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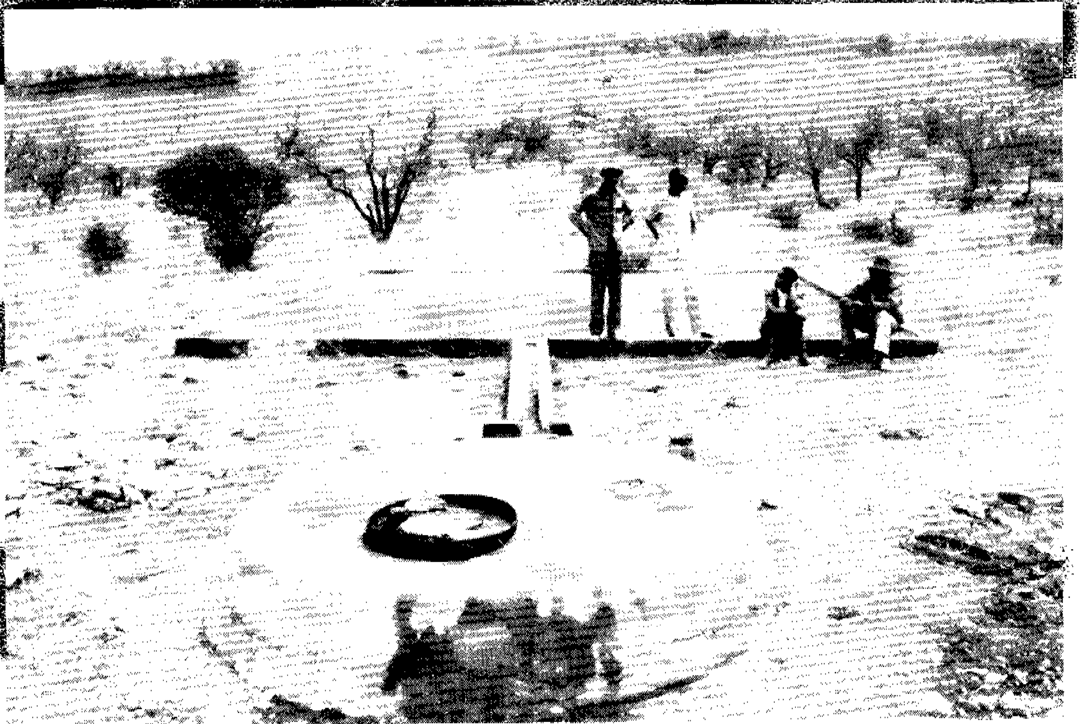
Water Harvesting

A Guide for Planners and Project Managers



30 Technical Paper Series

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Water Harvesting

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WATER HARVESTING

A Guide for Planners and Project Managers

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Abstract

The document describes key issues to take into consideration when planning water harvesting systems and shows the main features of the Arid and Semi Arid Lands environment including landscape profiles. It provides a description of the main water harvesting systems which are grouped under the following headings:
- rooftop harvesting
- surface harvesting
- underground harvesting
- runoff farming

The document particularly emphasizes the aspects related to community involvement, which is shown to be crucial to the development of sustainable systems. Techniques and systems need to be selected together with the community and due attention is needed to ensure that they match the skills of the people, so that systems can be maintained and extended when project interventions are no longer taking place.

It also summarizes financial and economic issues related to rainwater harvesting and potential financing arrangements.

Keywords: rainwater harvesting / planning / manuals / community participation / design / construction / maintenance / arid zones / semi-arid zones / economic aspects / financing / groundwater dams / runoff / irrigation.

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Preface

The purpose of this document is to introduce planners, decision makers and project managers to water harvesting and to show them where it fits into the overall picture of appropriate and sustainable community water supply development. Water harvesting is the collection, concentration and storage of water that runs off a natural or man-made catchment surface. Just like other water resources it is an option to be considered when planning an improved water supply system with a community. Depending on local environmental conditions water harvesting may provide a supplementary supply, an alternative supply or the only feasible improved supply, especially in rural areas of arid and semi-arid (ASA) countries.

Water harvesting: i) helps to smooth out variations in availability of water, ii) provides a more convenient water supply particularly in ASA countries and iii) helps provide a better quality water then traditional water sources.

Although some technical information is being shared amongst countries and projects, lack of information transfer continues to limit the development of effective intervention strategies for water harvesting. This particularly concerns the limited information and analysis which has been made concerning socio-economic and community aspects of water harvesting. This document attempts to fill some of the information needs of planners and decision-makers to a higher level than previously available by integrating a number of experiences from Africa and elsewhere. It also encourages project managers to publicize and exchange information about their own experiences, both successful and unsuccessful, for the benefit of the wider development of this important water resource.

The information provided on technical issues is quite specific as considerable experience is available in particular with the construction technologies involved in water harvesting. The information on socio-economic aspects is less specific as no blue print approaches can be given and much will have to be developed together with the population to cope with the differences in size, social organization, tendership and complexity of the rural communities.

This document has been prepared by Dr. Michael Lee and Mr. Jan Teun Visscher of IRC International Water and Sanitation Centre with financial support from the Danish International Development Assistance, Danida. The views presented in the document are the sole responsibility of the authors and do not necessarily reflect the official sector policy of Danida. The document was developed from a draft technical document prepared by Dr. Michael Lee and Mr. Erik Nissen- Petersen, which was based on the experiences of the Danida-assisted Mutomo Soil and Water Conservation Project in Kitui District, Kenya implemented by the Ministry of Agriculture. Experiences from other projects primarily in Africa but also from other areas in the world have been included to enable a strong emphasis on community involvement and to provide a broad-based view of the state-of- the-art in water harvesting as it applies particularly to the African context.

Special mention needs to be made of the experience gained from a UNICEF-supported study "Water Harvesting in Five African Countries" (Lee and Visscher, 1990).

In the development of the present document strong support was obtained from Mr. Kurt Mørck Jensen of Danida, and Ms. Christine van Wijk and Mr. Peter Heeres of IRC.

Furthermore we are grateful for the important contributions from the following persons: Mr. Barnabas J. Pullinga, Ms. Tineke Murre, Mr. Datius Rutashobya, Mr. Erik Nissen-Petersen, Mr. Kim Nissen-Petersen, Mr. Pierre Louis Lemercier, Mr. John Gould and Prof. Eggert Hansen, who reviewed the document and gave excellent comments.

1. *Introduction*

Water harvesting is a feasible option for improving the living conditions of many millions of people currently facing serious water supply problems. It is a very attractive supplement to traditional or improved water sources because it relieves the burden of water collection by bringing it closer to the home, and lowers the pressure on finite groundwater sources. Particularly in Arid and Semi-Arid (ASA) areas this approach can compete with other water supply alternatives such as handpump or piped schemes. This is most true for dispersed settlements and isolated rural areas occupied by subsistence farmers.

Despite the traditional emphasis of project designers on handpumps and piped schemes, it is gradually being recognized that water harvesting may provide these communities with the only feasible improved water source that is affordable and can provide an acceptable service level. When designing new projects it is therefore important to include the option of water harvesting as one of the possible solutions to providing a convenient and sustainable water supply to the users. Ignoring this potential may result in a considerable number of less suitable alternatives being chosen which are much more difficult to sustain.

The critical issue of working with the community as a partner in their own development process occupies an important place in this document. Chapter 3 provides insight into the ASA environment and conditions where the potential for water harvesting is considerable. Chapter 4 describes different water harvesting systems and discusses their characteristics, costs, advantages and limitations. It includes underground harvesting systems such as sand dams and sub-surface dams as a natural extension of surface dams. Furthermore, runoff farming, another form of water harvesting to increase crop production, is briefly discussed in Annex 1, as a natural compliment to water harvesting for domestic water supply.

Key issues to be taken into account in selecting a water harvesting technology are described in Chapter 5. Essential points in planning a programme together with the community are highlighted in Chapter 6. In Chapter 7 financial and economic issues are presented. The final chapters provide more detailed information on the main water harvesting systems being applied. These last chapters in particular may be of help to project planners and managers, as they explore a number of design and construction problems and give indications for improved siting of systems.

2. Approach to Water Harvesting

Water harvesting is the collection, concentration and storage of water that runs off a natural or man-made catchment surface. Catchments include rooftops, compounds, rock outcrops and hill slopes. Storage takes place in tanks, lined pits, behind small dams or in the sandy bed of a seasonal river. Stores are filled during rainstorms and inflow stops at the end of the rainy season. Water users are then left with a fixed volume of water until the next rains come. The amount harvested depends on the type of rainstorms, the size of the catchment and how quickly and how much runoff occurs.

2.1 Potential of water harvesting

Water harvesting has particular potential to:

a. smooth out variations in water availability; where rainfall occurs for only a few months and is followed by a period with no rainfall, lakes, rivers and shallow groundwater may all be plentiful but then gradually disappear as water evaporates, flows to other regions, and seeps deep into the ground. By collecting the rain and storing it more efficiently, in closed stores or in sandy river beds, a more continuous, reliable access to water can be assured.

b. collect and store water near to the place of use; where traditional sources are located away from the community or grazing grounds, collecting and storing water close to households, villages or pastures greatly enhances the accessibility and convenience of water supplies. This prevents the need to travel long distances or pump and pipe water expensively from distant sources.

c. provide good quality water; where groundwater or surface water is saline, contains high concentrations of harmful chemicals such as fluoride or nitrate, or is contaminated by pathogenic bacteria or other harmful substances such as industrial chemicals or pesticides, water harvesting can be used to provide a higher seasonal or year-round quality alternative.

2.2 Partnership and community management: key factors in the process

The key factors for success in water harvesting are developing a partnership with the users and planning for community management of the facilities. Only by creating a dialogue and by building capacity in the community can it be ensured that users will go on managing the water harvesting systems and constructing new ones. If this is not accomplished, the systems will not be expanded and service levels will gradually decrease as the population grows and new settlers come in.

Overall, the community's interests must take precedence over engineering considerations, provided this does not lead to unfeasible technical solutions. Communities deserve to make an informed choice concerning the technology they can best build, maintain and finance, and need to know what they must do to effectuate their choice. This requires dialogue between the project planner, field staff and the community, and also between the community members themselves. It also requires that the engineers and other agency staff can explain to the community in understandable language the essential aspects involved in the different technologies.

Government agencies and other support organizations which act as advisors to the community and openly discuss with them their needs and resources, the cost and technical feasibility of improved water supplies and the possibilities of community management and agency support, stand a better chance of establishing sustainable programmes. This is particularly the case for water harvesting, which has great potential for community involvement in management and in construction. To ensure sustainability, the project agency should be prepared to make a long-term commitment to the community, concentrating on skills training, group organization and decision-making and the after-care aspects of system management and maintenance (Table 2.1).

For any community-managed system, the local community or the individual families must be enabled to express their needs and preferences. It is essential that they are given responsibility for major decisions that affect the kind, size and scale of the system which they will have to manage and maintain. They also must have a say in other decisions such as who to select as craftsmen, who to train as caretakers, and how to finance the system. Thus, they must be involved in a process of information exchange so that they are aware of the benefits and drawbacks of different technologies and understand how they relate to their existing capacities and experience. No blue print can be given how this can best be done, as the conditions vary from community to community and country to country. An analysis of earlier experience with community involvement in a respective country in government or NGO projects may however provide some indications to build on.

The needs and preferences of people will depend on their current water supply coverage and service level, as well as their knowledge concerning different types of water supply sources, systems and their characteristics. Moreover, most households are faced with a number of equally important daily commitments in food production, child care, firewood collection and water collection. Any water development venture must therefore have obvious benefits which address the strongly felt needs of users, particularly if it requires significant time and energy inputs or financial contributions from them.

Table 2.1: Key elements of a sustainable approach to water harvesting

- Involving communities in identifying the most serious water-related problems and enhancing awareness about the importance and benefits of improved water supply.
- Involving communities in decision-making from the beginning and enabling them to make an informed choice between the different options.
- Jointly establishing adequate insight into local social, economic, geographical and environmental conditions.
- Training local community members in construction and management of the systems they choose.
- Proper selection, siting and construction of the water harvesting system.
- Organizing a lasting and locally suitable financial mechanism for cost recovery, re-investment, operation and maintenance.
- Focusing on women as the prime user group and involving them alongside with the men in decision making, management, and technical/financial aspects of projects.
- Provision of an adequate and easily accessible back-up support from government or non-governmental organizations.

Needs, preferences and possibilities will not be the same for all community members. There are clearly disadvantaged groups within every community, particularly in rural, dry-land areas. Most people agree that poor subsistence farmers and woman-headed households are generally the most important target groups. To date however, water harvesting programmes have not been very successful in really reaching these poorest groups, and considerable effort will be needed to overcome this inadequate situation.

Adequate agency support is essential for ensuring that the system chosen by the community is the right one for their needs in terms of quality, quantity, and reliability. The selected alternative must be affordable, manageable, have no serious negative social or environmental impacts and must be sustainable over the intended lifespan. This implies that the agency must have insight in local social, economic, geographic and environmental conditions. They should be able to communicate with the different user groups of men, women, rich and poor, and establish a dialogue between these different groups to guide the decision-making process.

3. *The Arid and Semi-Arid Lands Environment*

Water harvesting can be applied in many locations in the world but is of particular importance in countries with Arid and Semi-Arid (ASA) Lands, where it may often provide the only feasible solution for an improved water supply. Its potential very much depends on climate, hydrology, landscape and vegetation.

3.1 Climate

The harsh climate in the ASA regions is characterized by:
- low total quantity of annual rainfall;
- strong variations in rainfall through space and time;
- high temperature and evaporation levels.

Average annual rainfall figures in ASA regions range from 250-750 mm (Table 3.1). There is however, considerable spatial variation, for example due to differences in elevation. As a result some areas may receive no rains whilst others less than 10 kilometres away are experiencing floods. Community members living in the area may be very helpful in identifying locations with better rainfall characteristics and can often provide good information on surface runoff and groundwater flow characteristics.

Table 3.1: Classification of regions according to rainfall figures

Region	*Actual rainfall*
Desert	0 - 100 mm
Semi-desert	100 - 250 mm
Arid	250 - 500 mm
Semi-arid	500 - 750 mm

Seasonal rainfall variations are also considerable, usually with a greater number of dry than wet months. In parts of Kenya for instance, 'long rains' occur between February and May, producing roughly one third of the total annual rainfall, and short rains fall between October and December, producing the other two thirds. In between the months are dry.

Years with low and high rainfall are common, and the highest recorded annual rainfall in a sequence of years can be over six times the amount of the lowest recorded annual rainfall. For instance, in the Eastern Province of Kenya between 1974 and 1987 the lowest annual rainfall was 237 mm, and the highest 1471 mm, a ratio of 1 : 6.2.

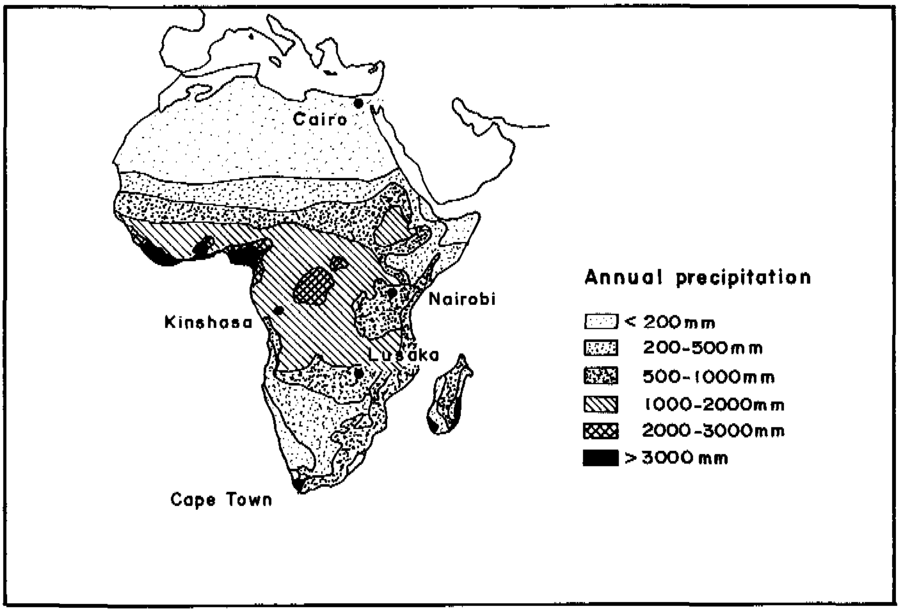


Figure 3.1: Average annual rainfall in Africa (Source: Tanke and Gulik, 1989)

Clearly, large variations and particularly the long dry periods hold important implications for the design of water harvesting systems. Often the largest proportion of the seasonal and annual rainfall is produced by a small number of high magnitude rainstorms with high peak intensities. It is not unusual to record rainstorms producing 50 mm in a single hour, and over 200 mm in three hours. Such heavy rainstorms lead to rapid runoff and quick filling of surface water stores and water tanks. These rainfall characteristics lend themselves well to harvesting techniques because a greater relative amount or runoff is produced than, for example, by light rains.

In addition to the low absolute quantity of rainfall, its seasonality and annual variability, the generally high temperatures within the ASA regions give rise to high potential evaporation and transpiration rates. The potential evaporation rate is the evaporation per square meter of open water per year, which is usually greater than total rainfall and often in excess of 1500 mm. Anything but deep surface water bodies will quickly disappear, and soil moisture reserves can quickly be transpired by vegetation. As a consequence perennial lakes and rivers are virtually absent in ASA regions unless they are fed by runoff from more humid locations.

3.2 Landscape and vegetation

Generally, ASA landscapes are comprised of four important landscape types, which can be easily distinguished as indicated in Figure 3.2.

Rocky top slopes and isolated rock outcrops exist in many areas, forming mountains and hills with steep slopes of up to 45 degrees or greater. Bare bedrock can comprise 80% or more of the surface area. In some cases, for example in Eastern Kenya and Botswana, isolated rock outcrops can emerge from plains in the form of inselbergs (also known as tors, or whale-backs).

Medium slopes are generally between 10 to 20 degrees and are covered with a mixture of rocky and soil-covered surfaces. They form a transition between high, rocky hills and the shallow plains and valley floor below. Soils are quite coarse, usually sandy loam. Gullying may occur in soils, especially where there is little vegetation cover, and streams rush forcefully down the hills during rainstorms.

Low slopes are between 1 and 10 degrees and usually broad and shallow, forming a sweeping apron at the foot of mountain ranges or hills. Additionally, they may occupy vast areas of undulating surfaces, separated by broad, shallow valleys. Soil cover is usually 100%, though variable, with areas of fine, clay soils as well as locally coarse deposits.

River channels, which are often called sand-rivers because they are seasonally-flowing, occupy broad sand-filled depressions and mostly have steep banks up to several metres high. They sweep through the low slopes until they dissipate into a wide floodplain, lake or the ocean.

