
   - Ground water recharge
   - Compatibility with cropping pattern/cropping calendar
   - Livestock water requirement
3. Feasibility under given natural conditions, for example:
   - Expected production as compared to present situation
   - Expected stability of production
   - Expected production risks
   - Movement of wildlife
4. Ecological viability, for example:
   - Expected effects on the natural environment
   - Expected effects on the long term productivity
   - Expected effects on diversity of agro-ecosystems
5. Economic viability, for example:
   - Profitability as compared to present situation
   - Expected effects on produce markets
6. Compatibility with other plans and programmes, for example:
   - Infrastructure
   - Domestic water supply schemes
   - Hydropower system

7.3.2 Decision-support system for screening of alternatives

The planners often face natural resources management problems that are complex and involve considerable uncertainty over the likely outcomes of any decision. They may recognize also that different stakeholders have conflicting objectives, but are unable to determine the trade-offs. Nevertheless, they are forced to reach a decision on a plan of action. The term 'Decision-Support System' (DSS) is a contemporary jargon for a computer-based tool designed to help make better decisions under such circumstances. An important characteristic of any DSS is that the user retains responsibility for making decisions based on 'what if' analyses of alternative scenarios. The computer assists through providing the means to assess alternatives efficiently, objectively and consistently. These require access to comprehensive and well-organized information. The DSS serves this purpose by integrating very different types of information into a common framework and allows the user to access and evaluate this information.

Some decisions are clearly too trivial to justify the task of developing a DSS. Others may have so many sources of uncertainty that a formal DSS may not be the best approach to decision-making. There are however many situations when a computer-based DSS can be a powerful planning tool because predicting future outcomes of decisions involve the use of biophysical, economic or other models, or a combination of several models. These include;

- managing risk involves doing a large number of repetitive calculations to assess alternative outcomes.
- large databases are required to support the necessary models and/or calculations.

DSS were originally developed for use in planning for industry and commerce. With the rapid spread of micro-computer technology during the past 15 years, their use has extended into a wide range of management domains including natural resources. Examples of their use include agricultural technology transfer (Tsuji et al, 1994), land use planning (O'Callaghan, 1995), rangeland management (Stuth & Lyons, 1993) and water resources management (Sheffield et al, 1998). A modal DSS for assessing the appropriateness of RWH technologies within a specified bio-physical and socio-economic environment is depicted in Figure 7.4.

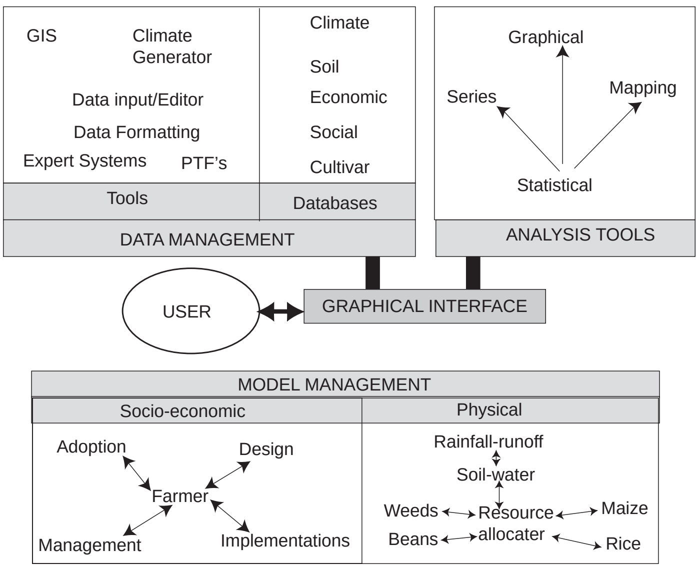

Figure 7.4 *Conceptual diagram of a DSS.*

7.3.3 Authorization

When a suitable strategy has been selected, the project should be presented for political and financial authorization. The final result of stage 3 is an authorized and funded project. Of course the project may not receive authorization and that will be the end of the process.

7.4 Stage four : Database development

The fourth stage in planning is to generate information or access existing databases for the data required for detailed project planning. The data collection process has been discussed in detail in chapter 2 to 6 of this book. It is therefore not necessary to repeat this discussion here. This stage will involve specification of the data and information required for the project, the actual process of data acquisition, processing and quality control, and finally building of databases especially into GIS.

7.4.1 Specification of needed data

The data needed must be specified in terms of three aspects: type, spatial and temporal intensity, and accuracy. Spatial and temporal intensity refers to the intensity of recording per unit area as well as the period over which data is available. Accuracy refers to a specification of what level of accuracy of data can be tolerated by the project. This is very important as it has implications on the cost of data acquisition.

Box 7.2 *Basic Information needs (modified after FAO and UNEP, 1997)*

Basic maps
- Topography
- Settlements
- Communication systems
- Administrative boundaries

Climatic
- Rainfall, temperature, light intensity day length, humidity and wind

Land
- Soil (description, classification, mapping, suitability)
- Topography (slope classes, physiographic units)
- Land units
- Land ownership records

Water resources
- Surface water e.g. rivers and flash floods
- Subsurface water (extent, yield and quality of aquifers)

Land covers and land use
- Land cover
- Land use
- Environmental requirements of crops

Population (number & location)
- Human
- Farm animals and
- Wildlife

Social information
- Groups (description and classification)
- Objectives (land users, community, government)
- Resources and constraints

Economic data
- Input costs
- Sales price and
- Transport cost

Physical infrastructure
- Markets and processing plants
- Road and railways
- Houses
- Water reservoir

Institution and legal aspects
- Information on relevant institutions and their responsibilities
- Documents of laws applying to relevant aspects of land

7.4.2 Data acquisition

Data acquisition process requires a knowledge of the sources of different types of data. As already mentioned in the previous chapters, there are many institutions involved in data collection. Therefore, the needed data may already be available in the database of an institution or even from the Internet as discussed in chapter 8. The assessment and evaluation of data already available should be the first and priority stage of any data acquisition process. If the available data is judged not to be 'adequate' for the planning process, a programme for additional data collection can be implemented. The benefits of additional data should however be weighed against the cost and loss to be incurred due to delayed implementation of the project. It is important to remember that no amount of data can really be adequate for predicting what will happen in the future. Common sense and expert judgement should be used to decide when the type, amount and accuracy of data is 'adequate' for the intended project.

7.4.3 Processing and data quality control

Even when existing data is used, processing is always necessary since data may have been collected and used for completely different reasons. The processing is done to generate necessary parameters like ratios, maps and information compatible with the requirements of the project under planning. Before the processing can be done, it is important to subject the data to a quality check. This check will for example relate to the length of recording any gaps in records, numerical accuracy of the data and spatial and temporal representativeness. One specific problem which is encountered when using a long-term series of hydrological data is to account for the changes that may have occurred in the catchment, for instance, new settlements and deforestation or afforestation. To ensure quality control, it is always necessary to select a reliable benchmark for comparisons.

The processing of data requires a decision on what outputs are required followed by selection of appropriate computer programmes and models for implementing the processing. If appropriate programmes and models are available and are used properly, the exercise should be simple and straightforward.

7.5 Development of final project plan

The final plan will depend on the results of the feasibility study or screening exercise of the alternatives. At this stage, the planner should identify various legal and regulatory systems that will affect the plans. Appropriate organizational and administrative structures for running the planned project should be identified. Possible sources of the risk and uncertainties associated with the project should also be identified. Sensitivity analysis to ascertain the risks associated with possible changes in socio-economic conditions is useful at this stage. It is also important to define or develop operational rules for the project.