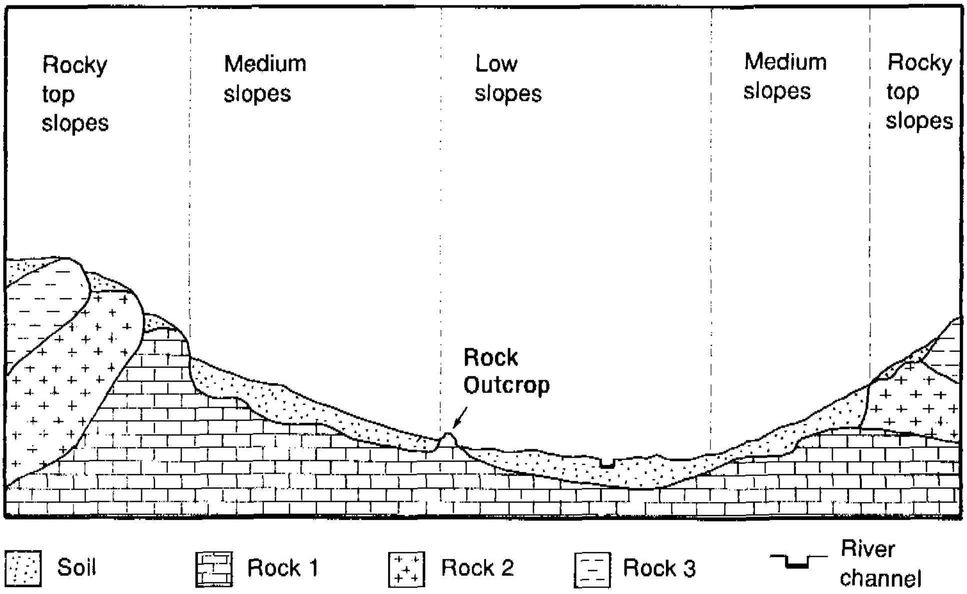


Figure 3.2: Landscape cross-section

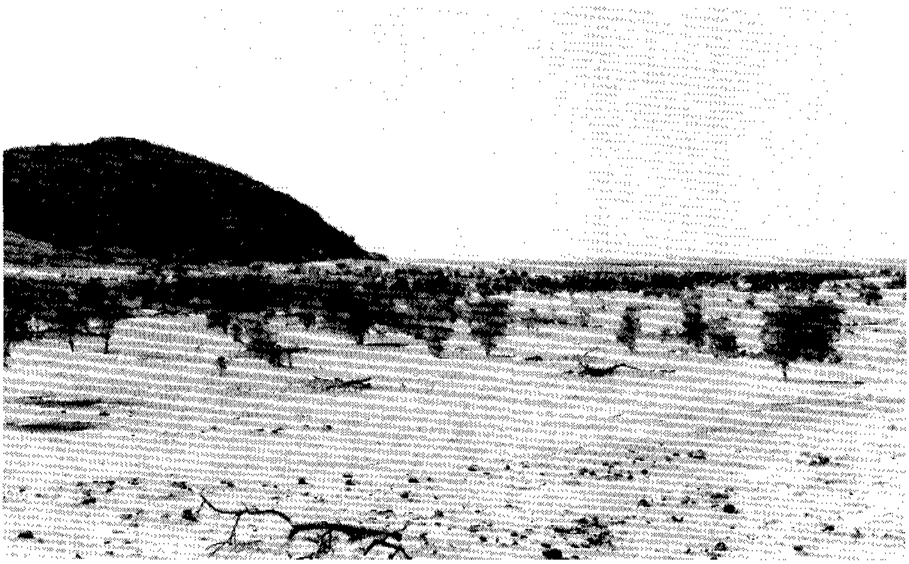


Figure 3.3: Rock outcrop in Quaddai, Chad

Not all of these landscape types may be present within a region. The proportion of rocky outcrops depends upon the exposure of major geological structures, such as volcanic intrusions, or major folds and faults in the bedrock layers. Where these features are absent, bedrock outcrops and medium slopes may not occur for hundreds of square kilometres, with the landscape dominated by broad valleys separated by soil-covered hills.

Below any rock outcrops, the soils are generally coarse and stony. They are usually sandy loams on the steeper slopes, changing to loams and silt loams as gradients decrease. On the low slopes, clay-rich black-cotton soils can form which have a low permeability and poor drainage of surface water. This depends on the underlying geology and the patterns of erosion and deposition. On the low-slopes, alternating wet and dry soil conditions can result in mineral concentration a few metres down in the soil column in the form of iron-pan, laterite or murram. These conditions may impede downward drainage and result in more frequent and rapid runoff.

Vegetation cover ranges from high density evergreen and deciduous tree and plant associations on the aprons surrounding rocky outcrops and along the drainage lines, to thorny low scrub on the more gentle low slopes.

Under conditions of low and erratic rainfall, the soils of ASA regions are often in a delicate balance with nature. As pressures on soils increase from farming, clearing of vegetation for firewood collection, charcoal production, and livestock grazing, the structure and nutrient content can rapidly degrade. The consequence can be intense gullying and soil loss on even the lowest gradient slopes. Surface reservoirs may rapidly fill with soils washed off a hillside or dams might be breached by torrential flows.

3.3 Hydrology

In the ASA environment, runoff rates rise and fall rapidly due to high rainfall intensities, steep slope gradients and low vegetation cover on the slope surface. However, because of the often short, sharp, intense bursts of rainfall, and the variations in slope gradient and surface type along flow-lines, runoff is not generated uniformly. Some locations react more rapidly and strongly than others because their surface has a low infiltration rate and little vegetative cover. The local population often has good insight and knowledge of the hydrological characteristics and, therefore, is a very important source of information to assess local conditions.

Locations that have deep, coarse soils or dense vegetation may produce little or no runoff. High density vegetation absorbs part of the rainstorm in the form of interception storage. Dense vegetation cover increases infiltration by breaking up the soil surface and increasing organic material content, thereby slowing down runoff flow velocity, and allowing more time for infiltration to take place. A similar effect results from the slope gradient. On shallower slopes where flow is slower and water more widely spread, there is a greater opportunity for infiltration to occur, providing a lower surface runoff. Steeper soil-covered slopes, although generally having coarser soils with high infiltration rates, can produce considerable runoff. Shortly after a burst of rain, soil infiltration capacity may be exceeded, thus producing runoff which concentrates in gulleys and can fill reservoirs.

In ASA regions, river flow is seldom permanent unless the river flows down from more humid regions such as mountain ranges or different climatic zones. Almost all surface flow carried is stormwater that rushes off the land during and immediately following rainstorms. However, in the river bed itself there is a slow, subsurface flow of water which depends on the porosity, the continuity of the pores and the hydraulic gradient (the longitudinal slope of the river bed). Flow rates are usually in the order of magnitude of 10-2 to 10-3 m/s for coarse sandy riverbeds and down to 10-9 m/s for compact clay.

The depth of the water below the surface can vary from tens of centimetres shortly after the stormflow, increasing to two metres or more some months later. In some river beds, flow stops completely as the moisture content falls to the point at which gravity flow is no longer possible. At this point, water will stop draining into any excavation made in the river bed. The volumes of water that will drain from different fully saturated soils are listed in Table 3.2, clearly showing the advantages of siting a shallow well in a sandy, coarse soil.

Table 3.2: Volumetric moisture storage in soils

Soil	*Clay%*	*Silt%*	*Sand%*	*% Draining*	*Volume drained/m^3*
Sandy	5	5	90	34	340 l
Loamy	20	40	40	21	210 l
Clayey	65	20	15	19	190 l

3.4 Current water situation

In African ASA regions today, as much as 80% of the total rural population relies on unimproved traditional water points. These include shallow water holes, depressions among rock outcrops, ponds or lakes, permanent or seasonal rivers, springs and shallow groundwater accessed by hand-dug wells.

The water quality of surface water is generally low because of a lack of protection from contamination. Faecal coliform counts are high, with incidents of amoebic dysentery, intestinal parasites, guinea worm and in some mud-banked reservoirs, bilharzia. Numerous insect larvae carry-out their life-cycle in and around the water source. A large number of pathogens result from the tendency to allow livestock to use the same water source, or be allowed into the immediate vicinity. People who extract water from the source use their own buckets or scoops, which are placed on the ground and then into the water. This introduces impurities such as soil, vegetation and most importantly disease carrying organisms. People may also use the point for washing clothes or bathing and children swim and play in the water. In many locations, unregulated open-air defecation or poor latrine facilities contribute strongly to the introduction of pathogens in runoff water and shallow groundwater (Lee and Bastemeijer, 1991).

In many communities, experience exists with using vegetation as a method of pinpointing a suitable location for a well. Usually several varieties of evergreen trees, shrubs and grasses that consistently correlate with sites of good groundwater potential are known to local people. Many of these sites, however, will be quite far away from settlements and remain relatively inaccessible because piped systems have not been introduced. Furthermore wells may not be deep enough or in the right place to access the complete groundwater potential.

Considerable potential thus exists to improve existing sources and better use the resource potential of an area. Yet these improvements often are not carried out due to lack of technical expertise and financial resources, or because users are not organized to implement such improvements.

Traditional water points are most numerous during and immediately after the rainy season. As consumption and evaporation continue into the dry season, the number, density and volume of reserves decrease and the quality generally deteriorates. Finally, at the end of the dry season or earlier during drier years, only a small number of permanent sources are left such as shallow wells in major drainage channels, isolated springs and a small number of boreholes.

It is usual that the water sources closest to each homestead are used first. They usually have a local, well-defined user group. As these sources begin to dry up, the larger water points, previously visited only by a local group, are visited by a large number of people from further afield. By the end of the dry season they may be serving the complete region.

The traditional coping strategy of journeying to available water results in a sliding scale of hardship. During the rainy season and immediately afterwards, the average journey time for water collection may be less than one hour, and family members may make several journeys a day to the nearest standing water. Water consumption per capita is relatively high due to the ease of collection, and general perception of plentiful reserves. Soon, because of evaporation and seepage, more distant points may be used and journeys increase to 2-4 hours with round-trips of 4-8 km. Many people will travel every day, collecting 20-25 litres on their backs. This is almost exclusively done by women. Those families who have donkeys or ox-carts collect four to eight times as much water respectively.

As the water points dry up, for some people the journey time increases up to 4-10 hours, round-trips up to 25 km, and the waiting time at the water point increases as queues form at wells and waterholes, especially at the end of the dry season. Those with donkeys or carts are able to travel only every 2-3 days and sell water to those who can afford it, such as merchants, cash croppers or those earning a migrant's wage. Collectors by foot will travel every second day, cutting down their water consumption to the bare minimum. Where families have more than four members and few water collectors, consumption can fall to 2-3 litres per person per day. Water collection becomes a full-time occupation and may easily lead to quarrels by people getting tired of waiting, trying to jump the queue or loosing their temper. These tasks of fetching and carrying water compete with other necessities of agriculture, child care and firewood provision to an unacceptable level.

In some areas, women go through considerable efforts to preserve certain higher-quality water points as drinking water sources (van Wijk, 1985). However, water scarcity can become so severe during part of the year that these efforts become unmanageable and water quality falls to a lower priority. Getting good quality drinking water from traditional sources may also be constrained by conflicting interests between different user groups. Women, for example, will often lose quarrels with powerful cattle owners over water sources. As conflicting interests may also influence use of improved water sources, they need to be identified and settled through discussions with and between user groups.

3.5 The communities in ASA regions

Historically, the population in ASA regions is largely based on semi-nomadic pastoralism. They were well-placed in their regions because there were few competing interests vying for land to farm. Groups of families chose to freely shift from water-point to water-point, using effectively the available fodder and supplementing diets with seasonal fruit and game. Some settled near permanent water points and subsisted on farming as a supplement to pastoralism. Other groups were forced to adopt a more marginal lifestyle in the ASA regions because of social tension, such as wars with other 'tribes' or foreign settlers over more fertile, better-watered lands.

More recently, for example in Kenya, a new kind of dweller has appeared who has adopted a more sedentary lifestyle heavily reliant on mixed farming. These are farmers from the more fertile lands who are not fleeing from conflict, but from political and population pressures exerted on the economically productive zones. Improvements in health care, diet and tribal stability have led to rapid increases in population which continues at a high pace today, with population levels doubling every 20-30 years. The pressures on the good land have grown so great that overspill into the marginal regions, where land is virgin and available, has become unavoidable. As a result, the practices of shifting agriculture and nomadic pastoralism have been largely restricted. Issuance of land rights along transhumance routes, the closing of national boundaries to free movements, and the establishment of quarantine zones for animals have further reduced the nomadic life style.

Large families of eight or more people are common in ASA regions. Often children are made responsible for many household and farming chores whilst mothers are busy collecting water and firewood. Children are expected to look after livestock and siblings, work in the fields, and assume responsibility for their elderly parents when they are full grown. While having large families is a common coping strategy, it implies high water and food requirements for individual families and places a heavy burden on parents and older children.

Most householders practice mixed farming and are dependent on both marginal rain-fed crops and livestock for their livelihoods. Generally their annual cash income is below US$200. Statistics from Kenya show that the majority of rural families in the semi-arid areas subsist on less than one hectare of farmland and eight standard livestock units.

The better off families are usually involved in local commerce, owning stores or transport businesses, but may also be landowners with access to perennial water sources where cash crops can be grown with irrigation. The poorest families are the subsistence farmers living in the driest zones, furthest from any water sources and on the poorest soils. At least one family member spends a large part of the day collecting water. The most disadvantaged are the families of widows, deserted wives and childless couples who are short of labour on their farms. Some families survive by one or more members, often the male head-of-household, leaving the rural community to find paid work elsewhere and sending home periodic remittances for family support.

Older people may be illiterate and lacking viable options to further develop their meager resources. Younger people are constantly better educated, with many countries having compulsory schooling to the ages of 14. This creates three major problems for the poorer parents. Firstly, there is considerable expense associated with sending children to school. Secondly, school removes children from the labour force, placing a larger load on mothers to collect firewood and water, and for cultivation. Thirdly, with the children's education levels and expectations increasing, the meagre conditions of rural subsistence farmers is rejected as insufficiently challenging or rewarding, and the able children flee to urban centres.

Improving water supply conditions alone will not modify the trend for rural people to migrate to already over-burdened cities in search of a better life. It must be accompanied by a range of integrated development activities that seek to improve agriculture, home industries, transport, energy supply, health and education. Nevertheless, improvements to the water supply are worthwhile even without these additional efforts because of their important contribution to improving local living conditions, particularly for the women and poor of ASA regions.

4. *Water Harvesting Technology Options*

Different types of water harvesting systems can be distinguished, including rooftop harvesting, surface runoff harvesting and underground harvesting. Each of these systems has its own characteristics, limitations and advantages.

4.1 Rooftop harvesting systems

Rooftop and tank systems provide an on-site source of water supply next to homes or public buildings such as schools or health centres. They can be constructed wherever there are permanent settlements experiencing difficult water supply conditions. Usually they require roof areas of more than 30 m^2, but even smaller areas can provide a partial supply to relieve some of the burden of fetching water.

Rooftop harvesting systems are comprised of the rooftop as the catchment area, connected by gutters and pipes to a storage container. The most suitable rooftop surfaces are corrugated iron sheet, although tiled and asbestos-sheet roofs can also be used. Thatched roofs pose problems as the runoff is lower and generally of a low quality. It is also more difficult to fix gutters to thatched roofs. The water collected from thatch is usually coloured, unattractive and more often contaminated (UNEP, 1983).

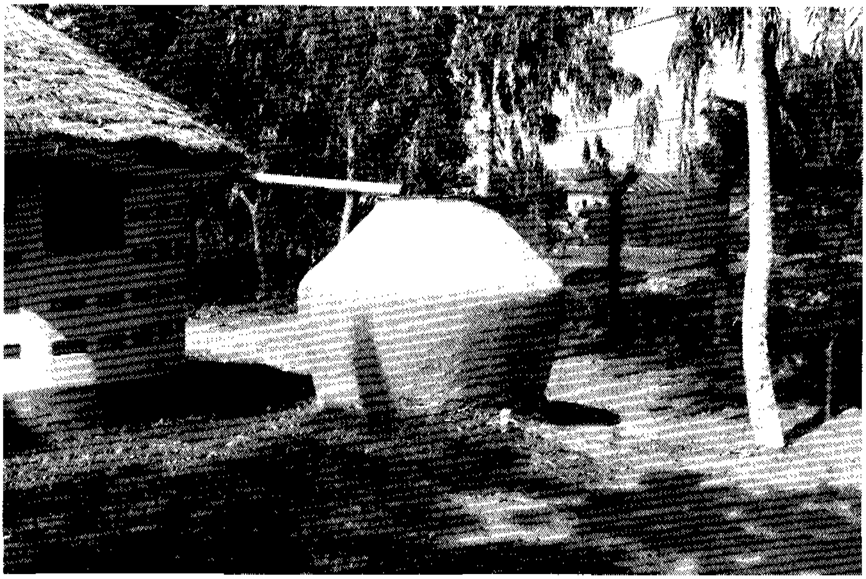


Figure 4.1: Rooftop harvesting system using a thatched roof

Simple rooftop harvesting is used traditionally in most ASA communities, even by many thatched-roof households (Figure 4.1). Pots and pans are placed below the roof edge to catch runoff. Innovative householders use a larger storage vessel such as an oil drum or a lined pit dug in the ground to store water, which is fed by a make-shift length of gutter fixed to the roof. However, they often do not go as far as building gutters and a large single storage tank that could provide sufficient water for the complete dry season if carefully managed. The reasons for this are:

- the lack of resources, both financial and technical, to construct larger systems;
- the poor local perception concerning the full resource potential of the household rooftop site;
- the temporary nature of some building structures or materials not warranting permanent harvesting fixtures;
- the poor suitability of the house design to support a larger harvesting system.

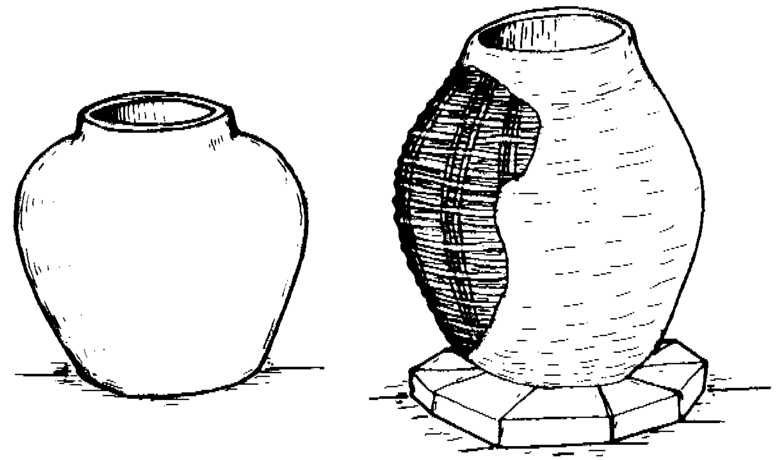
Improved systems differ from traditional ones in that a more effective guttering system is fixed to the roof and a larger storage vessel is provided. If properly designed, a first-flush device or detachable downpipe is fitted, excluding the first 20 litres of runoff during a rainstorm, which is generally most contaminated with dust, leaves, insects and bird droppings. Maintenance of this first-flush device however, is usually neglected, so in practice many fail to function adequately.

A wide range of storage tanks are being used, the most important of which are described in the next paragraphs. Sometimes new tank designs are introduced on a relatively large scale, without sufficient testing. This may easily result in failures affecting a large group of users. Thus, it is essential to allow sufficient time to make sure that a tank design is appropriate for the local conditions. In Thailand for example, it was decided not to introduce a tank design of interlocking bricks, as it proved too difficult to construct a leak-proof tank (Gould, 1991).