Development usually brings about economic, social and environmental changes. Although these changes are mostly positive, development can also bring negative effects and conflicts. Environmental Impact Assessment (EIA) due to the project activities should be made so as to eliminate or reduce adverse effect. EIA has three main functions (Lee & George, 2000):

- To identify any potentially adverse environmental consequences of a development action,
- To ensure that any such consequences are taken into account, and
- To influence how it is subsequently managed during implementation.

7.6 Implementation, evaluation and monitoring

It is important to plan for implementation of the programmes. Many of the development projects in the developing countries are failing because of numerous reasons. Perhaps the most important reasons are cost overrun and delays in implementation. These are often related to each other as cost overrun are caused by delays in implementation such as late delivery of equipment and recruitment of staff. Due to time value of money and high inflation rates, delay in implementation may increase costs of the project.

The planning process should clarify how the project is to be evaluated and monitored. There is therefore a need for setting up baseline information which will be used as a basis for monitoring and evaluation. Monitoring can be done using participatory approaches which involve consultation with stakeholders to identify indicators and develop a plan for monitoring. Participatory approaches can also be used for the evaluation, in helping to determine key stages for assessing progress and agreeing on qualitative and/or quantitative indicators of success. Indicators that are developed should clearly specify the performance standards required for meeting each output and project purpose. For an indicator to be useful, it should have the characteristics described in the Box 7.3. It must specify: target, quantity, quality, time of attainment, and location of the output of effect.

Box 7.3 *Monitoring and evaluation require good indicators of performance*

It is possible to measure every aspect of the project in the process of evaluating its performance, especially in relation to purpose. It is therefore necessary to use indicators. These are phenomena which are monitored before, during and after the project so that their trends provide indications of performance of the project. Indicators for the project activities are easiest to formulate and use while it is very difficult to develop adequate indicators for the goal. Indicators should have the following qualities:

i. Provide a direct measure of the intended result, output or changes brought about by the project. For example an indicator for an afforestation project should measure the hectares covered with well-established trees, rather than number of seedling distributed by the project.
ii. The measure must be objective, precise and full. For example, if the purpose of the project is to increase effective use of rainfall, an indicator looking at average increase in yields per hectare is not adequate. A good indicator will look at the change in yield of maize per hectare per mm of rainfall by farmers growing a given variety using a specified agronomy.
iii. As already shown in the example (ii) the indicator should be quantitative where possible.
iv. The indicator should also be practical in implementation, such that monitoring and evaluation of the programme does not cost too much. It is usually recommended that M&E cost should be between 10 – 20% of the project budget.
v. Finally, the indicator should be designed such that the data to be used for evaluation is readily available and reliable.

Chapter 8

The information technology for planning RWH: Exploit the power of knowledge

Hatibu, N; O.B.Mzirai and J. Rockström

Most, if not all, planners who will use this handbook have access to powerful computers. Most can, with little effort, gain access to the Internet. Sadly, most would be using the expensive computers mainly for typing, thus exploiting less than 1% of the in-built capacity. The purpose of this chapter is therefore to briefly introduce the planners to the possibilities available for data acquisition, storage and analysis, by using computers together with remote sensing, Geo-referenced Information Systems (GIS), and the Internet.

8.1 Remote sensing

Implementation of the technical appraisal necessary for RWH 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 RWH 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 which are either aircrafts or satellites (Harris, 1987). Aerial photographs have, until the early seventies, been the only approach to remote sensing. In Tanzania, aerial photographs still dominate the available data especially of land resources and land use. However, satellites have recently become the basic platforms for remote sensing. 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) RWH planning requires an integrated catchment approach. The whole catchment therefore 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. Most of the remote sensing data can be obtained freely or purchased in processed formats, ready for use.

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 RWH 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 rainwater harvesting 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 facilitate 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.

8.1.1 Land, topography and soil characteristics

Remote sensing can be used to provide topographical classification of land. Stereo images and non-stereo satellite data can be used to produce new maps or improve existing maps. It is the latter application where a planner can quickly obtain most up-to-date topographical information. However, it must be mentioned that aerial photographs coupled with cartographic procedures will produce better topographical maps.

Land catena is a common feature which is very important to RWH planning in semi-arid areas (see section 4.1.4). 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 RWH.

8.1.2 Land uses

Vegetation cover and other land uses have perhaps the largest effect on the partitioning of rainfall (see section 2.2). Planning for rainwater management therefore requires a good estimate of how land covers and uses are distributed. Following the discussions presented in chapter 3 and 5, the main category of land cover and uses are rangelands, crop fields, forest and woodlands including perennial crops, and urban areas (cities, towns, homesteads, railways, roads etc).

Mapping of land cover and uses is perhaps the most common area of application of remote sensing. Conventional methods of mapping are faced with a major problem of continuously being out-of-date. Adoption of remote sensing will thus provide the planners with the most up-to-date land use and land cover maps which can not be obtained from conventional sources. 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.

Once calibration is available, remote sensing becomes very useful in providing accurate and spatially continuous data and frequent updating. This facilitates the monitoring of changes in land cover during the year and over time. The resultant maps and statistics assist in improving the quality of planning. Urban areas, including infrastructures such as roads are very easy to identify in the images produced by remote sensing techniques.

8.1.3 Climate

The previous chapters have shown that rainfall and evaporation are the most important climatic parameters in RWH planning. To fully describe the rainfall characteristics of semi-arid areas a very high density of raingauges will be required. 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.

With regards to evaporation and evapotranspiration, there are also no methods for measuring them directly using remote sensing. However, methods have been developed for extrapolation of the point data to large areas through soil moisture measurement and modelling (Engmann, 1995).

8.1.4 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 can not 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. The soil moisture data so obtained can be used to estimate other hydrological parameters.

8.1.5 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 system which is currently fully available to the public is based on satellite radio navigation. The GPS receiver determines its position by satellite ranging. The GPS consist of 24 hours operational satellites controlled from Colorado Springs in the USA. These satellites carry on board transmitters which 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. If the receiver is moving, the informations together with the signals specifying time, are used to calculate velocity.

GPS can therefore be used for quick surveys of given areas or to geo-reference the location of certain occurrences or characteristics. For example, indigenous knowledge of land use or hydrological patterns can be geo-referenced by using a GPS to accurately locate position during interviews with local people.

8.2 Geo-referenced Information Systems (GIS)

All the previous chapters of this handbook have shown that 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 previous section in this chapter briefly introduced the new and highly efficient means of collecting data through remote sensing and GPS. All these point to one thing; that planning is largely data and information handling. Therefore, the primary requirement for effective planning in general and for rain water 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 computerised 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 RWH 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 section is designed to sensitize planners on the power of GIS as an effective and efficient tool for information management, which is a pre-requisite for effective planning. Every planner or decision maker should strive and be able to exploit this power.

8.2.1 What is GIS ?

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 (Figure 8.1).