Cement water jars - are 0.5 to 2 m^3 tanks made by plastering around moulds, such as a wet sack of sawdust. In Thailand over 9 million reinforced cement jars have been built over the last six years. A survey in 1987 indicated, however, that construction quality was not always adequate and several jar owners reported the necessity for repairs. In Kenya construction of Ghala basket tanks was promoted by UNICEF in the 1970s and several thousand were built, many have not withstood the test of time.

Granary tanks - are 4 to 10 m^3 tanks built from woven-stick granary stores reinforced with chicken wire and plastered inside and out. However, in practice performance of granary tanks has been inadequate and they are not recommended.

Standing tanks - are cylindrical tanks built above ground. The smaller ones of up to 13 m^3 are made from ferrocement or bricks, either built around re-useable formwork or an internal frame of iron mesh and chicken wire, while the larger ones of up to 40 m^3 are made of ferrocement moulded around a rigid iron grid-mesh frame. Ferrocement tanks hold the most promise for future application.



Cement jar, Thailand

Ghala basket tank, Kenya

Figure 4.2: Cement water jars

The ferrocement construction that uses a weldmesh/chickenwire frame plastered from the inside and the outside appears particularly successful worldwide.

Sub-surface ground tanks - are generally roofed hemispherical excavations lined with ferrocement, ranging in size from 10 to 200 m^3. A handpump is usually provided to draw water hygienically.

Factory-made tanks - are pre-fabricated tanks of different materials including PVC and galvanized iron. Tank sizes vary but usually do not exceed 3 m^3.

The main advantage of a rooftop catchment system is the convenience of on-site domestic water, reducing the need to travel long distances for all or part of the daily water supply. For example, a 1 m^3 water jar can provide a family of 8 with 5 litres of drinking water per person per day (lpd) for 25 days or longer, thus considerably easing the hardship of trekking for water. The supply is more easily regulated when the owner of the system is able to control who uses the water, the rate of use, and the quality of the water. It can provide a back-up for frequently interrupted piped or pumped supplies, reduces the load on other communal water supplies such as pumps or standpipes, and can provide an extra supply for garden irrigation, yard animals and other home uses. The larger ground tanks are built for public buildings and can provide 5 lpd of drinking water to 200 people for up to 110 days following the rainy season.

The capital cost of household tanks and the requirement of a suitable roofing material such as iron sheet are considerable disadvantages. Many poor rural villagers have neither cash nor iron roofs. The more affordable small tanks cannot provide all the water needs of large families and so strict rationing is needed if supply is to be reserved for critical needs such as drinking, food preparation and personal hygiene. This requires a high management input from families, particularly as water consumption tends to increase when water is more easily available by the home. The quality of water may be impaired if users do not manage and maintain the system, or the tank is not fitted with a tap and/or first-flush diverter and filter screens (Lee and Visscher, 1990). Furthermore, tanks may provide a breeding place for mosquitos, potentially aggravating reason for local health problems such as malaria, which, for example, was the reason the government of Thailand advised netting of tanks.

4.2 Surface harvesting systems

Surface harvesting systems catch rapid runoff from natural or man-made surfaces, then concentrate and store it at strategic locations. They harness water that would otherwise be lost through infiltration and evaporation. The water thus collected is often used for different purposes including drinking water, watering cattle and agriculture. Coupled with other water systems, surface catchment systems can provide a complementary source of somewhat lower-quality water for non-drinking domestic uses and for livestock. They can be built wherever the landscape has characteristics which produce large quantities of runoff from rain storms on a regular basis. The requirements are: a suitable site on which a dam or excavated reservoir can be constructed, and a sufficiently large catchment area to supply the required runoff volume to replenish storage capacity. Man-made ground surfaces such as compounds and roads are also potential catchment areas.

Rock catchments - impermeable bedrock surfaces found within the rocky top slopes or exposed rock outcrops in the lowland landscape often have natural hollows or valleys which can be turned into water reservoirs by building a dam. These are simple stone walls, up to five metres high, constructed around the downstream end of hollows or valleys. Stone and mortar gutters may be built across the rock to channel the runoff water into the dam. Water is piped by gravity to storage tanks at the foot of the rock outcrop. Reservoirs generally vary in size from around 500 to 10,000 m^3.

Excavated reservoirs - Depressions on the soil-covered medium slopes or low slopes can be excavated or deepened so that they can hold surface runoff water. At the smaller end of the scale they include dug and plastered pits and ferrocement ground tanks. On a larger scale, they include Hafirs, Charco dams and borrow pits. Water flows to the reservoirs by gravity. They vary in size from the 10 - 200 m^3 ground tanks, described previously as part of rooftop harvesting systems, to 500 - 5,000 m^3 reservoirs.

Earth dams - where water flows regularly into a small valley or depression, earth dams can be built to retain water on-site, usually at locations already used as traditional watering points by local villagers. Earth dams are raised banks of

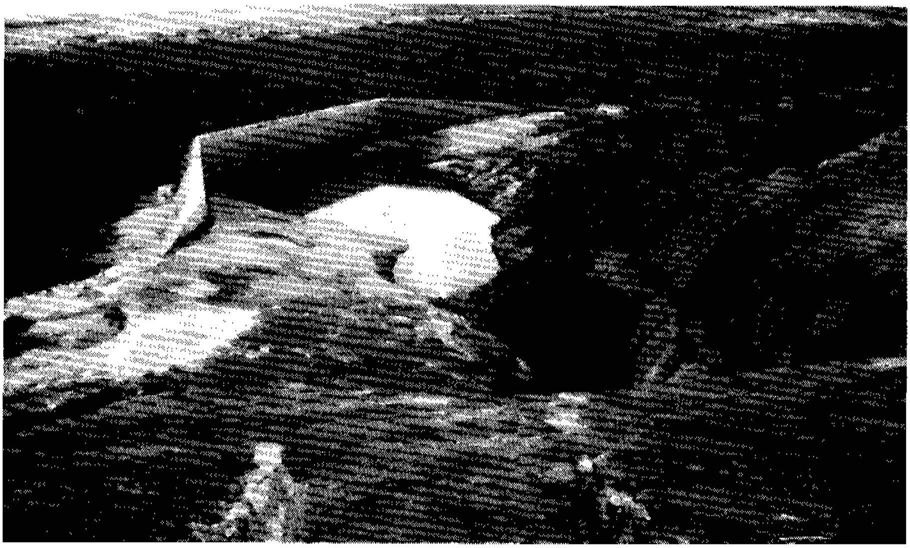


Figure 4.3: Rock catchment dam, Kitui District, Kenya (Photo M. Lee)

compacted earth, some 2 - 5 m in height, built at the downstream end of a hollow. These often include a clay core with stone aprons and a spillway to discharge excess runoff. The volume of earth dam water storage generally ranges between 1,000 and 20,000 m^3 and sometimes is as large as 50,000 m^3.

Surface harvesting systems can provide a large, concentrated source of water for communal use. A 5,000 m^3 storage tank, for example, can provide a community of 500 with 50 lpd during a 140-day dry season, even if 30% of the storage is lost by evaporation. Since most are traditional points, the sites are usually those most convenient or acceptable to the user groups in the surrounding landscape. Upgrading the collection and storage of traditional points can improve the quantity, reliability and quality of supply.

Surface harvesting systems have several disadvantages. Suitable catchments and storage sites for communal systems are often located a long way from individual settlements. Usually people and animals have free access to the catchment area and reservoirs. This entails a high risk of contaminating the supply and makes management, and particularly control of water allocation, more difficult. There are also the dangers of children falling into the reservoir while playing, which in several cases has resulted in fatalities. Fencing off of reservoirs is therefore a pre-requisite in many cases.

Surface water stores can aggravate the problems of malaria and other diseases. Earth dams in Tanzania for example, are often breeding grounds for mosquitos, and bilharzia and guinea worm contamination prevails in surface reservoirs of

West Africa (Lee and Visscher, 1990). Surface reservoirs for livestock can encourage rapid increases in grazing and degradation of the surrounding areas (Lee and Bastemeijer, 1991). Siltation of the reservoirs is another very relevant problem which requires frequent cleanings. A final drawback of open reservoirs can be high water loss through evaporation or seepage, which sometimes can be remedied through the use of covered or underground storage tanks.

4.3 Underground harvesting systems

Underground harvesting systems exploit water already infiltrated and concentrated through natural hydrological processes into the sand rivers that fill valleys in arid and semi-arid areas. River beds are traditional watering points. People use the surface flow during rainy seasons and dig shallow unprotected wells into the bed each dry season once surface flow has dried up. Underground systems comprise both sub-surface dams and raised-sand dams.

Sub-surface dams are vertical impermeable barriers of either compacted clay or masonry placed across and into the bed of a sandy river. The principles of sub-surface dam construction have been well documented by Nilsson (1984, 1988) who gives a range of case-study examples of different environments of application in Kenya, Tanzania and Southern India. The material in the river bed should be mostly sand; the coarser the better. Sub-surface dams are founded on bedrock or impermeable clay and must extend across the entire channel width. Clay-plug dams are cheapest and suited to deep river beds or those with a clay rather than a rock base. They are built by excavating a trench down to the impermeable layer beneath the river bed. This is then filled with clay and compacted to produce a relatively impermeable barrier. Stone masonry sub-surface dams can also be constructed by building a wall in a trench through the river, with its foundations on impermeable bedrock. Such structures are more expensive than clay-plug dams but are well suited to sites where a solid rock layer comes to within 3 or 4 m of the surface. A dam 3 m deep in a river bed 30 m wide will store around 5,000 m^3 of free-draining water if the soil is coarse sand. This provides a minimum supply of 110 lpd for 300 people over a 150 day period. Where water flow continues through the river bed from upstream locations as water is abstracted, the supply potential is much greater.

Sand dams are developed by gradually building up a wedge-shaped masonry wall in 50 cm stages, with foundations on impermeable bedrock. This results in sand being trapped behind the wall, whilst silt is washed downstream. The volume of the river bed upstream of the dam is increased and more water is stored in the newly enlarged or created shallow aquifer. The dam is raised as soon as the previous stage has been back filled by sand. Water is accessible to users either by a protected hand-dug well sited upstream or a gravity pipe and tapping station downstream. Sand dams are particularly suitable where the river has high, steep-sloping and stable banks. Sometimes, advantage can be taken by building a sand dam on a rock bar crossing the river bed. However, it should be checked carefully for fissures which would facilitate seepage of stored groundwater. As with sub-surface dams, a sand dam built up to 3 m high in a river bed 30 m wide, could supply over 5,000 m^3 of potable water.

Underground harvesting systems provide a large, concentrated source of water for communal use, extending the life or improving the yield of traditional wells used by rural people. The stored water quality is generally high, due to the filtering and purifying effect of the sand through which the water flows towards the dam or well. Evaporation losses are low in comparison to open reservoirs. The other advantage is that traditionally communities have used this type of storage, and therefore improvement of sand-river supplies is usually very acceptable.

The major disadvantage of underground harvesting is that it is the most site-specific of the water harvesting technologies. Water supply system locations are dependent on the position of sand rivers in the overall landscape and the location of a small number of suitable construction sites along their length. If built at the wrong location, dams can fail to improve the supply from wells because groundwater seeps away under the dam through impermeable layers or rock fissures. This obviously requires careful site selection before construction, since appropriate sites are less obvious than with surface harvesting. Many of the suitable sites will be far from villages, with women needing to walk long distances to fetch water. Another important drawback may arise from blocking the sub-surface flow in a river bed which may cut off the water supply of downstream vegetation and downstream users.

5. *Assessing Water Harvesting Potential*

Water harvesting techniques have a place amongst the range of water supply options which need to be built to improve the living conditions of the many people who do not have a convenient and safe water supply. The potential application of water harvesting will depend on its environmental, technical and socio-economic feasibility. Its long term success will depend on shared decision making and the "partnership approach" being put into practice by the agency promoting its application (see Chapter 6).

5.1 Environmental feasibility

Whether water harvesting is environmentally feasible primarily depends on rainfall amount, the type of rain storms, the length of dry periods and the availability of other water sources. The rainfall pattern over the year plays a key role in determining whether water harvesting can compete with other water supply systems. Climates that have short dry seasons and multiple high-intensity rain storms provide the most suitable conditions for water harvesting.

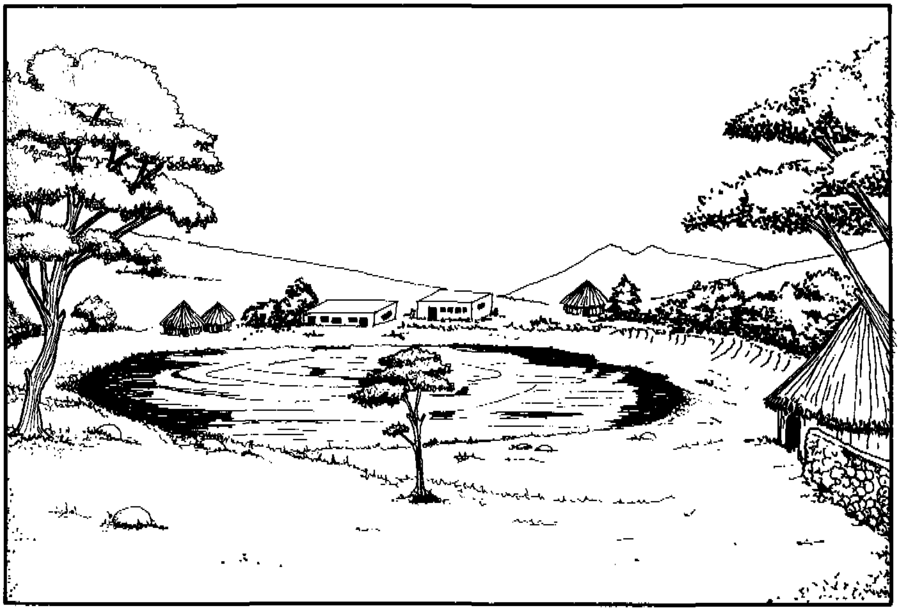


Figure 5.1: Traditional application of water harvesting. Banco-pit water source, (converted mud/clay quarry) in Mali

To evaluate harvesting potential, rainfall data is very important and should be obtained, for instance, from the closest airports or agricultural extension offices. If considerable differences in annual rainfall figures occur over the years, water harvesting has a lower potential and entails a higher risk that it will not provide a minimum service level. Nevertheless, even in such difficult conditions it may still be considered to provide a partial supply to help ease the lives of the people, particularly the women, for part of the year. The average rainfall figures for a region can provide a global indication of harvesting potential. This needs to be backed up wherever possible with local information, due to the variability of rainfall characteristics discussed earlier.

Through discussions with the local leaders, and other members of the community, insight can be obtained into places receiving more rain or runoff, which often can be confirmed by analyzing the local vegetation. Aereal photographs may be a helpful tool to establish the areas which receive larger quantities of water. Much can also be learned from traditional applications of water harvesting and experiences of water harvesting programmes.

The topography and the hydrology are also very important in determining the potential of water harvesting and identifying suitable catchment areas.

To establish the potential of a region a systematic review has to be made of the different landscape types which prevail. The four landscape types described in Section 3.2 are most common in ASA countries and will react differently to rainfall, thus having different potentials (Table 5.1).

Table 5.1: Summary of water supply options by landscape type

Landscape type	*Potential Site*	*Supply System*
Rocky top slopes and rock outcrops	Hollows, valleys, depressions	Rock catchments
	Rock fissures	Springs
	Settlements	Rooftop catchment
Medium slopes	Perched water tables	Springs
	Landscape hollows	Shallow wells
	Settlements	Rooftop catchment
Low slopes	Depressions, valleys	Earth dams
	Depressions, water-holes	Shallow wells
	Settlements	Rooftop catchment
River channels	Seasonal wells	Sub-surface dams
	Rock dikes	Sand dams

Rocky top slopes and isolated rock outcrops will have a rapid runoff response from impermeable rock surfaces, with large quantities of runoff water leaving the area onto the slopes below. Where rocks come up through, or near to the surface, springs can occur. Depressions or valleys in the rock surface fill with water during rains. Several possibilities for water harvesting exist on these slopes. Depressions can be enlarged into surface reservoirs with dams. Springs can also be protected and piped to users living on the slopes below.

Medium slopes may runoff more slowly due to vegetation interception and higher infiltration capacities of coarser soils. Depressions downslope filled with soil can infiltrate large quantities of water coming from above, retaining water in the soil. Where the surface is cleared of vegetation, soil erosion can be intense and flow velocity high. Where water tables in the soil rise up to the surface, springs will occur, although these may be seasonal. Options for water supply include improving seasonal springs by providing a protected intake. In some cases, hand-dug shallow wells can be dug into the soil-filled depressions on these medium slopes to access perched aquifers captured in sub-surface hollows in the rock strata.

Low slopes may not produce any runoff into river channels and streams because surface water infiltrates into the ground from puddles and ponds when the rain stops. However, where there are clay-rich soils, runoff may flow off the surface and collect in broad depressions or flow down into the sand rivers. Possibilities for water harvesting arise from the damming of smaller valleys and natural depressions to store the water running off the clay slopes. Shallow wells could be dug in the beds of water-collecting depressions to access water still stored in the soil after the surface has dried.

River channels will carry water as a function of their catchment size, the runoff character of adjacent slopes, the size of the rainstorm and whether rainstorms have occurred in previous days. Where the river is fed directly by many small streams flowing across the medium and low slopes from rocky areas, or from clay-rich low slopes, it may flow after every intense rainstorm. Possibilities for water supply are several. When the rivers are flowing, they can be used as a direct water source, either by constructing intakes for gravity pipes or by abstraction by hand from the bank. When the rivers are dry, shallow wells can be dug into the bed to access the sub-surface flow. To improve the yield from shallow wells and make them last longer, dams can be sunk across the river bed to hold back the sub-surface flow.

Additionally, with each of the three slope units described, the rocky top slopes, medium slopes and low slopes, wherever settlements are found with roofed houses and large compacted areas such as compounds, the potential exists for harvesting water into storage tanks.

Only a part of the rainfall falling on a roof or in a catchment area becomes runoff that can be harvested. A portion of the rainfall will infiltrate into the soil and some will evaporate. These are affected by factors including whether the catchment is flat or sloping, soils are coarse or fine, vegetation is dense or sparse and climatic conditions.

The yield of a catchment area can be computed as:

$$\text{Yield} = (A \times R \times f)/1000 \ \text{m}^3/\text{month}$$

where:
A = catchment area in m^2
R = monthly rainfall in mm
f = runoff coefficient

Table 5.2 gives estimates of the runoff coefficients of different types of catchment areas. Pilot runoff experiments could be implemented that examine how much water might be collected from a ground catchment before a full-scale program of sub-surface tank construction is initiated. By establishing plots on areas with surface conditions and slopes representative of those in the region, a practical estimate of appropriate runoff coefficients can be made which can be compared with the indicative figures of Table 5.2.

Table 5.2: Runoff coefficients

Roof catchments			
- tiles	0.8	-	0.9
- corrugated metal sheet	0.7	-	0.9
Ground surface coverings			
- concrete	0.6	-	0.8
- plastic sheeting (gravel covered)	0.7	-	0.8
- butyl rubber	0.8	-	0.9
- brick pavement	0.5	-	0.6
Treated ground catchments			
- compacted and smoothed soil	0.3	-	0.5
- clay/cow-dung threshing floors	0.5	-	0.6
- silicone-treated soil	0.5	-	0.8
- soil treated with sodium salts	0.4	-	0.7
- soil treated with paraffin wax	0.6	-	0.9
Untreated ground catchments			
- soil on slopes less than 10 percent	0.0	-	0.3
- rocky natural catchments	0.2	-	0.5

Based on: UNEP, 1983; Frasier, G., 1975 and Gould, 1989

By effectively using the different possibilities available in a region and choosing the right technology, the problems brought on by the unfavourable distribution of water can be eased. By developing more and larger stores of water, the overall supply situation can be improved tremendously. People may no longer have to adopt the traditional response of using up what is locally available and then moving further and further away in search of water.

During planning appraisals, a systematic attempt can be made to identify and record all potential catchment areas on a large topographic or photo-mosaic map. By also plotting the distribution of settlements and the locations of existing community groups or special target populations, a regional strategy can be adopted in which population needs can be matched with the hydrologic potentials of different catchment areas. In this strategy, optimal use should be made of all potential resources available for exploitation. Individually, for example, each rooftop and surface catchment system might only provide a partial supply throughout the year. However, seen collectively, every additional water harvesting system provides more convenient local water. They help conserve larger sources, which may be the only points left for use during long dry seasons or crisis periods. In the above-average wet years, local small and medium scale water points will provide sufficient water, with expenditure on water collection and transport being a minimum. In assessing the environmental feasibility also the possible negative aspects of intercepting the water flow in the respective catchment areas. This may have a very negative affect on natural vegetation and down stream users, including wild life.

5.2 Technical feasibility

The technical feasibility of the various water harvesting systems largely depends on the skills of the community, the availability of local materials and labour, and for the larger systems, on the availability of equipment. In assessing the technical feasibility of a particular system, it is very important to take into account the experience already acquired to avoid repeating mistakes previously made by others.

Relevant technical skills include masonry/ferrocement construction, carpentry, metalwork, plumbing and simple surveying. A lack of familiarity with water system construction is not a great barrier if these skills are present. Ferrocement roof catchment tanks need the highest skill level, followed by masonry rock catchment dams, masonry sub-surface dams, earth dams and clay-plug sub-surface dams.

Skills available in the community cannot always be put to good use. Most of the required technical skills are held by men, who may often be absent from the community earning a migrant's wage. Thus adequate skills training of women may be essential, provided local customs allow this. Such skill training may enable women to take an active role in the development process, for example as carried out successfully in Tonga (Fleming, 1986). A local training programme involves a significant commitment of time and resources prior to any implementation, whereas when skills are already widely held, hardware construction can usually begin at an earlier stage (Andersson, 1990). Expanding roles for women is very much in keeping with the traditional role women have played and are playing in the management and upkeep of existing water facilities (van Wijk, 1985).

The size of the systems and the required implementation speed will determine the amount of labour and type of equipment required. The availability of willing labour at certain key periods in the year for this labour-intensive activity is an important planning consideration. Sub-surface dams, rock catchments and earth dams all require significant numbers of person-days. Additionally, dams have to be constructed in the dry season, which is often a period when many men are absent. The shortage of labour can create a ceiling on the extent of work and size of construction to be undertaken. Lost earning potential can create resentment towards a village programme if participation in construction is made compulsory.

The extent to which women can assist in construction and management tasks needs to be carefully discussed and agreed upon with them. This is essential to avoid increasing their already heavy daily workload, including child-care, water and firewood collection and care of the home. Solutions may be found by encouraging the women to organize group child-care and by helping to provide temporary local supplies of water and firewood. Project agencies might help in this task by providing transport, a water bowser, or more efficient tools for time consuming jobs, such as a grain mill or provision of woodstoves to cut down on the need for firewood.

The quantities and types of materials required for the various options usually do not pose serious problems, perhaps with the exception of roofing materials, cement and chickenwire. Local availability of sand, gravel and stone are of particular importance for dam and tank construction. Where certain types of materials are not present within the community, local substitutes must be identified, designs modified, alternative technologies selected or materials imported from other areas. Checking of a detailed materials inventory against the local contract suppliers or natural resource surveys will point to any shortfall. Such surveys can be carried out with the local community, as will be further discussed in Chapter 6. Where materials need to be brought from other areas or imported, logistic arrangements need to be made to ensure future availability and transport.

Traditional thatch or mud roofs often found in rural areas are not very suitable for rooftop harvesting. A cleaner and more impermeable material such as iron sheet is required, as well as suitable guttering materials. Other possible materials include standard tiles, sisal-cement tiles and fibre glass sheet. Existing roofs with asbestos sheet can also be used although there are concerns over possible health risks associated with ingestion of asbestos fibres. This possible ingestion however is much more related to the production and installation of the asbestos sheets, when fibres can easily be liberated. Evidence from Kenya, Botswana and Togo indicates that in much of Africa, householders are switching to iron sheet, thus increasing the potential for rooftop systems (Lee and Visscher, 1990). To further accelerate this process for the poorer households, some project agencies such as the Catholic Diocese of Kitui in Kenya, the Government of Togo, and the Ministry of

Agriculture in Botswana, have developed roof catchments on pillars to accompany tanks. Recipients can use this structure as the basis of a new home or storage building.

Figure 5.2: Rooftop catchment structure, which could be used for housing

Commercial gutters are usually expensive, while home-made gutters of wood or bamboo are usually inefficient. Recently in Kenya, the Mutomo project pioneered construction of simple, improved low-cost gutters, deflectors and hangers from iron sheet and wire. Local production of gutters needs to be explored further, as it may contribute significantly to the effectiveness of programmes and offer a suitable source for generating income.

Many designs of water harvesting systems are simple, labour-intensive and require limited amounts of tools. Still, checks should be made to see whether even these simple tools are available. Reliance on heavy equipment such as diggers and movers, as is sometimes the case for building large systems, entails a considerable risk as they are frequently out of order and represent excessive cost. For example, in Dodoma in Tanzania, five out of six mechanical earth-moving teams were out of commission in 1989 due to equipment failure (Lee and Visscher, 1990). Wherever possible, labour-intensive inputs should be optimized and simple tools and instruments should be used. For example, theodolites should be substituted by more simple devices such as water pipe levels or A-frames that can be easily used by local technicians (Pacey and Cullis, 1986).

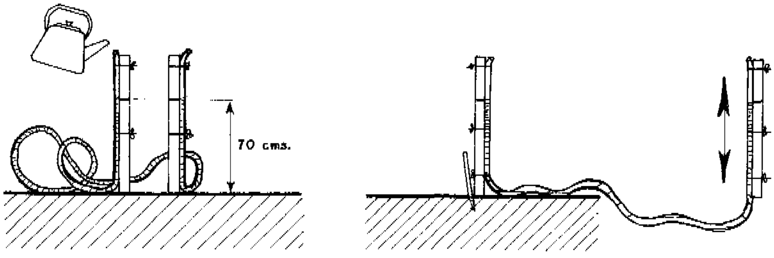


Figure 5.3: Simple hosepipe levelling device (Source: Pacey and Cullis, 1986)

The basic construction details for different rooftop catchment, surface catchment and sub-surface catchment systems are detailed in Chapters 8, 9 and 10. These include information on siting, design, construction and maintenance. Site selection is of particular importance for sub-surface dams, since there are many examples of dams that have been unsuccessful due to poor site selection and inadequate design. Inaccurate and inappropriate application of design standards are also a major reason for failure of other water harvesting systems, and therefore careful review of local design and construction practices is needed before embarking on large scale water harvesting programmes.

5.3 Socio-economic feasibility

Many publications indicate that water harvesting is rather expensive, but figures are not very adequate and costs are not always as high as they seem, as will be further explained in Chapter 7. Often there are few feasible alternatives, making it more an issue of what service level to provide and whom to benefit first. With limited resources it may be possible to provide a partial improvement of local conditions by providing a better water supply for part of the year. Even such partial improvements may require support from the government in cash or kind, particularly for the poorest groups in the communities. Whether a water harvesting system can be afforded and whether the community is willing to pay their share in the cost depends on many factors but is ultimately their own decision.

Systems are affordable when:

- the users are willing and able to pay the full cost;
- the cost is subsidized to an affordable level by external support;
- income can be generated to (partly) compensate the system cost by using the freed time or obtaining financial revenues from the surplus water;
- a financing scheme is created in which manageable repayment is possible, leaving sufficient flexibility to temporarily increase loans for larger repairs.

The role of men and women in household and village financial management and decision making needs to be taken into account when deciding on the socio-economic feasibility. Whilst often it may be men who decide on technical issues, it may be women who must save and organize income to pay for developments. Equally, men and women may have different views as to what is affordable and worthwhile (van Wijk, 1989). Women may value simple household systems with little recurring cost, whereas men might prefer more technical supply systems such as pumps, which will involve substantial recurring costs. Reconciling different views and coming to the most appropriate economic and financial decision requires open dialogue between the project agency and the different elements of a community group. Thus the implementing organization can only achieve if it has adequate insight particularly in the culture specific gender relation prevailing in the communities.

It is very important to realize that usually external inputs can only be provided for a number of years but that thereafter the community will continue to grow and new systems will need to be put in place. Projects thus should try to establish or build upon local systems which will facilitate the local financing of future extensions of the systems. To ensure the long term feasibility of a water harvesting system, close collaboration with other development projects is often required to overcome the lack of local banking facilities, the limited cash economy and create sufficient income-generating capacity.

Rooftop harvesting systems involve important management skills as they usually do not provide for all household water needs, but only for drinking, food preparation or essential personal hygiene. A survey in Thailand for example, indicated that some 36% of the people do not restrict the use of water for these purposes only, but also use it for clothes washing (Tunyavanich and Hewison, 1989). The same study indicated that many jars were not full at the start of the dry season, due to continuous use of the water. Effective management, therefore involves rationing of water use, especially during the dry season, but already starting during the wet season. Users thus have to understand and monitor the water balance in the storage tank or reservoir and adjust their use accordingly. Also, they need to maintain the rooftop catchments, which generally poses few problems. The quality of rainwater stored in roof catchment tanks is generally low in hygienic risk although animal faeces and bird droppings may cause contamination. According to Michaelides et al (1986), 82% of 37 roof catchment tanks sampled in Mauritius were free of all coliforms. However, there is considerable potential for contamination due to poor storage and use practices. More recent findings on 189 rainwater jars in Thailand partially confirm this picture, although here 60% of the systems were slightly polluted and did not meet WHO guideline values (Wirojanagud et al, 1989). Despite this finding it was argued that rainwater was potentially the safest water source and no steps were deemed necessary to further improve its quality. Improvements in the hygienic collection and handling of the water and sanitary practices were considered much more important. Nevertheless, there is scope for further research on water quality in water harvesting systems as part of the contamination may be easily prevented by improved maintenance practices.

In an analysis of 30 household systems in Kisii, in Kenya, it was noted that little maintenance had been carried out, resulting in leaking and blocked gutters. The same study showed that large communal rooftop harvesting systems in Kisii contained 100 - 1000 coliforms per 100 ml, (although not faecal) due to insufficient maintenance and absence of any form of filtering or first-flush systems (Omwenga, 1984). A pilot study of rural water quality surveillance in Indonesia indicated that out of 32 samples 12% of tanks had low risk of becoming contaminated, 50% intermediate/high risk, and 38% very high risk (Lloyd, 1991).

Most water harvesting systems, except for individual roof catchments, are communal systems, and require organization of the community to manage and maintain the system and avoid the risk of contamination. If no history of community-based management exists, this may prove to be difficult and it may even be better not to install the system until community management systems have been proven in a pilot area. This will particularly be the case for systems requiring large communal workforces.

It must be recognized that there is considerable potential for social conflict arising from the development of water harvesting systems. The main reasons are conflicts over ownership, water allocation rights and inequitable abstraction. This is particularly true in a non-cohesive society and under conditions of rising population. Where systems are not expanded with time, the finite supply from harvesting systems must be split between larger numbers of people, many of which may not have contributed cash or labour to their development. Other conflicts can result from upstream or downstream effects of dam construction or from alienated groups who do not receive preferential assistance from targeted aid (Lee and Visscher, 1990). Such potential conflicts need to be carefully reviewed together with the local communities to assess whether the potential systems are feasible or special measures must be taken to overcome the negative effects.

6. *Project Development with the Community*

Planning and implementation of a joint activity which adopts water harvesting as a prime technology implies very close collaboration with the community and individual community members. The prime focus needs to be on capacity building to ensure that efficient use is being made of the harvesting facilities, and that adequate upkeep and future expansion can be carried out largely by the community itself. Building on local skills, knowledge and needs is the most efficient way to initiate the process. If community members are not viewed as cheap labour but as equal partners, and if project and agency staff accept their supporting role, the basic foundation for success is established.

6.1 The partnership approach

The objectives of community members and agency staff in essence are quite similar although this is not always realized. Both aspire to establish a sustainable water supply which can be effectively used. In the process of establishing this water supply, both have things to offer.
The community:

- has knowledge of local conditions;
- can ensure that the facilities meet their own requirements;
- may provide labour and materials;
- can assume primary responsibility for long term maintenance and future expansion.

The project and agency staff:

- have the technical and organizational knowledge of technology alternatives;
- can advise on construction and maintenance implications;
- may contribute financial support when justified;
- may help to establish financing mechanisms appropriate for maintenance and long-term needs;
- can provide training and long term backstopping in case of major difficulties.

Relating to the community as a partner in the development process has important advantages. This will help achieve a larger coverage with facilities which are better used and maintained.

6.2 Assessment of local conditions

Before embarking on any programme, an overall image of the conditions in the programme area needs to be established. This broad picture comprises technical, socio-economic, environmental and organizational issues. This information is required to determine in general terms the need for improved water supply systems and the potential for water harvesting as discussed in Chapter 5. The community may be very helpful in expressing their felt needs, which they base on their understanding of the existing situation. These felt needs have to be compared with the health risks which often require the inputs of specialists. The broad picture emerging from this phase also will provide information for determining the project approach, the type of support required and the possible need for a pilot programme.

For the overview, not all site-specific issues need to be taken into account, but just enough basic information to enable a preliminary selection of technologies and to establish the programme. Table 6.1 provides an overview of the most important issues to be considered in this preliminary stage. Many of the issues indicated in the table require prior contact with the population. Informal discussions with local leaders and particularly older community members can provide insight in the historical development and the environmental conditions in the area. They will remember long dry periods, know areas of more intensive rainfall and can talk

Table 6.1: Checklist of key issues to provide a basis for programme development

- Rainfall figures and rainfall pattern.
- Landscape types present in the area.
- Quality and reliability of existing water sources.
- Relative distance and quantity of existing water sources.
- Current use of existing water sources.
- Potential for environmental degradation/erosion.
- Type of soil.
- Traditional or existing experience with water harvesting techniques.
- Size and number of communities in the area.
- Population density and anticipated growth.
- Target groups to be taken into account.
- Previous experience with water projects.
- Local interest in improving the water supply situation.
- Type of community organizations.
- Cohesion of the communities.
- Potential for social conflicts.
- Possibility for provision of labour.
- Types of skills available in the communities.
- Potential for financial and in-kind contributions.

about particular problems in the area. Care should be taken not to raise high expectations, and only low key contact with communities is advisable at this stage. Thus, full use should be made of experiences acquired by earlier projects and locally-based field staff of the relevant ministries, development organizations and NGO's. If necessary, this experience can be used to initiate activities in a few pilot villages, which should be as representative as possible for the villages in the area. Community meetings may be organized to explain the goals and ideas of the project agency and their potential support and to allow the community members to express their views and ideas. Smaller meetings with specific groups, of men and particularly women who are often not involved, may also be needed to obtain an overall idea of their views and to share the information with them.

A series of new techniques are recently being developed such as participatory rural appraisals and rapid rural appraisals to establish information on the local conditions together with the population. These techniques definitely are promising and hold a lot of potential for future application.

6.3 Identifying potential technologies

Insight into local conditions will provide the opportunity to identify the most suitable technologies which could be applied. If experience exists with traditional harvesting techniques, dialogue with users will give an indication of their appropriateness and acceptance. Landscape, land use and rainfall largely determine potential solutions, which can be used to improve the water supply situation. Often, different technologies may be technically feasible, but not all may be equally appropriate. According to Layton (1987) the most appropriate water harvesting technologies are those which:

- use local labour for construction and encourage small industries;
- apply materials, equipment and construction techniques which are familiar to local people;
- are based on locally available raw materials and manufactured components.

Technology choice should also reflect the level of social organization. The attitude of community members towards individual or communal water supplies will depend upon the degree of community cohesiveness and the existence of strong extended family links. Individual harvesting systems require considerable annual management inputs by the owners in terms of cleaning and rationing water use, to create the most favourable water supply conditions. Communal systems may be more economical than individual systems, but require the collective contribution of capital and labour, the equitable distribution of water and sharing of responsibilities. If households do not naturally organize into co-operative groups, it may be more appropriate to support technologies such as rooftop harvesting systems at a family level rather than through collective systems.

Key requirements for maintenance and effective use need to be taken into account in the selection process. This implies that the financial, technical and organizational aspects necessary to sustain the facilities are reviewed and agreed upon within communities. It is clear that if maintenance requirements are too high for the local population to manage, the harvesting system will not be sustainable. This is particularly true for systems developed with large communal work forces and with high labour costs. Much can be learned in this respect if experience with water harvesting already exists locally. A review of other programmes in the region, for example, may show major maintenance problems due to inappropriate technology selection or mistakes in siting and construction. Many examples exist of rock catchment dams which have been built on leaking earth foundations or earth dams that are made from cracking clays. A field survey to review existing experience will also prevent the copying of in-appropriate or less well accepted designs for water tanks, as is now still too often the case.

The overall assessment of the project area can only provide a general indication of the technologies which can be applied. The ultimate technology selection will largely depend on the skills, capacities, needs and preferences of the individual communities. It is essential, in order to assure system sustainability, that communities are provided with information concerning maintenance requirements and financial implications for each of the technology options considered. Preferably a range of technologies and options should be identified from which the community can choose the most feasible and affordable option closest to their needs. Communities may need assistance and advise in this respect. Before being asked to make a choice they must have information on and understand the various technical options, which may include other options such as handpumps, and realize the consequences in terms of costs, reliability, ease of administration and finance, and implications for hygiene practices and local development (van Wijk, 1989).

6.4 Selecting the partners

Depending on the range of harvesting technologies which are feasible, the community structure and the policy of the supporting organization, the partners may be one or more of the following groups:

- individual households who will privately own, use and maintain a water harvesting system;
- smaller community groups such as self-help, women's, church or school groups who will jointly own, use and maintain the system, restricting its use to members only;
- the whole village or large community groups who will use the system as a common resource with open access, and for which upkeep responsibilities must be delegated to specific members.

Water harvesting systems require considerable community commitment for the financing and construction of systems, the daily upkeep and further expansion of systems (Lee and Visscher, 1990). Community members with better kept waterpoints, housing and agricultural practices in this respect may be more promising partners. However, they may not be the group most in need of improvements, so poorer groups not possessing these traits should not be ignored. Many national governments and ESAs recognize that there are particularly disadvantaged groups amongst populations living in the marginal areas, such as poor subsistence farmers and female-headed households. For example, in Botswana, female-headed households in rural areas constitute 48% of the total (UNICEF, 1989). The poorer groups and the female-headed households, although primary partners, are often not reached because they lack capital, labour, draft-power, are less healthy and live far from a clean water source. Table 6.2 lists a number of special steps which may be necessary to involve women next to the men who are often participating more automatically.