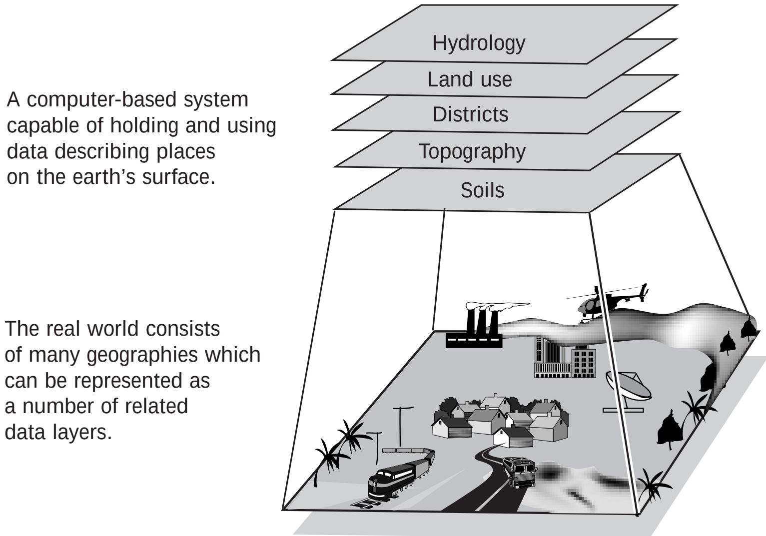

Figure 8.1 *An example of data layers in a GIS (after, ICIMOD, 1996).*

It must however be emphasized here that the data and information acquisition as discussed in sections 4.5, 6.5, 7.4 and 8.1 is vitally important to GIS. It must be recognized that despite its impressive speed, efficiency and graphic outputs, GIS is just a tool. The computer-based GIS needs data, just as an aeroplane needs fuel to get you anywhere. Just as wrong or poor quality fuel in an aeroplane will not get you anywhere, so does wrong and poor quality data in a GIS. Data acquisition should therefore be considered an important aspect of GIS. This requires that GIS managers should be clear on the following two issues (Tamlinson et al., 1976):

- Identification of all sources of required data (spatial and attribute), their location, accessibility and collection procedures.
- Development of links and collaboration with agencies and institutions involved in gathering the different types of data to be used as an input to the system.

Data is the most important component of a GIS. Accessing the correct quantity and quality of data should be given high priority. To do this, the following considerations are made:

(a) Input and storage of data

A computer-based GIS handles data in digital form. This is a major challenge because most of the existing data is not in digital form. It is mostly held in printed or oral format. Many institutions and agencies continue to collect information using analogy approaches. The most serious problem with a vast amount of otherwise valuable old data sets is the lack of, or poor geo-referencing. The advent of the GPS means that even oral knowledge of, for instance flood levels, can now be geo-referenced.

It is reckoned that data input is time consuming and may constitute the most expensive aspect of establishing a GIS. Data is normally available from many different sources and in different forms. The process of capturing data will include digitization, scanning, downloading digital data sets and keyboard entry of attribute data. The challenge is to produce a consistent and error free digital database from a variety of sources and forms of data collected by different institutions over a long period using different technologies. Expertise is required for editing the data that is automatically captured.

The product of data input and storage is a digital database suitable for manipulation according to the needs. The database must however be properly managed.

(b) Database Management

Effective database management includes ensuring adequate capacity to hold the data, maintaining its integrity and updating it regularly. Since the amount of data is very high for GIS, it is important to use software specifically designed for database management. It is normally recommended to use the relational design of database management system (DBMS) (ESRI, 1999).

(c) Manipulation and Analysis

This stage involves the retrieval of data and information from a database and undertaking combinations and analysis necessary to meet the objective of a given task. 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 (see section 8.2.2).

(d) Presentation and Reporting

After elaborate activities, there must be an output that can be useful to the decision-makers, most of whom are not GIS experts. GIS provides several ways for presenting information. The most exciting aspect is that the presentation can be changed at a slight move of the mouse. The output will include statistical tables, graphs, maps, three-dimensional images, text tables and photographs. It is even possible to produce multimedia reports from GIS.

8.2.2 What can GIS do ?

The main capability of GIS lies in its ability to link data together as shown in Figure 8.2 and discussed in sections 8.2.1.

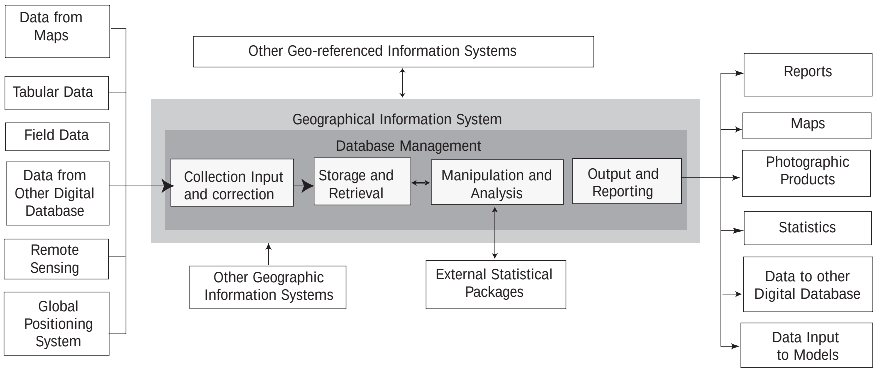

Figure 8.2 *Principal components and functions of GIS (after, ICIMOD, 1996).*

The second function lies in the GIS capability to answer five types of questions. These are:

- what exists in particular Location?
- where do particular Conditions exist?
- what Trends (Changes) have occurred over time in a given location?
- what spatial patterns exist?
- what effect will the intervention have?

(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 exist?

This query is the converse of the one in (a) above. In this case GIS can be used to obtain information such as:

- what is the location of land which is highly eroded?
- which parts of the catchment become flooded for more than 30 days during the rain season?
- which parts are occupied by mbuga soils ?

(c) Trends

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) Patterns

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? To query the GIS for patterns is basically testing hypothesis.

(e) What if?

This type of query require the GIS to link data with specified models to determine what would happen if this or that is done. For example, the GIS can be asked: what would happen to stream discharge if all the grassland was converted into coffee estates?

8.2.3 Establishing GIS

The low level of use of GIS in Tanzania has raised the way it is viewed by the Government as regards its establishment for purposes of planning, decision making and implementation of programmes. It is therefore imperative that all planners, especially from the district level onwards, should ensure that there is a policy support for the use of remote sensing and GIS.

The second most important aspect is manpower. The GIS technology will be of very little value without people who:

- effectively use GIS outputs for planning, decision making and management.
- Operate and manage the system for tackling problems of interest to the first group.
- Generate the data necessary for effective operations of a GIS.

The third aspect in importance is to have a clear definition of the needs. This is very well illustrated by Tomlinson et al., (1976) as shown in Figure 8.3.

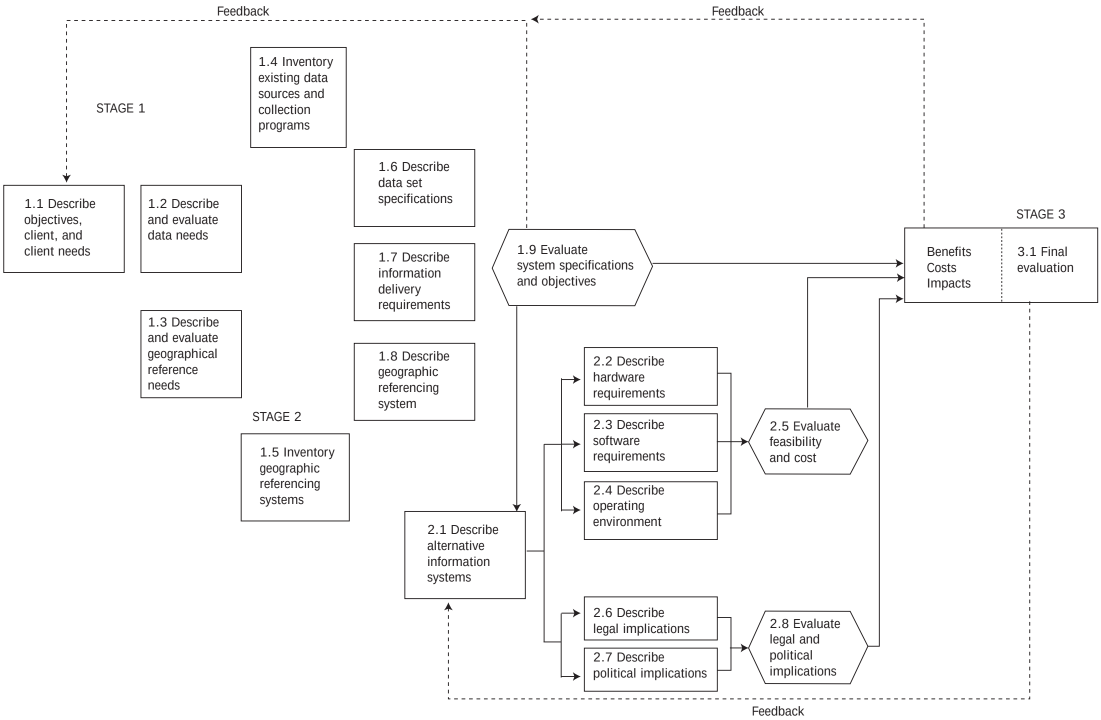

Figure 8.3 *An example of steps in the design of information systems (after, Tomlinson, 1976).*