Table 6.2: Ten main steps for including women in the full project cycle

- Orient male project managers to the benefits which involving women has on the achievement of project objectives.
- Work with women field agents.
- Discuss with local leaders the need to involve women in planning and development.
- Make sure women are informed about meetings and that they participate.
- Organize meetings when and where women are able to attend.
- Organize women participants to sit together at meetings, in a prominent location and to speak out.
- Stimulate discussion by actively inviting criticisms from women and asking respected women to speak.
- Organize special meetings to involve the poorest women so that their views are heard.
- Decide which management roles are best carried out by women and explain the requirements to candidates.
- Adapt skills training to women's needs and provide follow-up support and monitoring of progress.

Source: van Wijk, 1989

Without preventive arrangements, local elites and economically more able or active households can monopolize community developments or attract greater levels of assistance (van Wijk, 1989). Projects have often worked with influential and well-to-do individuals, providing them with considerable financial support. They expected that this would convince the other community members to construct their own systems. This assumption however, has not been proven. It is expected that similar or even better results could be achieved if poorer groups would receive the available support to set examples, provided this was agreed upon with the leaders in the community.

Clearly, targeting technical and financial support is a major responsibility of policy makers and planners, with assistance prioritized for those who really need it. On the other hand, those most able to help themselves should be encouraged to do so using a greater proportion of their own resources. Sensitive criteria that properly take local conditions into account are necessary to ensure that the most needy community members are not left unserved, as is often the situation today (Cairncross, 1989).

Efforts have been made, for example, by the Catholic Diocese of Machakos and Kitui in Kenya, to set criteria which include a fixed financial contribution from the individual towards waterpoint construction. In the case of Kitui, this meant that only those families with regular cash income could benefit (Lee and Visscher, 1990). Similarly, the stringent financial criteria used in the Utooni Development project in effect excluded those people who could most benefit from its activities (World Neighbours, 1988), i.e. those who cannot make regular contributions of cash and labour.

In an effort to reach the poorer families in Kitui communities, the Catholic Diocese adopted new criteria (Ferwerda, 1989):

- beneficiaries must walk more than 5 km to their current water source;
- the household should not have a metal roof or an existing water tank;
- the household should not own more than 3 cows or 10 goats;
- the household income should be below US$50 (Ksh 1000) per month.

However, since households still must be able to make a down payment of around US$35 and capable of repaying a loan of around US$250 within one year, it is not clear whether these new criteria will improve the ability of the Diocese to reach the poorer households bypassed previously.

These examples show that sensitive criteria are needed for establishing community contribution mechanisms that take into account the local socio-economic differences prevailing in the community. Any selection criteria must be subject to periodic review by the communities themselves, who must decide if it is appropriate to their own varying needs.

6.5 Choice of appropriate support strategy

Development of sustainable water harvesting systems requires the long-term commitment of the agencies involved, with support focused primarily on capacity building within communities and agencies. This process cannot be achieved with a short-term project. Project agencies must also accept that efforts directed at human resource development will result in initially low construction results as projects take time to get off the ground (Andersson, 1990). This will especially be the case in communities which have not shown strong skills in self-reliance, and thus require considerable efforts in awareness raising and capacity building. In other cases, however, a relatively small programme of technical, organizational and financial support might be all that is required. Earlier experience with water harvesting or with communal systems thus need to be taken into account when establishing the project approach.

No blueprint is available which sets out the most suitable project approach, but the following important features from more successful rooftop harvesting projects in Botswana, Kenya, and Thailand may have wider application:

- start small and grow slowly, develop and modify the programme on the basis of evaluations;
- run the project with local people in charge (although the role of outsiders as catalysts and facilitators is often critical);
- involve the community in planning, implementing, operating and maintaining the systems, and do not present them with a pre-set plan of action;
- do help to organize the creation or strengthening of a coordinating committee of elected representatives;
- work in communities which have a strong 'felt need' for the water harvesting systems which figure high on their priority lists;
- make sure the community contributes funds and labour, but at levels within their capacity (adapted from Gould, 1989).

If water harvesting has a good technical and environmental potential but communities show a low level of awareness of its potential and little willingness to participate in its development, resistance could be overcome by a pilot programme. This programme may include some or all of the following elements:

- engage community members in dialogue concerning the merits of water harvesting systems vis-a-vis other systems;
- use local media such as radio and newspapers (where appropriate), posters, and local community representatives and workers to communicate the principles and benefits of water harvesting;
- introduce water harvesting to children at school, and work with them in a way which results in out-reach to their families;
- organize trips for a number of community members, not just the leaders, to neighbouring regions where water harvesting is practiced under similar conditions;
- construct a demonstration unit, for example at a school, and arrange for demonstrations to introduce it to the community.

Addressing community needs and preferences is a pre-requisite for the sustainability of the system. This involves a dialogue between the project agency and the different groups in the community. Preferences may differ, and therefore dialogue should be held with different partners in the community including village leaders, male and female heads of households, women responsible for water collection and particularly those expected to be responsible for future use and maintenance. No blueprint can be given for promoting dialogue, since people may have very different needs and views as to what the government or agency should provide. However, an open dialogue in which the possibilities and limitations of the proposed support are explained is an essential foundation for partnership. An atmosphere of mutual trust is necessary to open discussions on otherwise obstructive issues, for example the alienation of water-sellers who may sabotage systems (Tanzania) and the fear of disturbing ancestral spirits who live in the water source (Zimbabwe).

A pilot programme is also required if there is little experience working with communities in a partnership approach. Such a pilot programme could be established in a number of representative communities and would follow a learning-by-doing approach, which provides training and learning opportunities for both the agency staff and the communities. This programme could also be used to develop the basic training required for community members to maintain their facilities and for involving the community and local artisans in system construction.

Increasingly, cash and in-kind contributions are required of users. This is comprised of financial and labour contributions for construction as well as loan repayments and payment of maintenance costs (Chapter 7). This issue needs due attention in project development to ensure that users' contributions are equally shared and in line with their capacity to contribute. Often mechanisms such as revolving funds and banking facilities may have to be established to ensure that payments can be made and used.

Formal contracts, with a timetable, can be helpful in regulating the roles, responsibilities and rights of all those involved in the implementation process including the user, the technician, the supplier, the project agency, and the national authorities. For example, in Togolese projects, contracts were signed between the village development councils, the project agency and the government, regulating the role of each (Lee and Visscher, 1990). Such contracts can also set the terms for "community management" by specifying the role and responsibility of the community as well as the agency, particularly for the crucial period after construction. Where community groups are weak or non-existent, it is essential that project agencies help set up a viable water management organization, assist in defining organizational tasks and train members in maintenance, management and financing (van Wijk, 1989).

6.6 Training

Training appears to be one of the most important components of any water harvesting project. This often constitutes a wide range of target groups including:

- orientation of policy makers and project planners;
- training of project staff and staff from other agencies related to the project;
- training of local artisans;
- training and orientation of community members.

Water harvesting projects imply a longer-term commitment from government agencies. Technologies need to be explained and 'sold' to policy makers, who require a full view of the relative costs and benefits of the proposed project approach and planned activities. Short meetings, seminars, video presentations and newspaper articles may prove to be very good tools to reach these persons.

The skills of the staff working with the community is another important issue. The need to work in support of and act as advisor to local communities may be new for many project managers and staff. Cairncross (1989), for example, argues that engineers who are usually the project managers often have insufficient training to cope with the very complex social and political issues involved in local organization of maintenance. Hence, involvement of staff with adequate expertise in these issues is crucial, as well as the training and orientation of the technical project staff. This particularly concerns the role of women in building and managing water harvesting systems. This is being realized by the Women Development Sections of the Ministry of Panchayat and Local Development in Nepal, which amongst other goals, is trying to eradicate negative attitudes to women's involvement in water tank construction (Pradhan, 1989).

It appears that project staff still do not sufficiently realize that women hold also technical skills and those who build houses can also, with adequate training, build tanks since this involves similar concepts and skills. Involving women next to the men can be very beneficial, provided this is culturally acceptable and not increasing their work load to an unacceptable level. Overcoming constraints to women's involvement is very important as women tend to share their new skills and knowledge with each other, whereas men often keep the knowledge to themselves.

Workshops for project staff can be organized on working with communities, using participatory techniques such as role-paying (Srinivasan, 1990). When training in these techniques is carried out within project communities it appears to be a very effective way to prepare project staff for their tasks. Practical training is also needed in the siting and construction of harvesting systems, for example by constructing demonstration systems in selected communities. This can provide future trainers of local artisans and community members with valuable hands-on experience.

Government extension workers and staff may not be directly on the project payroll, but may nevertheless perform important supporting tasks in community development and hygiene education. A training workshop for these workers, combined with necessary field experience, should orient these workers adequately to the various water harvesting options. Often further efforts are needed to enable the trainee to function and work together with community groups. Support measures, such as the provision of a subsistence allowance as encouragement, may be necessary.

Sustainable development of water harvesting implies that local skills for long-term operation, maintenance and expansion of the facilities need to be available in the communities. This usually means training of local artisans and community members in all issues related to construction, maintenance, management and finance. Preferably an approach is followed which builds on the local capacity and involves technical training and learning from experience. Trainees preferably should be selected by the community themselves, but some preliminary selection criteria may be necessary to orient the selection process. Criteria for selection includes a vested interest in the construction of the system (i.e. the trainee technician should be a member of the group), a long-term commitment to remain in the community, and a desire to continue to maintain, replicate and expand systems wherever possible.

At Ban Can Nua village, Thailand, the Khon Kaen project used its craftsmen training programme to train three people from the village who would build the jars for the community. The criteria for selecting from those that applied were:

- literacy;
- basic masonry knowledge;
- aged 25-50 years;
- demonstrable willingness to make sacrifices for village (free-time, etc.);
- acceptable to majority of community;
- middle income category (Menaruchi, 1987).

Several programmes have started to train women in tank construction. In Tonga for example, women community workers were trained in 7000 litre ferrocement tank construction as part of a six-week regional workshop (Fleming, 1986). In a water harvesting project in Capiz, the Philippines, women were included in a team of 11 people trained in ferrocement tank construction, which moved from site to site within the region building rainwater stores (Salas, 1989). The women enjoyed the work and found little conflict with their other domestic responsibilities. Women indeed may be a special target group for training, and trainees may include members of existing women committees (Figure 6.1).

Figure 6.1: Women committee meeting in Domisé-kope, Togo (Photo de Vries)

Training youth members, who often have few prospects for employment outside family farming, to function as independent contractors for agencies has been adopted as a useful strategy in several rooftop catchment harvesting projects. One example is a project in Papua New Guinea, where unemployed youth set up local contracting services after a period of training. This helps curtail the drain of young people to urban centres and migrant positions, whilst creating a source of income within the community. The Village Industry Research and Training Institute in Papua New Guinea realized that if a tank could be designed that could be mass-produced by rural-based entrepreneurs, not only would this create much needed rural employment, but it would also fulfil a local demand for a cheaper, longer-life tank. The focus for training in construction, accounting and marketing were the young, unskilled rural unemployed. In addition, the local government supported the training initiative with matching share capital for start-up funds (Layton, 1987).

It may also be possible to stimulate local contractors do enhance their skills in construction of water harvesting systems. This may help them to cater for demand possibly of better off households. Project agencies can facilitate this process by maintaining a register of approved contractors, as successfully adopted by the Catholic Diocese of Machakos in Kenya.

To simplify the training needs and facilitate trainees becoming trainers, designs and construction methods should be standardized as much as possible. In the short-term, independent training workshops can be held which move from village to village, or region to region. A number of workshops on rooftop catchment system construction have been held, which are useful sources for guidelines and recommendations. They include Edwards (1984) and World Neighbours (1987). Training must usually be adapted to the local conditions and the fact that literacy is often low in rural areas. In a Togo project (Roark, 1988), over one-third of the masons hired for training as artisans were functionally illiterate and could not keep records or use any of the written materials provided for their training workshop. They were trained by verbal and practical explanation. In such cases, it is imperative to follow up workshops with refresher training at regular periods to consolidate techniques and correct any errors or bad habits.

6.7 Construction planning

Careful planning of the construction stage with the community is very important. Involvement of experienced staff who have worked in the area before can give insight into difficulties that previous water harvesting projects have faced. These problems may be related to siting, construction, management and maintenance of systems. In many rural areas adult men leave to take urban jobs, sometimes sending home remittances to support their families. There is also a tendency for young adults to move away for urban jobs, partly as a result of their increasing levels of education and aspiration. They often regard subsistence farming as unrewarding and look further afield for employment. The absence of male labour year-round or at slack times in the farming calendar, has important implications for water harvesting system construction. Where women comprise the remaining workforce, most technical skills are held by absent men. As such, both skill and labour intensive projects must look to the women for significant inputs in management and implementation. If women are employed in system construction, project agencies must support the women's group to provide for child care, water and firewood collection, and food preparation.

Whilst typically women have contributed labour, fetched and carried materials or looked after technicians carrying out the work, they have not been effectively involved in the technical aspects of water harvesting in Africa. This is true even though they constitute the majority of effective heads of households in many locations (Lee and Visscher, 1990). Women also often complain of a lack of involvement in management. For example, in Tanzania women felt little impact on their lives from the development of village water tanks since they had no control in planning and deciding priorities for the use of water provided and its distribution (Smet et al, 1986).

6.8 Management of maintenance

As part of any project approach, attention should be given to the after-care period of the implementation cycle. Many water harvesting systems involve quite a high management input to maintain water quality and ensure it lasts out the dry season. In many cases, water users are unaware of the links between themselves, their activities in the catchment area, the water stored and its quality. Without such knowledge, it is unlikely that users of an earth dam, for instance, will practice soil and water conservation in the catchment area or keep their livestock from drinking directly from the reservoir. Efforts must be made to identify these links and communicate them to the users concerned. Checklists of management and maintenance requirements for different water harvesting systems are included in Chapters 8, 9 and 10.

In order to determine the effectiveness of user management efforts, monitoring the various water harvesting systems is required to see whether the management requirements are being met. Each water harvesting system has its own management and maintenance requirements to promote the desired level of service. The considerable body of experience that has been developed on operation and maintenance schemes provides a ready source of guidelines and checklists concerning the setting up of monitoring and management programs (Bastemeijer and Visscher, 1987).

7. *Financial and Economic Issues*

Financial and economic issues are crucial to the introduction of water harvesting systems. Earlier literature indicates that price levels of water harvesting systems are high compared to other water supply systems. However, recent studies indicate that a more balanced picture arises when taking into account the service level provided and true pricing mechanisms. Apart from systems cost and cost-benefit analysis other aspects need to be considered, including affordability, willingness to pay, provision of subsidies and financing mechanisms.

7.1 System costs

When estimating the costs involved in water harvesting systems, figures quoted in the literature must be treated with caution. Cost estimates show a wide range, depending on the method used to arrive at the figures. Factors which contribute to these differences include:

- inflation since time of calculation;
- exchange rate conversions;
- exclusion or inclusion of overhead project costs;
- exclusion or inclusion of commercial materials, skilled labour, local materials, self-help labour, transport, equipment, technical advisor;
- different pricing in different countries (for example in Tanzania the equivalent wage for self-help daily labour in 1989 was US$0.25-0.50, in Kenya US$0.70-1.00, in Botswana US$1.50 and in Togo and Mali US$1.50-2.00) (Lee and Visscher 1990).

Figures from the literature therefore, should only be used as an indication, and an up-to-date breakdown of costs should be made locally for each technology option before any decisions on the basis of cost differentials are made (World Neighbours, 1987). Estimating costs requires access to a detailed bill of quantities and knowledge of the number and cost of skilled and unskilled person-days for construction. Transport costs and institutional costs of planning, construction and monitoring also need to be assessed. All costs should be included to get a clear view of the implications of choosing different technologies. Estimates should also be made of recurring costs in labour and money, since this is of particular importance in an assessment of the long-term cost-benefit of different systems.

Some costs of rooftop catchment systems given in project documents and by project managers during interviews in 1989 are summarized in Table 7.1. Clearly there is a considerable range in capital costs for the same size system. This reflects differences in costing procedures by managers as well as other factors such as economies of scale in materials purchase, quantities of commercial materials used and differences in construction methods. For instance, some projects might line ferrocement ground tanks with 6 cm of reinforced mortar, whilst others may use 8 cm. This can impose material cost increases of 33% between the two tanks.

Where roofs are not suitable for water harvesting, cost of constructing new roofs and gutters will have to be added to the cost of the tank. Again a wide variation in cost is indicated in the literature ranging from US\$3.80 per m^2 for a 36 m^2 roof with subsidies in Kenya, to US\$11.70 per m^2 for a 80 m^2 roof in Togo.

Where roofs are suitable, but not already fitted with gutters, cost of gutters must be added to the cost of the tank. For example, in Kenya these vary from around US\$1.80 per metre (1988 prices) for gutters made by the Danida-assisted Mutomo project, to US\$4.00 per metre for commercial round guttering.

Table 7.1: Construction costs of rooftop catchment tanks (US\$) per m^3 of tank volume

System	*Volume m^3*	*Cost/m^3 tank volume (US\$)*
Cement jar	1	25
Granary tank	8-10	17-31
Standing tank (reusable formwork)	5.5-13.5	25-75
Standing tank (integral formwork)	20-30	25-44
Masonry standing	50	70
Ferrocement ground tank	70-80	11-26

Based on: Lee and Visscher, 1990

Cost figures for surface and sub-surface harvesting systems presented in the literature also show a considerable variation (Table 7.2).

Table 7.2: Examples of costs of surface and sub-surface harvesting systems

Description	*Volume m^3*	*Country*	*Cost per m^3 storage volume (US\$)*
Ground tank	17	Botswana	19.1
Sub-surface dam	3,500	Kenya	2.5
		Tanzania	3.9
Charco dam	8,000	Tanzania	2.4
Rock catchment	13,000	Kenya	1.6
Small earth dam	30,000	Tanzania	1.9
Medium earth dam	60,000	Tanzania	2.1

7.2 Cost-benefit analysis

Several attempts have been made to compare capital costs of water harvesting and other water supply systems. In some comparison, water harvesting came out cheaper and in others far more expensive than other alternatives. Pacey and Cullis (1986) quote 1971 prices in an analysis of capital costs of water harvesting and other supply systems. Household rainwater tanks came out on average to be 13-20 times more expensive than hand-dug wells and 6-10 times more expensive than piped water supplies. Communal rainwater tanks came out 3-10 times more expensive than hand-dug wells and 2-5 times more expensive than piped supplies.

In 1984, Omwenga conducted a comparative cost analysis of water harvesting in Kisii, Kenya, in which he included costs for roof, guttering and transport, but not for labour. Based on his calculation, which only covered a small number of tanks, per capita construction cost of household roof-top harvesting came out 3.8-16 times more expensive than protected springs and 1.3-6.4 times more expensive than dug and drilled wells. Piped supplies however, came out 0.7-3.9 times more expensive than roof-top harvesting.

In Togo, the cost of a cistern project was roughly US$53 per capita, compared with a cost of US$47 per capita for a deep well with handpump. Whilst the latter provides much more water per person, it is not technically feasible in many villages in some regions (O'Brien, 1990).

The problem with these cost comparisons is that they are based on figures which only partly include the true cost. Also they do not take into account the recurring costs, which are much lower for water harvesting systems than for handpumps or piped supplies.

A more realistic cost comparison is possible by estimating the capital and recurrent cost per m^3 of water provided by the system. This, can be done by converting the capital cost into a series of equivalent annual costs (EAC) over the total lifetime of the system. The sum of the annual equivalents will be greater than the initial capital cost, because interest over the remaining debt is included in each annual instalment. The annual equivalent cost of a capital investment (C), over an expected lifetime of (n) years, can be calculated with the equation:

$$EAC = C \times \{r(1+r)^n\} / \{(1+r)^n - 1\}$$

where: EAC = equivalent annual cost
C = initial capital cost
n = expected lifetime
r = discount rate

Calculating the EAC per m^3 of water implies that an estimate has to be made of the total cost, relative to the volume of water which will be provided on an annual basis. This will, however, very much depend on the type and frequency of rainfall and the number of rainy periods. A recent attempt to put cost figures from the literature in perspective assumed that, where there are two rainy seasons, tanks will supply triple their volume each year and where there is one rainy season, twice their volume. Furthermore, a 30-year lifetime was assumed for the tanks, with no recurring cost for tank maintenance. The resulting annual equivalent cost varied from US$0.12-0.27 /m^3 for ferrocement ground tanks and US$0.22-0.49 /m^3 for ferrocement standing tanks. Similar calculations were made for rock catchments and sub-surface dams in Kenya, assuming a 30-year lifetime, producing a supply equal to their volume. With the recurring cost estimated at US$0.033 per m^3, for both systems the resulting EACs were US$0.09 and 0.11 /m^3 respectively (UNDP/IFAD, 1988). These costs are only 1.5 to 1.9 times more expensive than the EAC of shallow wells in Kenya, which amount to US$0.60 /m^3.

Although this approach only provides a global indication, it shows that the cost of water harvesting systems are closer to those of other systems than, for example, indicated by many other authors. The main limitation of the estimation of the cost per m^3 is that no data were available in the literature to underpin the assumptions made on available water volumes. It may well be that larger tanks are built in areas where rainfall shows strong variations and, therefore may not provide the assumed triple their volume each year. Local experience and available rainfall data should allow a reasonable estimate to be made of the volume of water a particular system can provide and how much that water will cost per m^3.

Assessing benefits

In comparing technologies, not only the costs but also the potential benefits need to be taken into account. The benefits of water harvesting systems are both direct and indirect. As such, many systems cannot be valued in conventional cost-benefit terms. These benefits may include:

- resource conservation through flood control and increased groundwater recharge;
- employment and/or building up of local skills through water harvesting system construction;
- increased local self-reliance in water supply;
- increase in local organization capacity and community cooperation in developing and managing their own services;
- time saved in collecting water, which can be invested elsewhere (child care, food preparation, income generation);
- lower management and maintenance needs and costs.

Time gains can be an important reason for system introduction. For example, the benefits of rooftop systems rise with increased distance to or inaccessibility of other water sources (Hasse, 1989). Results of a questionnaire issued to tank owners by the Catholic Diocese of Kitui in Kenya indicated that savings by families, in terms of daily walking for water, were considerable. On average, 6412 km was saved per tank per year or over 17 km per day, equalling 3-4 hours per family per day (Schriever, 1990). The value of rooftop systems also rises with the level of contamination of traditional water sources. These benefits need to be taken into account when a system is being selected to provide an acceptable service level on a sustainable basis.

7.3 Affordability and willingness to make community contributions

Whether a water harvesting system can be afforded and whether the community is willing to pay depends on many factors, but is ultimately the community's decision. They therefore should clearly understand the costs and inputs required of them in construction and maintenance of the system.

Community members often can and are willing to provide a considerable contribution in cash and kind to obtain a better water supply. Encouraging such contributions will help a government or ESA to achieve a better coverage at lower cost and more important, stimulate users to accept greater responsibility for the system.

A review of water harvesting in five African countries showed that community contribution to construction varied from 10 to 40% (Lee and Visscher, 1990). Contributions in kind and labour will often be more easily realized than cash contributions. Financial contributions will be possible where households have a regular cash income or where payments can be made at times when cash is available, as for example is the case in Thailand (Tunyavanich and Hewison, 1990) and Kenya (Wacker, 1990).

To ensure the commitment of households involved in a rooftop harvesting scheme, many projects require definite commitments from participants before the external assistance is provided. Some projects expect groups to prepare a site for construction and deliver all local materials before construction work could begin. In Machakos, groups willing to build household tanks would only receive support from the Catholic Diocese if they:

- arranged for three tanks to be built in the same locality;
- provided an artisan to act as the Diocese artisan's helper and apprentice;
- provided all local materials, such as sand and aggregates;
- provided food and accommodation for the Diocese artisan.

Because users are required to provide some financial contributions in cash or kind, often only the most prominent in the community can participate. In this way, subsidies intended to encourage poorer groups to develop their water supply system still end up with the wealthier individuals. In Botswana in the early 1980s, for example, the ALDEP programme required ground tank recipients to make a US$75 down payment (15% of the cost of the tank) and provide self-help manual labour. However, with 70% of rural female- and 62% of male-headed households earning less than US$50 per year (UNICEF, 1989), this was beyond the means of most families.

This clearly brings out the need for differential subsidies to ensure that the poorer groups also have access to the improved water supply and are not being marginalized further. Care must also be taken that by requiring self-help labour inputs from all members of a participating community, families do not lose essential migratory income elsewhere.

The contributions households are willing to provide will depend, for example, on the benefits they perceive and whether tenure of land and housing is secured. Participant communities therefore, can be best asked for their own estimates to get an impression of the willingness to pay (Katko, 1990). As the freeing of time will be an important benefit which particularly concerns women, their involvement in the decision-making process is very important, as they may be willing to provide larger contributions from the family income than their husbands.

7.4 Provision of subsidies

In many cases, it will not be possible to install water harvesting systems without external support. Covering a large portion of the cost by subsidies, however, entails a risk that communities will become more dependent. Examples exist where communities did not want to participate in subsequent projects unless similar subsidies were provided. Striking a balance between subsidies and community contributions is therefore a very important process that is better established together with the communities.

Each programme has to decide the extent of subsidies, which groups should benefit and under what conditions. Setting conditions is very sensitive. Some programmes have even set quite controversial conditions, as for example in Thailand, where the Population and Community Development Association provided subsidized tanks to villagers who would join a family planning programme (Hayssen, 1986).

Appropriate subsidies and incentives can be very useful, but should be carefully considered to avoid encouraging dependency. Sometimes problems can be reduced by providing a partial in-kind subsidy. Tools which can be used for other projects later, skill training and provision of additional communal facilities are examples of this. It may also be appropriate to top-up local cash funds, provided this will benefit the community as a whole and particularly the financially weaker sections.

7.5 Financing mechanisms

Financing mechanisms are a key to the development of water harvesting systems and need to be established in dialogue with the communities. These mechanisms must be well suited to the socio-economic and cultural characteristics of the community. In some communities groups are already organized and make regular contributions to village accounts for communal activities and participation in externally supported projects. Such cases should be studied carefully and may be used as models to establish a financing mechanism to pay for water systems in those communities. Sometimes, community members experienced with these mechanisms can be helpful in assisting people in other villages to implement the same system. Next to discussions with men, special attention has to be given to dialogue with women, who usually value water supply systems more highly, but may face many constraints in access to financing and credit systems (van Wijk, 1985).

In West Africa, community financing arrangements seem more formal and widespread than in East or Southern Africa. Complete communities join together, with many villages having bank accounts and joint fund-raising activities like working on communal fields. What financial capacities already exist within the community should be used as a basis for a more organized or widespread financing system.

Banking facilities unsuited to individuals and communities are an important constraint to local financing and community development (Katko, 1990). Even where banks are available, community groups cannot always use banks effectively because these banks do not meet the minimum requirements, including:

- easy access for making regular deposits;
- secure and trustworthy;
- offering suitable interest rates to offset inflation;
- offering accounts and procedures that require multiple signatures on withdrawals and prevent mis-use by community members.

In the financial vacuum, due to inadequate institutions, many projects cover the largest share of the cost of systems themselves, requiring community labour inputs and sometimes a small down payment from the users. This not only entails the risk that users see the system as not belonging to themselves, but also leaves them with a problem in the case of repairs and future expansion of the system. However, project and agency willingness to continue with subsidies appears to be changing. In Tanzania for example, water committees are now expected to set up their own village water fund, capable of financing operation and maintenance costs.

Cases of community financing

Relatively little experience exists of more innovative approaches in which community financing schemes are established. Those that do exist, however have been established primarily with NGO support and come particularly from the Far East where income conditions are relatively better than in Africa.

Thailand provides the best examples, where a national programme aimed to develop 9 million rainwater jars by the end of the water Decade. The Thai government pledged US$13 million for a revolving fund. Together with the local

NGO administration, they have created relatively successful village-level revolving loan schemes for household tank construction (Wirojanagud and Chindraprasirt, 1987).

In the Khon Kaen project, cooperative revolving village funds were established with external financial support. To become a member of the fund, a villager has to buy at least one share (US$4). This entitles him or her to loans of up to US$150, provided by the administrative committee for the purpose of building rainwater tanks or sanitary facilities. Although the scheme has been highly successful, some problems were experienced. Rather than support each other, some villagers compete for shares and loans. In some cases, monthly delays in loan repayments meant subsequent delays in loans for new tank builders. Village sanitation committees were therefore given more training on financial management in an attempt to overcome these problems (Menaruchi, 1987).

A similar approach was found in a World Neighbours-assisted project in Utooni, Kenya, through village cooperatives. Members paid an entry fee of around US$4 to join the cooperative. Thereafter, they made varying monthly as well as occasional contributions, depending on the activities of the group. If the cooperative voted to aid a particular family with a water tank, to build a sub-surface dam or granary store, money would be requested from all members at regular compulsory meetings. For large projects, co-financing is arranged through project agencies by World Neighbours (World Neighbours, 1988).

In Central Kenya, 24 women's groups built over 600 rainwater tanks of 2250 litres each, which are partly financed by their own labour inputs. These women's groups received on the job training from two project masons while building three water tanks, thereafter receiving advice when needed. Members of the group were then able to construct water tanks themselves for other members, thus earning sufficient funds in some eight months to construct their own water tank (Wacker, 1990).

The Catholic Diocese in Machakos, Kenya, initiated a group funding arrangement in which members contributed monthly 50 Kenyan Shilling (US$ 2.5) to finance construction of 2 tanks per month. In this way, a group of 50 families received tanks within about two years.

Setting up a revolving fund can be a very good way to stimulate development and overcome the risk that after a project leaves an area, no further expansion of systems takes place. However, it must be accepted by all concerned that the use of revolving funds implies a considerable delay between the first user receiving financial assistance and the last. For instance, it took five years to organize financial contributors for a gravity piped supply in Kenya, assisted by the Canadian Hunger Foundation (Lugonzo-Campbell, 1989). The literature provides a range of examples, which together provide the key elements for a successful revolving fund system (Table 7.3).

Table 7.3: Key elements to be considered when setting up revolving funds

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- Sufficient seed money to ensure that benefits can be obtained by all participants within a mutually agreed time frame.
- Funding for depreciation and administration costs, through additional payments.
- Accounting systems and internal control procedures which are understood and agreed upon by the beneficiaries of the fund.
- Fund coordinators, who are capable and well-trusted men and women, to receive adequate training to ensure that sufficient leadership and administrative capacities exist.
- Procedures established together with the community which set out who can benefit from the fund, at what time and under which conditions.
- Incentives for repayment and, if necessary, development of income-generating activities.
- Repayment procedures which are agreed upon well in advance and might include short payback periods to facilitate quick results.
- Incentives to prevent defaults such as requiring guarantors to make payments in place of defaulters, peer pressure by members of the fund, imposition of fines, and legal action.

The success of revolving funds and loan repayments will depend on their proper management and the repayment capacity of the community in relation to the system costs. For example, poor villagers in Thailand were capable of allocating around US$4 per month to pay for water systems (Wirojanagud and Chindraprasirt, 1987). Each water jar constructed could be paid off in 15 months or less. In the Philippines' Capiz project, the financing scheme required householders to repay the cost of water jars in regular instalments, over a three-year period. However, some farmers were allowed repayment schedules to coincide with the harvest period and the sale of crop surpluses (Salas, 1989).

Incentives to stimulate loan repayments can be quite effective. In the Tungnam project run by the Population and Community Development Authority in Thailand, those individuals paying the full cost of the tank on completion of construction received a 5% discount on the regular cost. One unconventional method adopted for loan repayments was the 'two she-goat' policy of the Dian Desa programme in Indonesia (Aristanti, 1986). Householders were given two she-goats, which were kept until four kids were produced. Two kids were sold to pay for a water jar, two kids were kept by the householder, and the she-goats were passed to the next prospective tank owner.

In Togo, villagers were encouraged to establish a village fund to be used for maintenance. An initial deposit of US$15.60 and subsequent annual contributions were collected. Since maintenance costs are very low, the fund eventually held over US$1000 kept to repair the system in case of hurricane damage. However, people became less willing to contribute as they felt a lot of money was building up which was sitting idle and depreciating in value. This underscores the need for suitable banking facilities which provide sufficient interest to compensate for inflation and the need to establish income-generating activities. Community contributions should be kept at realistic levels to meet maintenance costs and possibly some depreciation. Additional generated funds can be used for other local improvements for which the community has a need or from which it can benefit financially.

8. Rooftop Harvesting Systems

Rooftop catchment tanks are storage containers which receive runoff water from the roof of a house, a shed or a public building via a gutter and downpipe.

The most suitable roofs are those covered with iron-sheets, tiles and fibreglass-sheet. Existing roofs with asbestos sheets can also be used as the health hazards from inhaling and ingesting asbestos fibres is very much related to the production and construction process. Thatched roofs are also being used, particularly for traditional systems, but give a much lower yield and often produce coloured water.

There are a wide variety of tank shapes and sizes ranging from small jars, cylindrical or square standing tanks, to hemispherical excavated tanks. A range of materials is used for water tanks including polythene, galvanized iron, brick, stone masonry, reinforced concrete and ferrocement. Apart from a period when it was hoped that basket tanks (mortar reinforced with a lattice structure of branches or bamboo) would provide the best low-cost tank for developing countries, most practitioners now agree that 2 to 100 m^3 ferrocement tanks provide the easiest and cheapest solution in most situations.

Ferrocement is particularly appropriate because it has a tension resistance to shrinkage and load-stress cracking, high impact resistance, can easily be repaired and is made of materials that are usually readily available.

Tank construction involves skilled labour. Those involved in tank construction must possess basic practical skills such as formwork erection, plastering, and pipe fitting. A rigorous set of instructions must be followed closely, with attention to detail and quality control.

Tank use involves a fairly high degree of organization and commitment if optimum benefit is to be derived in terms of quality and reliability of supply. Because storage is finite and recharge depends on seasonally varying rainfall conditions, rooftop tank systems may not always provide a full or year-round supply to users. Variations in the annual rainfall, the length of the dry season and the consumption schedule of water can lead to the tank drying up prematurely. Failure to ration water for essential uses, prevent wastage, and provide proper cleaning and care for the system can lead to rapid exhaustion and gradual contamination of the water supply.

8.1 Site assessment

Assessing the site conditions together with the future tank owners is the first step towards a sound system design. The site conditions to be assessed are:

- availability of suitable roof catchments;
- foundation characteristics of soil near the house;
- location of trees;
- estimated runoff to be captured per m^2 of roof;
- availability and location of construction material.

A suitable roof with sufficient area and made of unpainted sheets of iron, tile, or fibreglass, is required to provide adequate supply free of contamination. If a roof area is too small, flat, inappropriate for guttering, or made of a material such as mud or thatch, it will not provide the required quantity or quality of runoff water. The height of the roof should be sufficient to allow the water to gravity-feed the proposed water tank. If a number of smaller roofs are available within a compound, the collection of runoff into a single tank may be considered or a few smaller tanks may be built.

If trees overhang the roof, falling leaves and seeds will block up the gutters and screens, and insects and bird droppings falling onto the roof will be washed into the tank. Important in the case of ground tanks, is that root growth may damage the foundations or sub-surface tank lining, causing cracks and leaks. This is particularly true for ASA vegetation, which may aggressively search for water and can penetrate poorly prepared sub-surface tanks.

The presence of solid, compact or rocky soils is an advantage for tank construction. Cracks can occur more easily where tank foundations are built on soils with subsidence or swelling and shrinkage characteristics.

8.2 Estimating the required system size

The actual size of the system will depend on various factors. Size will be strongly influenced by system cost, amount of rain to be collected, expectations and needs of tank owners and level of external support.

The key is how to match supply and demand to the full satisfaction of the user at lowest cost. The volume of rain and its distribution over the year, the size of the catchment area and the projected supply ultimately determine what size tank can be filled and how often (see Section 8.5). Usually the worst scenario will present itself during the longest dry season. The size of the catchment area and tank should allow sufficient supply for the users during this period. These are acceptable guidelines to follow, unless this proves too costly and/or other means are available to supply water during part of this period. If it is assumed that the tank will be full at the beginning of the dry season and the average length of the dry season and the average water use is known, then the tank volume (V) can be calculated by the following formula:

$$V = (t \times n \times q) + e_t$$

where:
V = Volume of tank
t = Number of days in the dry period
n = Number of people using the tank
q = Consumption level per capita per day
e_t = Evaporation loss during dry period (t)

Since evaporation from a closed storage tank is negligible, the evaporation loss (e_t) can be considered to be zero.

The necessary catchment area can be determined by dividing the tank volume by the accumulated average rainfall volume per m^2 over the preceding wet months, multiplied with the runoff coefficient which for galvanized iron or tiled roofs can be set at 0.8.

Experience shows that people with tanks next to their houses will often use between 20-40 litres of water per person per day (lpd). However, this may rise in time as people relax their water use habits because of ease of access. This clearly contrasts with the consumption levels of less than 10 lpd in a similar environment, with people fetching water from distant traditional sources. Together with the community, a decision must be taken as to how the water will be used or what affordable service level can be provided. If, for example, 30 lpd is agreed upon and a dry period of 100 days is normally not exceeded, a storage volume of 21 m^3 would be required for a family of seven members.

If a year is exceptionally dry however, the dry period may start earlier or last longer. The same tank volume can supply the family for this longer period of time only if an adequate rationing programme is adopted, with less water being used each day. This is of course more easily achieved when the dry period starts earlier and the tank volume can be divided by the estimated dry period at the beginning. When the dry season lasts longer, little water will be left to carry out the rationing. It is therefore important to establish an understanding with the users that depending on the risk of a longer dry season, a minimum strategic reserve should be kept. This would imply that when this reserve of say 1000 litres is reached, consumption should drop to the bare minimum.

In cases where rainfall data indicate that a given size of tank cannot be filled from the existing roof area, a larger roof catchment must be constructed. Where tanks fill up rapidly and overspill during the rainy season, a larger tank can be considered to provide a higher service level.