The fourth aspect is the hardware and software requirements. This will include for example:

- Hardware:
  Computer
  Global Positioning System (GPS)
  Scanning/digitizing technology
  Communication technologies
  Multimedia technology
  Printing technology

- Software for:
  Data capture
  Data transformation
  Analysis
  Display and reporting

8.3 The Internet

The e-mail which is perhaps common to the majority of the readers of this handbook, is a component of the Internet. The Internet can be defined as a global information system of logically linked computers and networks. It is made of four main components, which are:

- The computers – of different sizes, linked together, and which communicate and share data.
- The special computer programmes and protocols that enable the communication between computers.
- The database or content that is contained in different computers.
- The information and data communication infrastructure, which include communication satellites, telephone cables and receiving stations.

8.3.1. How GIS links up data electronically

A computer that is Internet-enabled has computer programmes with Transmission Control Protocol (TCP)/Internet Protocol (IP). The protocol enables the communication between computers (Howe, 1998). With the ability on the computer and if it is appropriately connected, it is possible to do two major operations:

- Send and receive electronic mail (email)- this is now quite common even in areas with no telephone services.
- Access the World Wide Web.

The World Wide Web (WWW) or the Web, is a network of servers connected to the Internet that offer all sorts of information, including land resources data (Gates, 1996). The WWW protocols make it possible to link many websites. These are like computer files located in servers where information is held. Utility of the web emanates from the number of links between sites. This makes it possible to access sites quickly and easily in order to pursue a data search.

Connection to the WWW can therefore simplify the planning process since it is possible to obtain or purchase climatic, hydrological, land use and other data through the Internet. United Nations organizations such as the Food and Agriculture Organization (FAO); United Nations Environmental Programme (UNEP); and World Meteorological Organization (WMO), have made most useful datasets, models and information available through the WWW. The private sector is also providing data through the web. Very soon therefore, nearly all the data that is needed for planning could be available through the Internet. For example, it is possible to purchase high-resolution remote sensing imagery through the Internet, for direct downloading into a local GIS. But it is also possible to access GIS database located in computers of other organizations.

The Internet is the foundation upon which the information age is being built. As already mentioned, planning involves mainly information handling and interpretation. The Internet is the most versatile tool for this job ever invented. It is important that those charged with making plans for RWH should have access to and use of this tool.

8.4 Case Study - Water balance accounting for dry spell mitigation using CROPWAT

The lack of meteorological data is frequently identified by planners and rural development officers as a major bottleneck in farming systems development. Similar constraints are generally brought forward regarding water flow parameters like runoff, crop water requirements, deep percolation, and soil moisture. It is true that daily rainfall and potential evapotranspiration (PET) data are not available for every location in Tanzania. But already, there are well-developed resources that can enable planners access meteorological data to estimate crop water requirements for RWH planning.

8.4.1 Introduction - Using available software for RWH planning

This case presents the possibility of using CROPWAT software and meteorological database, CLIMWAT, to plan RWH systems for dry spell mitigation using supplemental irrigation. The purpose is to give the planner an efficient and user-friendly planning tool based on available modern resources. CROPWAT is a software developed by FAO. It enables planners to estimate maximum crop water requirements and irrigation needs using the procedures presented in Chapter 3. CLIMWAT is a database containing meteorological data and crop coefficient data for 144 countries for the major food crops. In Tanzania alone, monthly rainfall and potential evapotranspiration is available for 46 locations. The CROPWAT software and the CLIMWAT database are available for free and can be downloaded from the FAO web site on: http://www.fao.org/waicent/faoinfo/agricult/guides/resource/soft.htm (or start with the FAO homepage (http://www.fao.org) and continue to the agriculture page and from there click on software).

8.4.2 Rationale for water balance accounting

Crop water stress leading to yield reductions or complete crop failure, is more often caused by dry spells than by seasonal droughts. Dry spells are short, and constitute 2-4 week periods of water scarcity during crop growth. If a dry spell hits during growth stages sensitive to water stress such as during flowering, the result can be a complete crop failure. In semi-arid areas, this means that crop yields are often chronically low not due to inadequate total rainfall levels but rather due to the detrimental effect on crop growth of dry spells. Dry spells are a result of poor rainfall distribution. Rainwater harvesting structures like farm ponds or earth dams can be an efficient method of managing dry spells.

The challenge for a planner is how to assess the amount of water needed in order to mitigate dry spells. Conventionally, the design of water harvesting structures for supplemental irrigation is based on one or several of the following;

- the runoff production potential based on a study of the catchment area
- the actual crop water requirements, and if applicable,
- the potential size of the storage structure determined by investment capacity, and/or the actual land surface area available and the depth of soil.

The problem with this planning approach is that most assessments of runoff, rainfall, and crop water requirements are carried out on a seasonal basis. The method used for seasonal planning is outlined in Chapter 3, where irrigation needs are calculated on the basis of an analysis of effective, seasonal design rainfall compared to cumulative crop water requirements after having corrected for losses.

8.4.3 The principles of water balance accounting

Water balance analysis on short time steps is normally seen as very complicated due to the dynamic and complex processes involved when water flows through unsaturated soil. But in order to assess water needs to bridge or mitigate dry spells, a detailed water balance analysis has to be carried out. Further more, the accounting has to be carried out on a time step that actually captures the occurrence of dry spells. Such a time step is ideally on a daily basis, but for practical purposes not longer than 10 days.

The basis for water balance accounting is to focus on the most important flow parameter for the farmer, namely the change in soil moisture storage in the root zone (ΔW). In doing so, the water balance discussed more in detail in Chapter 2, takes the following form:

$$\Delta W = R - Roff - D - ET \quad (1)$$

where

R = rainfall,
$Roff$ = surface runoff,
D = deep percolation below the root zone, and
ET = evapotranspiration.

This means that the change in plant available soil moisture in the root zone is equal to the input of rain water minus all the losses of water through runoff, deep percolation and evapotranspiration.

The change in soil moisture is given as ΔW because it is a moisture change over the time step used (e.g. 1 day, 1 week, or 10 days), that is the soil moisture content at the end of the time step (W_{out}) minus the soil moisture available from the previous time step (W_{in}).

Writing out ΔW gives:

$$W_{out} - W_{in} = R - Roff - D - ET \quad (2)$$

For the purpose of water balance accounting, it is good to focus on the soil moisture available at the end of one time step (W_{out}), which for the next time step becomes the available initial soil moisture (W_{in}):

$$W_{out} = R + W_{in} - Roff - D - ET \quad (3)$$

The water balance equation now states that the soil moisture storage available to the crop in the root zone at the end of a time step is equal to the input of water (rain + soil moisture at the beginning of the time step, W_{in}) minus all losses (*Roff*, *D* and *ET*).

Box 8.1 *Account water like money - suggested extension message to make water balance everybody's business*

The water balance equation can be used for water flow accounting in the same way as you would be accounting for the flow of money in and out of a bank account. Figure 8.4 shows the money flows in and out from a bank account showing the analogies with water flows. The safe in the middle can be seen as the farmer's soil. The time-step can be taken as a month between salaries. The resource or input at the beginning of a month is the salary (i.e., rainfall) and possible savings from the previous month (initial soil moisture, W_{in}). The flow of money out from the account can go towards purchasing several items, some productive and some non-productive. However, to begin with directly, as the salary flows in, taxes are deducted (runoff) and the net salary (Rain - runoff) is what actually enters your account (or enters the soil = infiltration). This infiltrated money/water can be drained away on, for example, non-essential goods….(or deep percolation!), or evaporated away as pure loss when, for example, playing on lottery…(evaporation). But a part of the salary will go into production, like food etc. (plant transpiration)…and finally, there will hopefully be something left at the end of the month that can be saved for the coming month/time step (soil moisture, W_{out}).

If some money is saved at the end of the month (W_{out}), this will benefit the following month (W_{out} turns into W_{in}). But, if the expenses (*D*, *Roff*, *ET*) exceed the assets ($R + W_{in}$), then the account will be overdrawn and W_{out} will be negative. Suddenly there is a debt which can be solved either through credit, or by borrowing money. The crop does not have access to credit and can not borrow water from a neighbour. Every time the soil moisture at the end of a time step is negative, it means that the crop is suffering from a dry spell. Adding up the deficits over a rainy season gives an estimate of the total amount of water needed to bridge dry spells. This amount of water can then be used in planning for a rainwater harvesting system for supplemental irrigation that will function as a credit buffer.

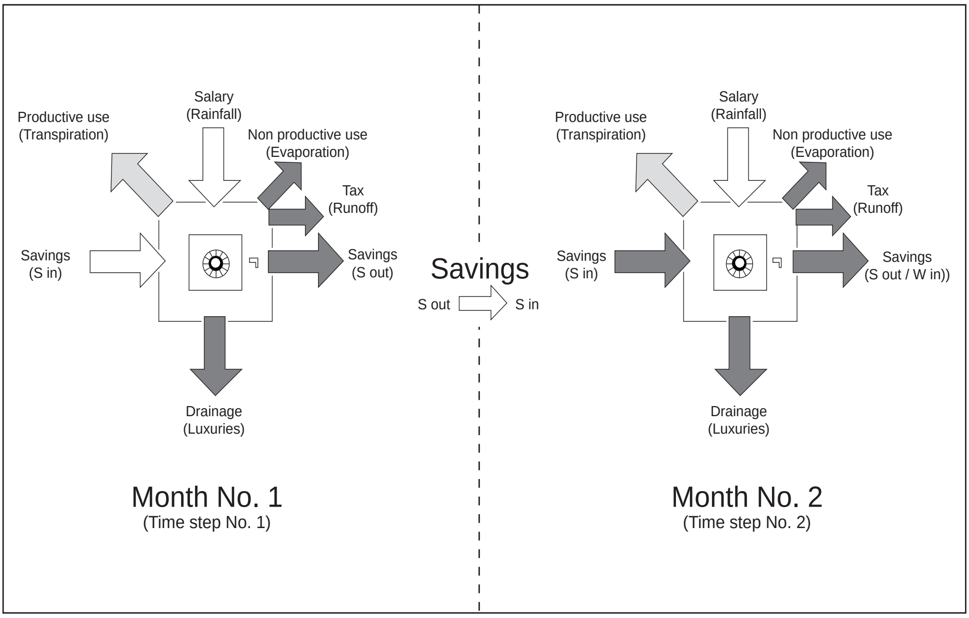

Figure 8.4 *Schematic presentation of money-flows and their analogy with water-flows through a bank account/soil over two time-steps (monthly for salary flow).*

8.4.4 Water balance accounting for a farmer in Same

The following case is taken for a farmer in Same who is cultivating maize in the semi-arid farmland close to Same town. The rainfall data is from the long rains 1992, which had a severe dry spell during flowering. The objective is to design a farm pond that can supply enough water to cope with dry spells in that region. From interviews with farmers in the area, it seems that dry spells occur almost every rainy season and farmers are especially concerned with 3-4 weeks of dry spell hitting the crops during flowering. The farmer's *shamba* is 2 acres, and he cultivates a monocrop of maize.

A time-step of seven days is used in order to capture when the crop actually starts to suffer from water scarcity.

In order to carry out a full water balance accounting over a whole season, we need to;

- obtain data on rainfall (preferably on a daily basis).
- estimate surface runoff.
- estimate water holding capacity and field capacity of the soil.
- estimate hydraulic conductivity of the soil in order to calculate deep percolation losses.
- estimate crop water requirement.

All these flow parameters are difficult to calculate accurately on a daily basis. This is especially the case for estimates of water flow through unsaturated soil. In this case example, we simplify the calculations to a maximum in order to show the principle of water balance accounting using a minimum of input data.

8.4.5 Rainfall

As discussed earlier in the handbook, for planning purposes, several methods of rainfall estimates can be used. Here two cases are presented. First the case when there is daily rainfall observations available (which is the case for Same town). Secondly, using CROPWAT and CLIMWAT for the same farmer in Same, using only the meteorological data in the CLIMWAT database.

The figure below shows the observed rainfall during the 1992 long rains in Same (Figure 8.5 a) and the average rainfall data from CLIMWAT for Same town (Figure 8.5 b). Rainfall is given as the long-term average. The line shows daily potential evapotranspiration (mm/day) also from CLIMWAT (Figure 8.5b). For the observed rainfall in 1992 (Figure 8.5a) the onset corresponds to the 1st of April (1st day after planting). As seen in this figure, there was a severe dry spell at flowering and maturing (from around 55 days after sowing and onwards).

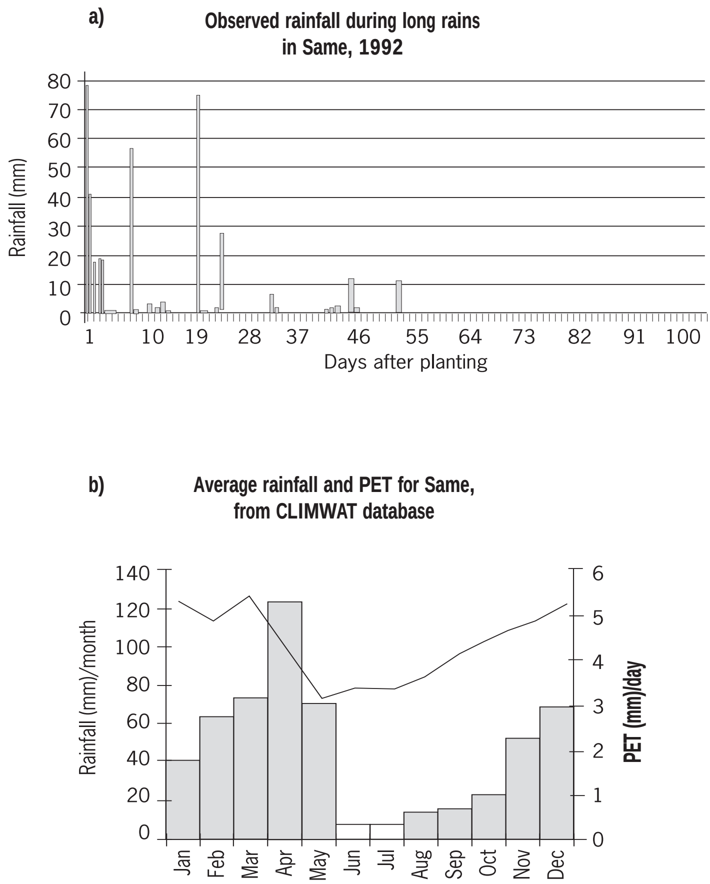

Figure 8.5 *a) Observed rainfall in Same, 1992. b) Long term average monthly rainfall in Same (in bars), with potential evapotranspiration (PET) shown on line graph (in mm/day).*

As seen from Figure 8.5b, the database CLIMWAT also includes good data on daily potential evapotranspiration (PET). As PET does not change significantly between years and only slightly over periods of weeks, the data in CLIMWAT can be used directly for planning even on weekly basis.