8.3 General design features

Rooftop harvesting systems can provide a very good quality of water if the design features outlined in Table 8.1 are taken into account.

Table 8.1: Design considerations for rooftop catchment systems

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- Non-toxic roof substances should be used.
- Roof surfaces should be smooth, hard and dense since they are easier to clean and are less likely to be damaged and shed materials into the water.
- Painting of roofs is not advisable since most paints contain toxic substances and may peel.
- No overhanging trees should be left near the roof.
- The nesting of birds on the roof should be prevented.
- All gutter ends should be fitted with a wire mesh screen to keep out leaves, etc.
- A first-flush capacity, such as a detachable downpipe section, should be installed.
- A hygienic soakaway channel should be built at water outlets and a screened overflow pipe provided.
- The storage tank should have a tight-fitting roof that excludes light, a manhole cover and a flushing pipe at the base of the tank (for standing tanks).
- There should be a reliable, sanitary extraction device, such as a gravity tap or a handpump, to avoid contamination of the water in the tank.
- There should be no possibility of contaminated waste water flowing into the tank (especially for ground tanks).
- Water from other sources, unless known to be of high quality, should not be emptied into the tank through pipe connections or the manhole cover.

Adapted from: Michaelides and Young, 1985

8.4 Design of system components

A rooftop catchment system consists of the following components:

- roof
- guttering and first flush device
- storage tank.

8.4.1 The roof

The roof should be smooth, made of non toxic substances and sufficiently large to fill the tank with the available rainfall conditions. Existing roofs of houses and public buildings can be used for a rooftop catchment system. In some cases enlarged or additional roofed structures can be built.

Figure 8.1 shows an example of a purpose-built rooftop catchment system for farmers in Botswana. This comprises a 40 m^2 iron-sheet roof supported by six poles.

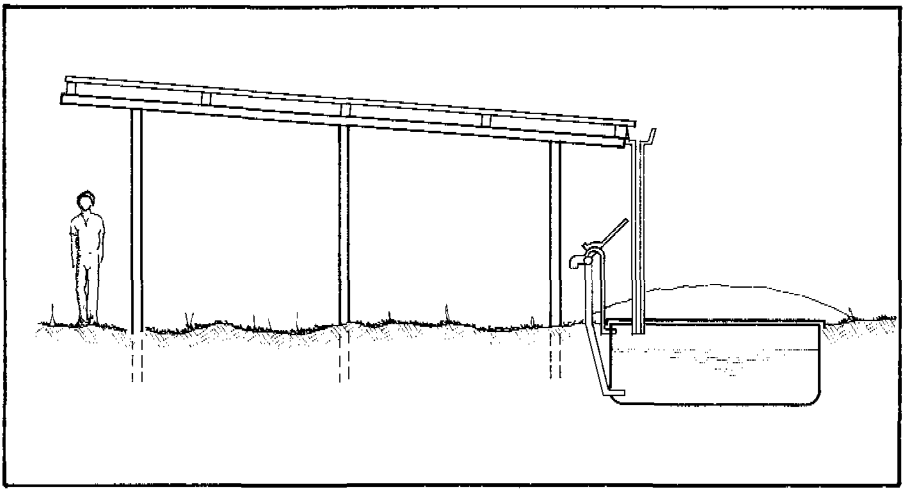

Figure 8.1: Sketch of ALDEP harvesting system in Botswana (Lee and Visscher, 1990)

8.4.2 Guttering and first-flush device

The function of guttering is to protect the building by collecting the water running off the roof and direct it via a downpipe to the storage tank.

The gutter should have a uniform slope of 0.5 % (Hasse, 1989) and be large enough to collect the heavy runoff from high-intensity rains.

With all roof catchment tanks, the first 20 to 30 litres of rainwater running off the roof, which contain large quantities of leaves and bird droppings, should be discarded to keep the water potable. The importance of first-flush devices was recently shown by studies undertaken in Malaysia (Yaziz et al, 1989). Faecal coliforms in runoff water were reduced in range from 4-60 per litre to zero, as the first 5 litres of runoff washed the 15 m^2 roof.

Some projects have experimented with automatic first-flush devices in which a mechanism, usually a pivoting reservoir, diverts the initial runoff. Generally, these devices have proven inadequate due to malfunction or poor maintenance. For example, in a USAID Togo Rural Water Supply and Sanitation project, over half of the 250 cisterns constructed had their foul-flush system malfunctioning after three years. Most were blocked open by users (O'Brien, 1990). Instead, a simple detachable downspout allowing the pipe to be swivelled to the side of the tank inflow and to be switched back a minute or so after the rainstorm has started, is probably the most appropriate system. Regardless of the device selected, they all need either regular maintenance or active operation to ensure good quality stored water.

8.4.3 The tank

In using ferrocement technology, there are different designs available ranging from 2 to 200 m^3. A free-standing cylindrical tank can be built in sizes between 10 to 30 m^3, while a capacity of up to 200 m^3 can be achieved with sub-surface hemispherical tanks. The latter are most economical when capacity exceeds 50 m^3.

The principles of construction of ferrocement tanks involving the use of corrugated iron moulds as illustrated by Watt (1978), shown in Figure 8.3, are widely adopted. An alternative design, not using formwork, is presently being applied in constructing 46m^3 tanks at primary schools in Kenya (Lee and Nissen-Petersen, 1989). The technique for construction involves erecting a circular frame made of weld-mesh bars spaced at 15 cm and covered with chicken wire (2.5 cm gauge) onto a reinforced concrete base. This is then covered on the outside with sacks or cloth and a 1.5 cm layer of mortar (1 part cement, 3 parts sand) is plastered onto the inside in two coats to produce the tank wall. Two further coats of plaster are added, one on the outside after removing the sacks and one on the inside, to provide a tank wall thickness of 6 cm. A waterproof coat of just cement and water is then added to the inside of the tank.

When the walls are complete, a wooden frame is constructed inside the tank to support metal templates made from old oil drums which form the mould for the domed roof. The roof is also reinforced with weld-mesh and chicken wire. To ensure good quality, the floor, the walls and the roof need to be properly cured by keeping their surface moist for a week and preferably longer. This process should start immediately after each component is ready. As an alternative one can also apply the construction method adopted in Thailand in which the first coating on the wall is placed by two persons, working opposite each other, one on the inside and the other on the outside of the tank.

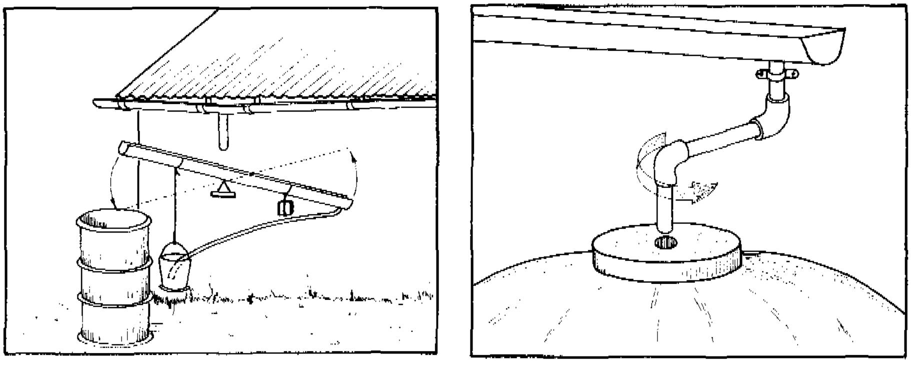

Figure 8.2: Two types of first-flush device

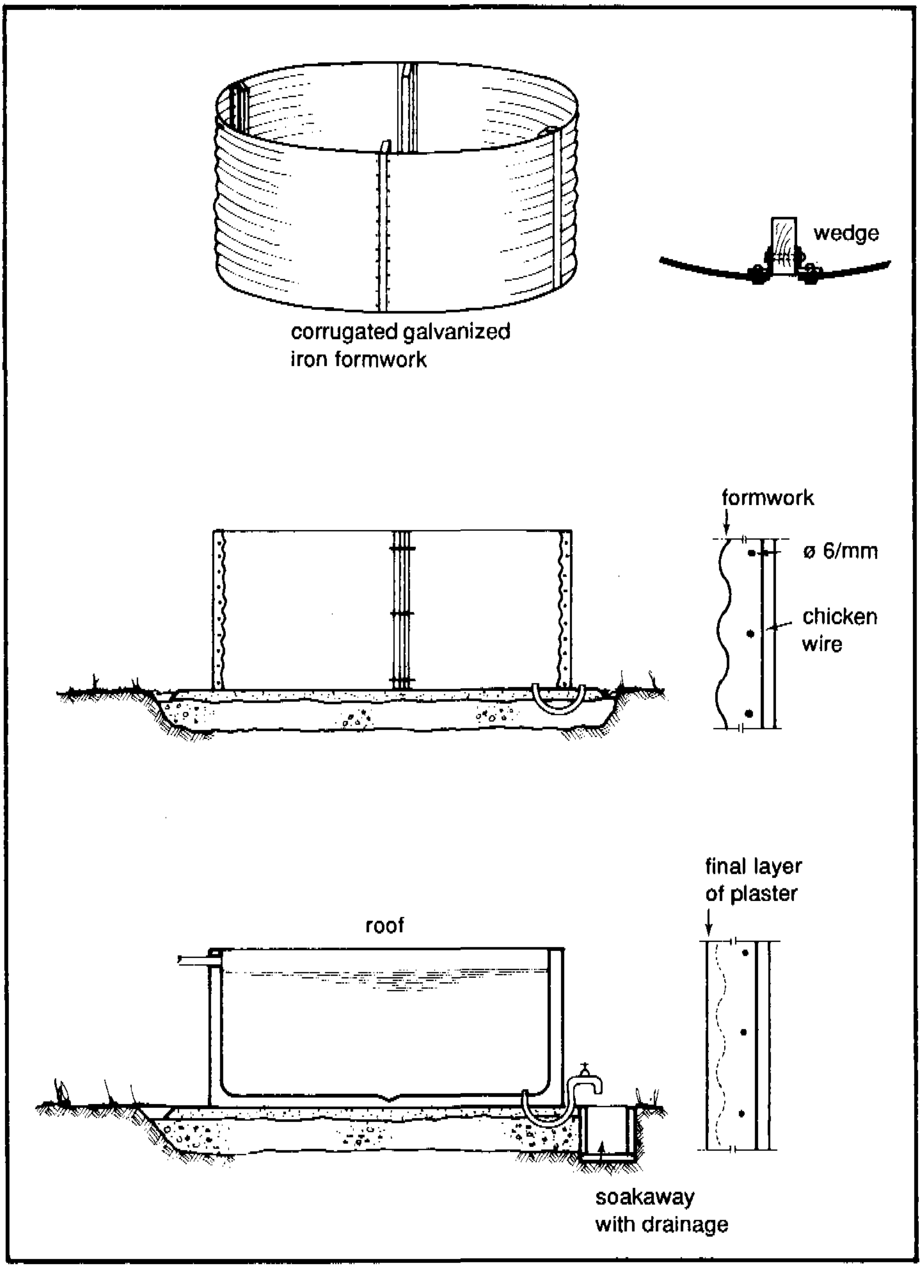

Figure 8.3: Principles of construction of small ferrocement standing tanks (Watt, 1978)

Construction of sub-surface tanks in ferrocement is also gaining popularity and often is more economical than tanks constructed from other materials. Figure 8.4 shows the different steps involved in construction of a ferrocement ground tank.

An advantage of ferrocement tanks is that an approach can be adopted in which, instead of building large tanks, a series of smaller tanks is built over time. This approach of constructing smaller tanks has proven popular in Thailand, but is not yet being applied in Africa. Smaller tanks have the advantage that they are easier to construct by local contractors or users, but the cost per m^3 is often higher.

All tanks should be properly covered to avoid deterioration of the water quality and evaporation losses. If ferrocement is selected for the tank cover, care must be taken to prevent reinforcement from being left exposed. Serious corrosion can take place as vapour condenses on the inside of the roof. This can lead to corrosion, iron contamination and possible roof failure. Sub-surface tanks should always have a roof, and if, for some reason, a roof is not fitted, they should be fenced off to prevent drowning incidents from occurring.

With any tank the inlet, overflow pipe, drain pipe and any air vent should be effectively screened to prevent the breeding of mosquitos in the tank. To avoid stagnant water around the tank due to spillage at the tap, waste from the first flush or overflow when the tank is filled up, a drainage pipe leading to a soakaway should be incorporated in the design. Periodically, thorough cleaning of tanks is required. Hence, if possible a drain at the bottom of the tank for emptying purposes and a covered manhole must be included. While the abstraction of water from the standing tanks should be by gravity-fed tap, water should be taken from the ground tank by means of a handpump.

8.5 Design example

This example is for a family household rooftop system:

Data:
- Family of 7 persons (n)
- Daily consumption per person 20 litre (q)
- Annual rainfall (p) of 750 mm (lowest value in a period of 5 years)
- Runoff coefficient (f) of 0.8 (corrugated metal sheet)
- Dry period (t) of 125 days

The two questions to be solved are: how large should the roof catchment be and what is the minimum capacity required for the tank to provide sufficient supply year-round.

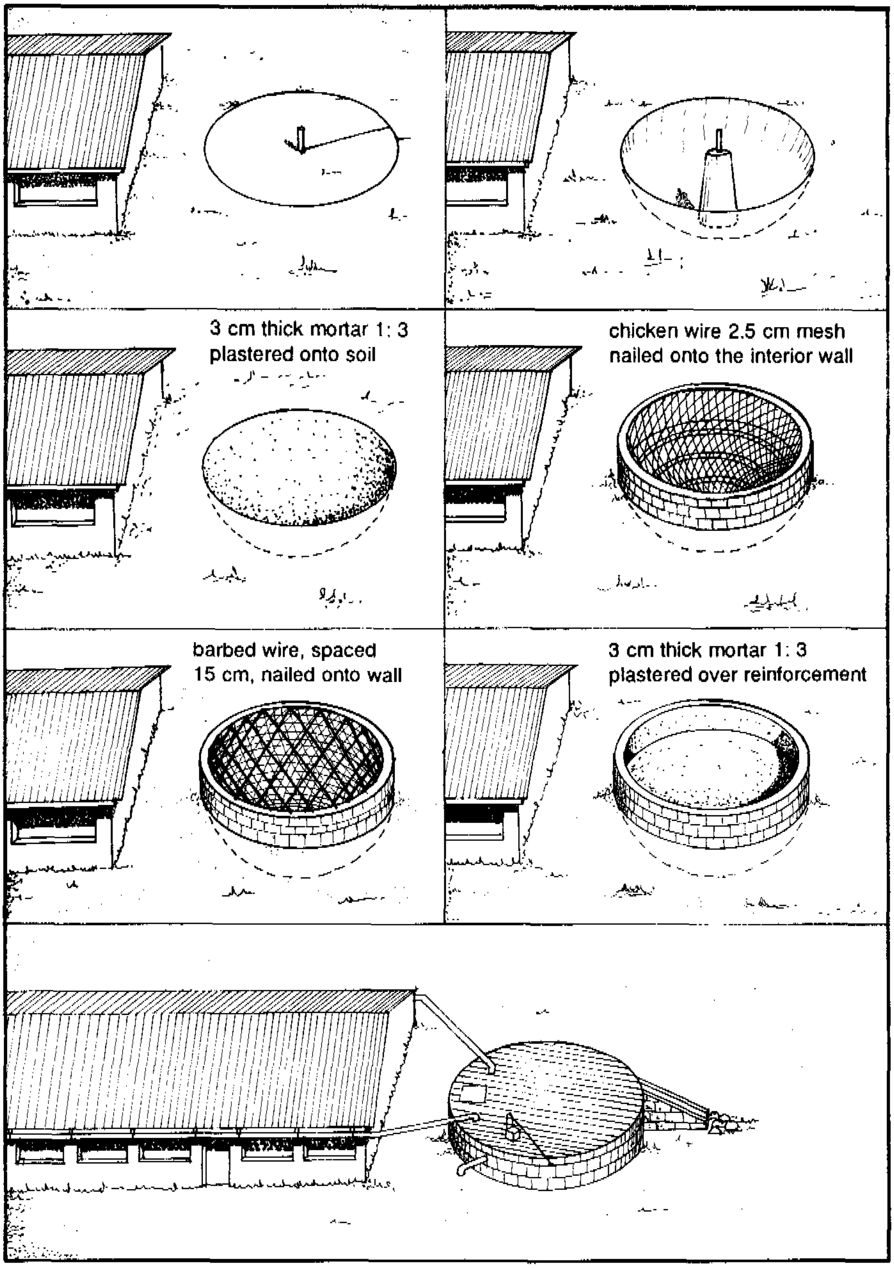

Figure 8.4: Stages in the construction of a 78 m^3 ferrocement ground tank (Lee and Nissen-Petersen, 1989)

Required roof catchment

Annual consumption $Qa = n \times q \times 365$

$$Qa = 7 \times 20 \times 365 = 51{,}100\ \text{l}\ (51.1\ \text{m}^3)$$

Required roof catchment: $A = Qa/(f \times p)$

$$A = 51.1/(0.8 \times 0.75) = 85\ \text{m}^2$$

Required tank volume

The required tank volume depends on the length of the dry period and the pattern of rainfall and water use.

In the absence of reliable monthly rainfall data, the tank volume can be established by assuming that the tank will be full at the start of the dry season and only has to satisfy the water needs for the dry period.

If we further assume that no evaporation of stored water will take place, the required volume is:

$$V = t \times n \times q$$

$$= 125 \times 7 \times 20 = 17{,}500\ \text{l}\ (17.5\ \text{m}^3)$$

This approach, however, entails a risk that too small a tank will be constructed, so it is better to increase the tank volume by, say, 20%.

A more precise estimation of the tank volume can be made if reliable monthly rainfall data exists. Preferably, data should be available for a 10-year period, from which the lowest annual rainfall figures can be selected. Table 8.2 sets out the data for our example indicating monthly rainfall in mm and collected runoff volumes from an 85 m^2 roof, using a runoff coefficient of 0.8.

The total runoff that could be collected from this roof is 51.1 m^3, if sufficient tank volume is provided. The required volume can be identified by plotting the balance between the monthly cumulative runoff and the monthly cumulative demand of 4.26 m^3 (Figure 8.5). The first month plotted is October, being the first month after the dry season in which monthly rainfall exceeds monthly demand. From Table 8.2 and Figure 8.5 it can be seen that the maximum volume to be stored is 19.05 m^3. If this tank volume is provided, all water will be collected and demand will be met. In less dry years however, more water will be collected from the roof, which may result in occasional overflow of the tank.

Table 8.2: Example of monthly rainfall figures and runoff volumes

Month	*Monthly rainfall (mm)*	*Monthly runoff* m^3	*Cumulative runoff* m^3	*Stored water * volume* m^3
October	64	4.3	4.3	4.30
November	98	6.7	11.0	6.74
December	103	7.0	18.0	9.48
January	85	5.8	23.8	11.03
February	95	6.5	30.3	13.27
March	103	7.0	37.3	16.01
April	107	7.3	44.6	19.05
May	60	4.1	48.7	18.89
June	10	0.7	49.4	15.33
July	0	0	49.4	11.08
August	0	0	49.4	6.82
September	25	1.7	51.1	4.26
Total	750			

* For the purpose of calculation it is assumed that the accumulated monthly rainfall, falls in one burst on the first day of the month.