The problem with the rainfall data in CLIMWAT is that it is given as monthly averages, while dry spell assessment requires daily or at least weekly rainfall data. The average data is also not very useful as the only thing we can be sure of in drylands is that the farmer will never receive exactly the average rainfall. If daily rainfall observations are available as in the case of Same town (Figure 8.5b), then this data can be used directly for water balance accounting.

If rainfall observations are not available, then CLIMWAT can be used for water balance accounting. However, in water balance accounting for planning of RWH structure for dry spell mitigation, the planner needs to manipulate the rainfall data in CLIMWAT. The reason is that while rainfall in CLIMWAT is given as monthly averages, assessment of dry spell occurrence requires preferably daily or weekly rainfall data. The following procedure can be used to solve this:

- Start by discussing with farmers on the occurrence of dry spells.
- Ask the farmers to assess how long they are and when they hit the crop.
- If, let's say 2 - 3 weeks of dry spell is common during flowering, and this is identified as a major concern among farmers, then a planner can use this information and merge it with the monthly CLIMWAT rainfall data.

Start by dividing the monthly rainfall data in CLIMWAT into the accounting time-step (e.g., 7 days). Then delete the 2 - 3 weeks of rain that falls (according to the average data in CLIMWAT) during flowering. This creates a new series of average rainfall including a dry spell induced by the planner, hitting the crop during flowering. In order to assess needs for supplemental irrigation, run the water balance accounting on this rainfall series following the procedure below:

- *Surface runoff*
  Estimate how much of the rainfall is lost as surface runoff. As mentioned earlier in the handbook, this will depend on several factors like surface crusting, plough pans, rainfall intensity, soil moisture content, soil texture, and slope. For the purpose, of this planning exercise, we have opted for a constant runoff coefficient for all rainfall events exceeding 20 mm (assuming zero runoff for rains < 20 mm depth). This estimate was based on observations in the farmer's field. The runoff coefficient used in this example is 0.2 (meaning 20 % of the rainfall is on average lost as surface runoff for rainfall events exceeding 20 mm).
- *Crop water requirements using CROPWAT*
  Estimate crop water requirements (CWR). For this purpose, we follow the procedure outlined in Chapter 3, where maximum crop water requirements are calculated from PET and crop coefficient (kc) data. Using CROPWAT, it is possible to estimate maximum crop water requirements for a maize crop cultivated in Same during the long rains in this case of 1992. Meteorological data are retrieved from CLIMWAT (primarily PET for CWR calculations).

Using CROPWAT, data is retrieved on crop coefficients. The soil type and information can be set on planting dates, cropping pattern, length of growing season, and lengths of each growth stage.

In our case we plan for a 90-day maize variety and the crop coefficients are set for a 20-days germination phase, a 30-days vegetative phase, a 30-days flowering and grain filling phase, and some 30 days to full maturing and drying. With all the site-specific information set, CROPWAT generates estimates on a 7 day basis. This is of maximum crop water requirements for the maize crop cultivated under the agro-climatic conditions prevailing in Same chosen according to the time step we use in the water balance accounting). The distribution of maximum *ET* on a weekly basis is shown in Figure 8.6. The cumulative maximum *ET* for a full crop yield amounts to some 290 mm.

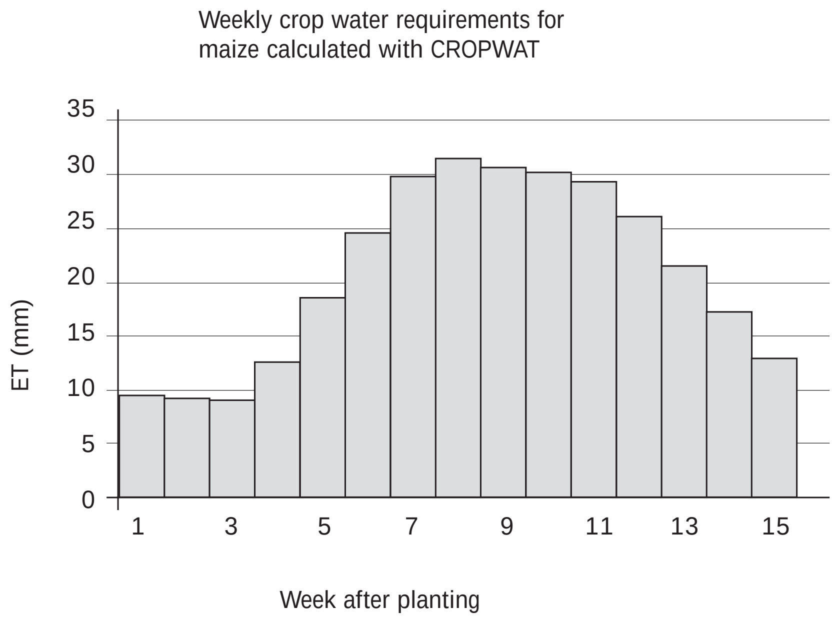

Figure 8.6 *Weekly maximum crop water requirement (in mm* ET *flow) for maize cultivated as a monocrop in Same, calculated by CROPWAT.*

- *Deep percolation*

  The remaining water balance component before full accounting can be carried out on a weekly basis is deep percolation. Deep percolation below the root zone (which we for simplicity have assumed to a maximum depth of 1 m applied throughout the season) occurs when the water content in the rootzone exceeds the field water holding capacity (FC) of the soil. The field capacity of a soil is a conventional characteristic of a soil (defined in Chapter 2). Field capacities of a soil will range from some 5% in sandy soils to about 45% in heavy clay soils.

For the purpose of water balance accounting, we need to know, when deep percolation occurs and, once deep percolation occurs, how much water is actually percolated below the root zone. To properly estimate the process of water flow through saturated and unsaturated soil is very complicated. For the purpose of RWH planning, we adopt an extremely simple approach which is still under development.

We assume that deep percolation occurs when infiltration exceeds field capacity in the soil. A simple rule of thumb is that a light soil has a field capacity in the range of 100 mm/m of soil, a medium textured soil an FC in the range of 140 mm/m, and a heavy soil an FC in the range of 180 mm/m. In our case, we have assumed a field capacity of 150 mm for the whole root zone (150 mm/m over a root zone of 1 m depth).

This field capacity gives us a threshold of when deep percolation occurs. As soon as infiltration plus soil moisture from a previous time step exceeds 150 mm, we know that there is percolation occurring beyond the root zone. The tricky issue now is to estimate how much deep percolation will occur. This is basically impossible to estimate accurately without complicated mathematics, as deep percolation will be high when the soil is wet and rapidly decline when the soil dries out. Here, we have assumed a very simple constant value for deep percolation, based on saturated hydraulic conductivity data for different soil types (Table 8.1).

For medium textured soil light clay used in this case, we have assumed a maximum of 35 mm deep percolation per time step (7 days). As seen from Table 8.1 this is very much lower than the flow rate of some 2.5 – 5 mm per hour for a light clay with intermediate structure (which would amount to up to 100 mm per 24 hr). The reason is that the data given in Table 8.1 are for saturated soils (that is when the permeability is highest). The hydraulic conductivity will decline exponentially with the drying of the soil and therefore we have assumed only a couple of hours of saturated flow occurring over a 24 hr period after a rainfall event.

Table 8.1 *Estimates of saturated hydraulic conductivity or saturated flow of water through wet soil (mm/hr)*

Soil Type	Organic Matter	Permeability (mm/hr) Soil aggregate structure			
		None	Weak	Intermediate	Good
Sand	Low	25-50			
	Adequate	50-250			
Sandy loam	Low	15-25			
	Adequate		25-120		
Loam	Low	10-20	20-60		
	Adequate			60-120	
Clay loam	Low	2.5-5	5-20		
	Adequate			20-60	
Light clay	Low		<2.5		
	Adequate			2.5-5	5-20
Medium/	Low		<2.5		
heavy clay	Adequate			<2.5	5-20
Clay (sodic)		<1	<2.5	8	

Source: FAO Soils Bulletin No. 72, 1995

Water balance accounting if you have daily observed rainfall

Taking all these estimates from CROPWAT, CLIMWAT and soil characteristics, now gives us the possibility of assessing the storage capacity needed for supplemental irrigation to bridge dry spells. We assume for simplicity that there is no plant available soil moisture left from the previous rainy season. This means that the initial soil moisture (W_{in}) equals zero if planting is done immediately after the first rainfall event. If some showers have fallen before planting, this rainfall is put as the initial soil moisture storage at sowing (meaning that W_{in} is then equal to the sum of all rain received before sowing). Table 8.2 shows the whole seasonal water balance accounting for a farmer cultivating maize during the long rains of 1992. This is based on actually observed daily rainfall.

The actual accounting procedure is carried out one time step after the other. For the purpose of this case, the whole season is presented in one table. The start of the first time step corresponds to the onset of the rains and sowing. Sowing date in Same in 1992 was assumed to be 9th of April after some good showers exceeding 20 mm. The cumulative rainfall set for the first week of the 1st time step, amounted to 68 mm. Runoff immediately reduced infiltration to 54 mm (20% of rainfall lost as runoff).

Total moisture in the soil is equal to $I + W_{in}$, which amounted to 54 mm + 10 mm in this case as 10 mm of rainfall was received before planting and set as W_{in}. These 64 mm of water storage in the root zone do not trigger deep percolation (64 mm < then the deep percolation threshold of FC = 150 mm). The only consumptive use of moisture is therefore the relatively limited ET flow of 9 mm during the first week of germination. Soil moisture storage at the end of the time-step (W_{out}) then equals:

$$W_{out} = I + W_{in} - D - ET = 54 + 10 - 0 - 9 = 55 \text{ mm} \quad (4)$$

This finishes time-step No. 1, which shows that during the 1st week after planting, there was a build-up of plant available soil moisture in the root zone. Then we go to time-step No. 2. Here, W_{out} from time step No. 1 turns into W_{in} of time-step No. 2. Rainfall minus runoff gives an infiltration of 56 mm, which together with W_{in} give a total moisture content in the root zone of 56 mm + 55 mm = 111 mm. This is still below the deep percolation threshold, so the only outflow is again ET = 9 mm, giving a final W_{out} for the 2nd week of 111 - 9 = 102 mm. W_{out} turns into W_{in} for the next time-step and so on. The accounting continues like this for all the time-steps until maturing and harvesting of the crop.

During the accounting season of 1992, deep percolation occurs on the week starting on the 23th of April during the end of germination. This is as a result of excess rainfall during the early parts of the rainy season and relatively low crop water requirements (total of 30 mm). Then the rains suddenly end during the initial flowering. On the week starting 25th of June during grain filling, there is not enough soil moisture left to cover crop water requirements. W_{out} turns negative (- 21 mm). As there never can be a negative soil moisture content, W_{out} for accounting purposes is set to 0 mm (i.e., the root zone is emptied on plant available soil moisture). The negative W_{out} is put on the row below denoted W_{out} (def), because it indicates the quantity of additional crop water needed. What actually happens is that the crop suffers from water stress, and reduces its water use in this case, by some 20 mm (the crop absorbs water until the soil profile is empty on plant available soil water, which gives W_{out} = 0 mm). The following time-steps result in a similar water stress.

The cumulative water deficit amounts to minus 72 mm. With no supplemental irrigation, this late season dry spell of minus 70 mm will result in lighter cobs (poor grain filling) and thereby lower crop yields. It is worth observing that despite such a severe yield reducing water stress, the farmer experiences deep percolation that is normally a sign of too much water!. The effect is that on a seasonal basis, there is a rainfall total of 300 mm (minus 290 after planting and 10 mm before planting). This seems sufficient and actually even exceed crop water requirements of 293 mm. But due to the poor distribution of rainfall, the farmer looses large volumes of rain as runoff and deep percolation early in the season and suffers from water scarcity during the critical grain filling stage. The season looks good in the annual rainfall statistics but in reality, the farmer experienced a severe loss of yield.

Water balance accounting if no rainfall data is available

If you do not have any rainfall data available on a daily basis, you can still use CLIMWAT and CROPWAT for RWH planning to cope with dry spells. Following the procedure outlined under “Rainfall” above, we start by finding rainfall and potential evapotranspiration data for Same from the CLIMWAT database. The average monthly rainfall data given for Same is displayed in a table using CROPWAT and then saved as a text-file in order to be able to manipulate the rainfall data in a spreadsheet. We need to do this because the rainfall data from CROPWAT / CLIMWAT is not very useful in planning RWH as the rainfall becomes a monthly average. Dry spells never appear in monthly average rainfall data!. In this case, the monthly rainfall is adjusted by dividing it into weekly rainfall. The monthly rainfall is divided by 30 / 31 days and then multiplied by 7 to generate weekly rainfall data.

As a planner, the objective may be to design a storage RWH system that can cater for a 3 weeks dry spell during, for example flowering as this has been identified by the farmers as a critical issue causing serious yield losses. Table 8.3 below shows the same water balance accounting for Same as the above case with observed rainfall 1992. The difference here is that we have set rainfall to 0 mm for the 2 weeks at the peek of flowering (i.e., we induce a dry spell for planning purposes). This changes the seasonal rainfall from 285 mm (which is the long term average rainfall from mid-March to July according to the CLIMWAT database) to 251 mm for a year with a 2-week dry spell during flowering.

The results in this case indicates the water problems facing the farmers cultivating maize in drylands of Same during years of a dry spell during flowering. It shows that some 74 mm of additional crop water is required to cope with the dry spell. This is very similar to the 1992 accounts which indicate that using the average rainfall data from CLIMWAT and inducing a dry spell based on field experience and dialogue with farmers, may well be a good approximation of the realities in the field.

Planning of RWH based on water balance accounting

Based on the water balance accounting it is now possible to plan for a storage system for supplemental irrigation. Both the 1992 accounting and the full CROPWAT accounting indicate that farmers in Same area require approximately 75 mm of additional crop water requirement (AWR) in order to cope with short dry spells during flowering of a maize crop. Assuming an irrigation efficiency (I_{eff}) of 70 %, the actual supplemental irrigation requirement (*S*irri) would amount to:

$$S_{irri}\ (mm) = AWR\ /\ I_{eff}$$
$$= 75\ /\ 0.70$$
$$= 110\ mm\ (or\ 110/1000$$
$$= 0.110\ m) \quad \text{.......} \quad (5)$$

The farmer has a two acre maize plot which corresponds to area (*A*) = 8,100 m^2. The storage volume (*S*) would then amount to:

$$\text{Storage volume } S\ (m^3) = S_{irri} \times A \quad \text{.......} \quad (6)$$
$$= 0.110\ m \times 8{,}100\ m^2$$
$$= 891\ m^3$$

The result indicates that a storage volume of approximately 900 m^3 would form an adequate basis for the design of a RWH storage structure. Then depending on the type of structure, it may be necessary to consider seepage and evaporation losses from the RWH system (e.g. an open water pond).

Concluding remarks

The Same case shows that modern and user-friendly computer tools are available for RWH planning. There is also some easily available meteorological data that can be very useful for planning purposes. Rainfall data often, is collected with little thought of its use. When the objective is to find options to improve rainfed agriculture in areas with frequent water scarcity, all data related to water are needed. For example in the case above, knowledge was required on every aspect of water flowing through the landscape in order to properly design a small earth dam.

Finally, the computer capacity and human skills needed to do water balance accounting are available in probably all district government offices in Tanzania. A personal computer would do the job. Computers are generally available but are not fully utilized (mainly functioning as quick type-writers). There is an opportunity for planners to tap the information technology available at their doorstep.

8.5 Planning guide

The main message in this chapter is that land resources planning in general and RWH planning in particular, can be done better by applying information age techniques for data acquisition, storage and analysis. Efforts should be made to ensure that the advanced techniques are adapted in RWH planning at district level and above.

There is often an unnecessary hesitation to adopt new technologies on the basis of relevance, cost-effectiveness and institutional constraints. Given the amount of data required for RWH planning, there are hardly any situations where modern information technology is not justified. However, it is important to ensure that a conducive environment for effective utilization of these tools is created.

Adoption of remote sensing, GIS and the Internet will require thorough sensitization of stakeholders in the planning and decision making process. Experts should ensure that the capabilities of these tools are well understood by the decision-makers.

Planners should strive to achieve an institutionalization of remote sensing, GIS and the Internet at district level. The cost of these tools will be extremely low compared to the benefits if all sectors such as health, education, agriculture etc adopt their use.

To ensure success, it is important to observe the following:

- That basic and appropriate hardware and software is available.
- Pay more and adequate attention to the information users to plan the system.
- That the outputs from the system effectively support decision making. They should therefore be simple and clear to senior decision makers.
- Adequate budget is available to obtain data and services, including from private providers, universities and international organizations and companies.
- Adequate attention to information management, if possible a professional information manager should be hired.

Table 8.2 *Water balance accounting on a weekly basis for a 90-day variety of maize cultivated in semi-arid Same, long rains 1992. The negative values appearing on the bottom line (Wout (def)) shows the requirements for supplemental irrigation to manage the dry spell hitting the crop at late flowering and maturing (72 mm of supplemental irrigation). All numbers are given in mm of water.*

	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	Sum 105 days
Growth stage	**Germination**			**Vegetative**				**Flowering+grain fill**				**Maturing**				
Date	4/9	4/16	4/23	4/30	5/7	5/14	5/21	5/28	6/4	6/11	6/18	6/25	7/2	7/9	7/16	
R	68	70	77	30	10	7	15	12	0	0	0	0	0	0	0	289 mm
Roff	14	14	15	6	0	0	0	0	0	0	0	0	0	0	0	49 mm
I	54	56	62	24	10	7	15	12	0	0	0	0	0	0	0	240 mm
Win	10	55	102	141	138	131	116	104	87	59	31	4	0	0	0	
Moisture	64	111	164	165	148	138	131	116	87	59	31	4	0	0	0	
WHC	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	
Dp (mm)	0	0	14	15	0	0	0	0	0	0	0	0	0	0	0	29 mm
Dp max	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	
ET	9	9	9	12	17	22	27	29	28	28	27	25	21	17	13	293 mm
Wout	55	102	141	138	131	116	104	87	59	31	4	0	0	0	0	
Wout (def)	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-21	-21	-17	-13	**-72** mm

Notes: R = rainfall (mm/timestep), Roff = surface runoff, I = infiltration, Win = soil moisture at the beginning of a time step, Wout = soil moisture at the end of a time step, FC = field capacity, Dp = actual estimated deep percolation, Dp max = maximum assumed deep percolation per time step, ET = maximum crop water requirement during the time step, Wout (def) = soil moisture deficit to be covered by supplemental irrigation.

Table 8.3 *Water balance accounting on a weekly basis for a 90-day variety of maize cultivated in semi-arid Same, based on CROPWAT simulation (and inducing a dry spell of 2 weeks during flowering). The negative values appearing on the bottom line (Wout (def)) showthe requirements for supplemental irrigation to manage the dry spell hitting the crop at late flowering and maturing (74 mm of supplemental irrigation). All values are given in mm of water.*

																Sum
	7	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	105 days
Growth stage	**Germination**			**Vegetative**				**Flowering+grain fill**				**Maturing**				
Date	3/14	3/21	3/28	4/4	4/11	4/18	4/25	5/2	5/9	5/16	5/23	5/30	6/6	6/13	6/20	
R	51	17	7	17	29	29	29	29	0	0	17	17	7	1	1	251 mm
Roff	10	0	0	0	6	6	6	6	0	0	0	0	0	0	0	34 mm
I	41	17	7	17	23	23	23	23	0	0	17	17	7	1	1	217 mm
Win	0	32	40	39	43	49	51	47	41	13	0	0	0	0	0	
Moisture	41	49	48	55	67	73	74	70	41	13	17	17	7	1	1	
WHC	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	
Dp (mm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 mm
Dp max	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	
ET	9	9	9	12	17	22	27	29	28	28	27	25	21	17	13	293 mm
Wout	32	40	39	43	49	51	47	41	13	0	0	0	0	0	0	
Wout (def)	OK	OK	OK	OK	OK	OK	OK	OK	OK	-15	-10	-8.4	-14	-16	-12	**-76** mm

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The Swedish International Development Cooperation Agency (Sida) has supported rural development programmes in countries in Eastern Africa since the 1960s. It recognises that conservation of soil, water and vegetation must form the basis for sustainable utilisation of land and increased production of food, fuel and wood.

In January 1998, Sida inaugurated the Regional Land Management Unit (RELMA) based in Nairobi. RELMA is the successor of the Regional Soil Conservation Unit (RSCU), which had been facilitating soil conservation and agroforestry programmes in the region since 1982. RELMA's mandate is *to contribute towards improved livelihoods and enhanced food security among small-scale land users in the region*, and the geographical area covered remains the same as previously, namely, Eritrea, Ethiopia, Kenya, Tanzania, Uganda and Zambia. RELMA's objective is to increase technical know-how and institutional competence in the land-management field both in Sida-supported programmes and in those carried out under the auspices of other organisations.

RELMA organises training courses, workshops and study tours, gives technical advice, facilitates exchange of expertise, and initiates pilot activities for the development of new knowledge, techniques and approaches to practical land management.

In order to publicise the experiences gained from its activities in the region, RELMA publishes and distributes various reports, training materials and a series of technical handbooks.

About this book:

Runoff is generally seen as an enemy in land management, causing soil erosion and leading to land degradation. Most planning efforts have therefore focused on disposing of runoff as far from the farmers' fields as possible. This book demonstrates an effort to change such notion by giving district development planners, a solid basis for managing runoff as an asset and a source of water for different uses. The book provides guidelines on how to integrate rainwater harvesting for agriculture, rangelands development, wildlife, forestry, land conservation and control of flooding in district development plans. Each stage of planning for successful rainwater harvesting is outlined. The book is a reflection of the decentralisation of planning in Tanzania down to the district level. The target group for the book is primarily district planners in Tanzania, but the book is useful for professionals involved in rainwater harvesting projects in semi-arid regions of Eastern and Southern Africa.

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