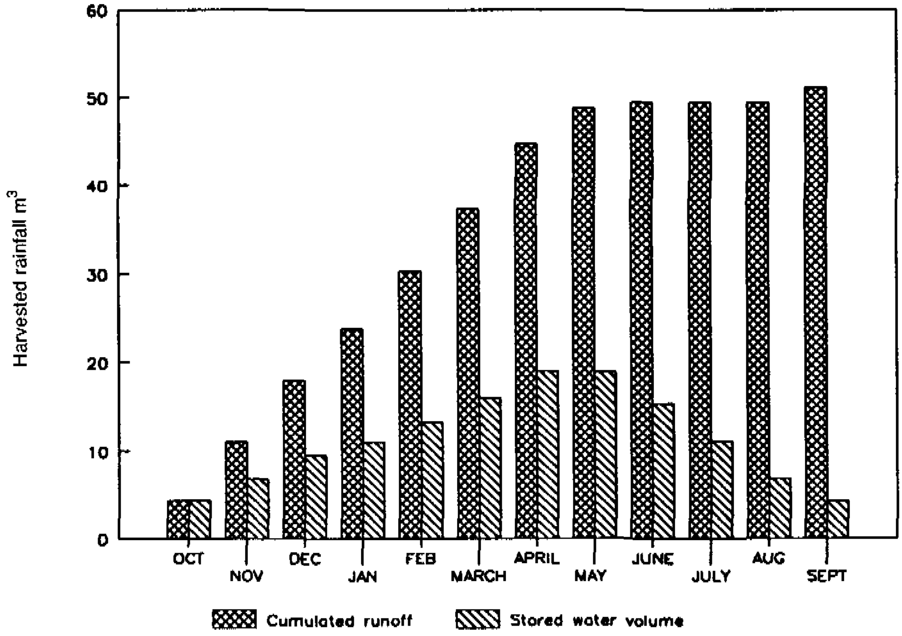

Figure 8.5: Graphic illustration of cumulated runoff and stored water volume

We can now also calculate the effect of a larger catchment area. In our example we have increased the catchment area by 20% (Table 8.3). The total runoff thus increases to 61.32 m^3, out of which 9.57 m^3 will be spilled over and 0.65 m^3 will be left in the tank at the end of September. It would thus be possible to satisfy the demand with a tank volume of 18.4 m^3.

By constructing tables that determine the balance between runoff, demand and storage over the year and by plotting the data as monthly or daily graphs, suitable design decisions can be made concerning the best size of tank and rooftop for a given climate and user demand. By recalculating the data with a number of possible catchment sizes and storage volumes, the best balance between the two characteristics can be determined that satisfies the water need and the financial status of the owner. The implications for the water supply service level because a cheaper and smaller catchment or smaller tank is selected can easily be identified.

Other graphic and statistical methods exist, including computer models. See for example, those described by Schiller and Latham, (1982) and Latham, (1983). The use of computer-produced graphs is, for example, widely promoted by the Government of South Australia (Gould, 1991). Application of more sophisticated methods will have particular benefit for large scale programmes.

Table 8.3: Effect of 20% increasement in catchment area

Month	*Monthly runoff volume m^3*	*Accumulated runoff m^3*	*Stored water volume m^3*	*Overflow volume m^3*
October	5.16	5.16	5.16	0.00
November	8.04	13.20	8.94	0.00
December	8.40	21.60	13.08	0.00
January	6.96	28.56	15.78	0.00
February	7.80	36.36	19.05	0.27
March	8.40	44.76	19.05	4.14
April	8.76	53.52	19.05	4.50
May	4.92	58.44	19.05	0.66
June	0.84	59.28	15.63	0.00
July	0.00	59.28	11.37	0.00
August	0.00	59.28	7.11	0.00
September	2.04	61.32	4.89	0.00

8.6 Costing

Experience from the field suggests that cost is the overriding decision criterion, followed by water needs and expected supply. The actual costs of a given tank type and size clearly varies from location to location, depending mostly on local material or labour costs. However, from experience it can be expected that the cheapest price for a 10 m^3 standing tank and an 80 m^3 ground tank will be around US$250 and US$1000 respectively (at 1989 prices). In order to assist in the calculation of costs, the bill of quantities and labour requirements are given for two types of tanks: the cylindrical standing tanks ranging from 10 to 30 m^3 (Table 8.4), and ferrocement hemispherical ground tanks of 75 m^3 (Table 8.5). Both types are constructed with ironsheet roofs supported by wooden rafters.

Table 8.4: List of quantities for cylindrical standing tanks

Capacity (m^3)	*10*	*20*	*30*
Weld mesh - 200 cm wide (m)	15.24	21.58	30.49
Chicken wire (2.5 cm) - 90 cm wide (m)	30	48	57
Binding wire (kg)	6	10	13
Portland ferrocement (50 kg sacks + 10%)	21	32	43
Sand (m^3 + 10%)	1.67	2.45	3.38
Gravel - 20 mm (m^3 + 10%)	0.41	0.77	1.18
Galvanized corrugated iron roof sheets (m^2)	8-10	14-16	20-22
Roofing timber - 10 x 5 cm (m)	15.84	30.42	36.26
(above as individual timbers)	1x2.84	1x3.96	1x4.82
	2x2.10	2x3.65	2x4.47
	2x1.85	2x3.53	2x3.65
	2x0.95	2x1.85	2x3.20
	4x0.80	2x1.65	2x1.85
		2x0.95	2x0.95
		4x0.80	4x0.80
Polythene sheeting - minimum (m^2)	40	65	85
Cloth/sacking - 200 cm width (m)	9.5	12.75	15.5
Strong string (kg)	2	3	4
12 mm plastic/galvanized iron pipes (m)	4	4	4
12 mm plastic/galvanized iron elbows	4	4	4
12 mm plastic/galvanized iron tap sockets	1	1	1
12 mm tap fittings	1	1	1
12 mm pipe cap	1	1	1
Clean water - add drinking/curing (l)	2100	3200	4300
Mosquito-proof 1 mm galvanized gauze (m^2)	1	1	1
Nails - 10 cm (kg)	5	8	10
Roofing nails (kg)	5	8	10

Table 8.5: List of quantities for 75 m^3 hemispherical ground tank

Chicken wire (2.5 cm) - 90 cm wide (m)	130
Barbed wire (m)	1150
Binding wire (kg)	1-2
Portland ferrocement (50 kg sacks + 10%)	70
Sand (m^3 + 10%)	5.7
Stones approximately 60 mm (m^3 + 10%)	7.1
Galvanized corrugated iron roof sheets (m^2)	46
Roofing timber - 10 x 5 cm (m)	38.74
(above as individual timbers)	2x6.74
	2x5.94
	2x2.64
	2x1.45
	2x0.90
	4x0.85
Polythene sheeting - *minimum* (m^2)	130
Handpump - direct action	1
Galvanized iron pipe - 4 cm (m)	4.06
Metal plates - 30 x 30 cm	2
Clean water - add drinking/curing (l)	7500
Mosquito-proof 1 mm galvanized gauze (m^2)	4
Nails (6.5 cm)	20
Nails - 10 cm (kg)	10
Roofing nails (kg)	15

Included in any cost determination must be the expenses incurred in transporting material and skilled labourers to the site and any other incidental project costs.

Labour requirements

Ferrocement tank construction requires only a few basic skills, but rigorous attention to detail, quality control, and curing are essential.

Tank construction requires:

- two technical workers, one experienced and one on-the-job trainee, to carry out formwork construction and plastering;
- three to six manual labourers, depending on the size of the tank, to prepare the site, fetch materials, sieve sand, mix mortar and generally help out;
- one supervisor, who will periodically visit the site during planning, construction and later as part of a management monitoring programme.

Assuming an average of three labourers helping in standing tank construction and four in ground tank construction (six in preparation), the total labour costs have been estimated (Table 8.6). These are conservative estimates and potential exists for saving labour.

Table 8.6: Total working days for tank construction

	Standing tank (10 - 30 m^3)		
	Technicians	*Labourers*	*Supervisor*
Planning	0	0	0.5
Preparation	2	3	0
Construction	16-20	24-30	1
Follow-up	0	4	1
Total	18-22	31-37	2.5

	Ground tank (75 m^3)		
	Technicians	*Labourers*	*Supervisor*
Planning	0	0	1
Preparation	10	75-100	1
Construction	24-30	48-60	2
Follow-up	0	4	1
Total	34-40	127-164	5

8.7 Construction

For both types of tanks, the proposed site should be cleared of vegetation, loose surface soil and any large, moveable rocks. Adjacent trees should be removed to prevent debris accumulating on the roof and avoid root growth under and around the tank that might cause future structural problems.

Reinforcement is needed to avoid cracks and leaks. Standing tanks experience the greatest stresses in the bottom third of the tank, which is why most cracks and leaks appear here (Hasse, 1989). One useful approach is to wrap barbed wire more densely around the lower third of the tank.

Ground tanks are also subject to considerable stresses. Therefore, a good supporting back bone should be provided with wire ribs stretching from wall to wall across the apex of the hemisphere. A dense, evenly spaced reinforcement of chicken wire and vertical and spiralling wire reinforcement in the sidewall is required, since together these resist the radial and lateral forces against the walls.

The plastered surface should be kept wet and should always be covered by plastic sheets or wet rags after every stage of plastering is complete. Rapid loss of moisture when drying exaggerates shrinkage cracking and can lead to tank failure or dam leakages. Once plastered, a tank should be carefully filled with a minimum of 10 cm of water to aid the curing process. Although ferrocement appears hard, it does not reach its full strength until a year after plastering. It should be kept damp throughout curing, for at least seven days, to ensure that it reaches a good strength and has a long life.

Once cured, the filling of tanks should be a slow process, since rapid filling can lead to severe cracking. Tanks should never be allowed to dry completely, unless for a short period of cleaning.

If repairs are ever necessary, the mixture of ferrocement mortar should be identical for the repair as for the original tank. Thus it is useful to scratch the mixture details onto the side of the final outer mortar coating on completion of each tank. Additional information can be included with the date and names of both the owner and the technician. This provides a useful point of reference.

8.8 Management and maintenance

Rooftop catchment tanks, like all water supply systems, require good periodic management and maintenance to ensure that the quality and reliability of the water supply is high. If the various components of the system are not regularly cleaned, water use is not properly managed, possible problems are not identified or necessary repairs are not performed, the roof catchment system will cease to provide reliable, good quality supplies.

The following timetable of maintenance and management requirements gives a basis for monitoring checks:

During the rainy season - the whole system (roof catchment, gutters, pipes, screens, first-flush and overflow) should be visually checked before and after each rain and preferably cleaned after every dry period greater than one month.

End of dry season - the storage tank should be scrubbed out and flushed of all sediment and debris at the end of each dry season just before the first rain comes (the tank should be re-filled afterwards with a few centimetres of clean water to prevent cracking). A full service of all tank features just before the first rains are due to begin, including replacement of all worn screens and servicing of the outlet tap or handpump.

Year-round - if in any doubt about the presence of organic contaminants in the water source (for instance, after an outbreak of diarrhoea), the water can be chlorinated with 10 grams of free chlorine for each m^3 of stored water. Water must not be allowed to leak from tap fittings. Not only will this waste water, but it may also provide a basis for algal growth and lead to the development of bacterial colonies which can make the water supply unsafe. The water tank should regularly be checked for leaks and cracks, which need to be repaired. Only small weeping leaks, which may occur on first filling the tank, need not be repaired since they usually seal themselves.

8.8.1 Water use management

Control over the quantity of water abstracted from the tank is necessary to optimize water use. Water use should be managed so that the supply is sufficient to last the dry season. Failure to do so will result in the utilization of lower quality water sources and the need to once more trek long distances to alternative sources. However, underutilization of the water source due to severe rationing may leave the user dissatisfied with the service level provided.

Water use management can be implemented through a number of management actions:

- fitting the tank with a lockable tap and inspection hatch;
- leaving the key with someone responsible who understands the concepts involved and who can make calculations concerning sustainable water use;
- developing a commitment amongst users to preserve tank water for specific purposes from which health benefits result, e.g. drinking, food preparation and personal hygiene. This will require discussions on hygiene habits with the community and possibly identifying other water sources for non-drinking purposes;
- fitting a transparent tube to the outside of the tank to provide a simple indication of the water level in the tank.

The user needs to know how much water can be drawn per day. This can be facilitated by putting marks on the tank for every two weeks, accumulated consumption. With the users by experience knowing when the next rains are due, they can adjust use accordingly. A strategic reserve of, say, two months *drinking* water for the family should be indicated beyond which the user should fall back on a surviving strategy, bringing water use back to the bare minimum. In this way a safeguard is provided to ensure water is available if the dry season lasts longer than normal.

If a dry season starts earlier than planned for, the rate of daily consumption needs to be adjusted. The biggest problem however will occur when the rainy season is later than expected. Managing water use at schools and public buildings will be much more difficult. It may be needed to, for example, restrict use to only a short period per day or to nominate someone who can sell the water.

9. Surface Catchment Systems

Surface catchment harvesting systems are large-scale communal water supply systems that collect and store water running off a specific part of the landscape. This entails either a rocky outcrop or an area of compacted or clay-rich soil. The former is coupled with a rock masonry dam and the latter with a semi-circular clay earth dam.

Where feasible, rock catchment masonry dams are generally the preferred of the two options because water quality is generally higher. With rock catchment dams, both the catchment and storage sites are virtually impermeable, yielding greater runoff efficiency and lower seepage losses. The catchment area can be kept clean more easily, resulting in higher quality runoff. The dammed reservoirs generally have a high depth to width ratio, resulting in relatively low losses to evaporation. The catchment area is usually small, isolated and often has no other uses such as agriculture or livestock grazing, thereby being better protected from contamination. However, the costs of construction are quite high, due to the considerable quantities of cement and skilled labour required for even modest structures. Appropriate sites are often far away from where the water is needed.

The earth dam is low on the list of preferred options to supply household water since quality is generally low. As a source of non quality-essential water however, it can bring larger quantities within easier reach of households. Water can also be used for irrigation and livestock watering. Earth dams can be constructed with few commercial materials, a maximum of volunteer self-help labour and a minimum of user cash contributions.

For all surface catchment systems, the catchment area should be protected from erosion, unsanitary conditions or the use of toxic substances which could lead to contamination of runoff water. The system should be conveniently located near the user group, who should be keen to help develop the system, convinced of the need for it and willing to protect the catchment area and storage site from erosion and contamination.

Factors important for determining the size of the reservoir include:

- the size of the catchment;
- the expected runoff in a given season or year;
- the shape of the site where the dam can be built;
- the water demand;
- the amount of labour that a user group is willing to contribute.

9.1 Rock catchment dam systems

A masonry rock catchment dam may consist of a single straight wall or a number of sections of different heights or lengths, depending on the shape of the site and the desired size of the reservoir. Walls have been built that range from 2 to 6 m in height and 10 to 60 m in length. In Southern Kenya, reservoirs have been built containing 20 m^3 to 4,000 m^3 of water all using the same design, construction methods and materials.

9.1.1 Site assessment

Dams are constructed on rock outcrops, either in rocky top-slope areas or in the lowlands where individual inselbergs are found. Siting features to look for are hollows, depressions or gullies where the rock dips across and/or down the slope.

The rock above the dip should preferably be wide and form a funnel towards the dip so that water will drain there. However, other types of slopes are also suitable catchments. Simple stone and mortar gutters can be extended out from the ends of the dam, reaching up and across the rock to channel runoff from a wider area and bring it down to the dam. The site for the dam and the bottom of the reservoir should be devoid of rock fissures or fractures that might drain the water away from the site. Aerial photographs and a field survey could assist in the detection of fractures and in the selection of possible sites. Special experience in photo

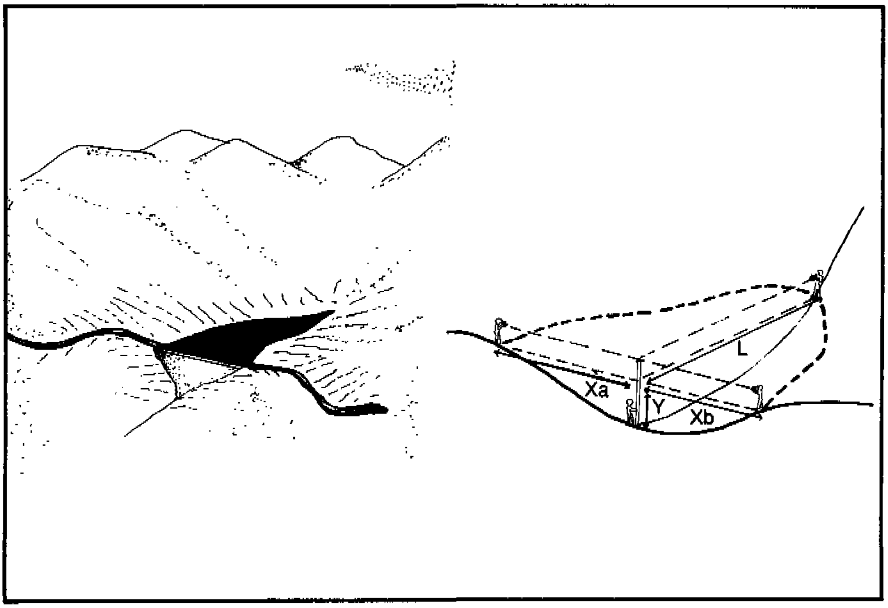

Figure 9.1: Catchment area and reservoir dimension of rock catchment dam

interpretation is required if a systematic survey of potential sites is to be made. A minimum of 1:50,000 scale photos in stereo pairs is necessary, but a scale of 1:10,000 is preferred.

Table 9.1: Summary checklist of rock catchment siting factors

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- Dams should be built at sites that can produce a relatively high depth to surface area ratio so as to minimize evaporation losses.
- Rock surfaces should not be fractured or cracked, which may cause the water to leak away to deeper zones or underneath the dam.
- Dam foundations must be of solid impermeable rock with no soil pockets or fracture lines.
- Convenient location for user groups.
- No soil erosion in the catchment area.

Dams should be sited along the edges of depressions or directly across the lower ends of deep gullies into the rock. Looking down the slope of the rock, the best site is the outer edge of a dip, where the angle of the rock face is near horizontal, before it steepens again or before the soil cover begins. The foundations must be sited on almost flat, unweathered, rock surfaces or ones sloping slightly backwards to the reservoir. This gives the dam the greatest stability, negating the need for reinforcement and simplifying the design. The reservoir should preferably be deep, minimizing reservoir surface area to reduce evaporation losses. The dam should not exceed a maximum height of five metres for this simple masonry wall design.

9.1.2 Calculation of runoff and storage volume

Catchment Area

The runoff in the catchment area can be estimated with the following formula:

Runoff = Rainfall x Runoff Coefficient x Catchment Area

The runoff coefficient is the proportion of rainfall that will result in runoff. The coefficient for rock surfaces is approximately 0.8. For other types of catchment areas, different coefficients apply (Table 5.2).

The required catchment area for a given demand can be identified as follows:

Catchment Area = (demand + evaporation loss)/Runoff

$A = (Q + e) / R \times f$

where: A = catchment area (m^2)
Q = (yearly) demand (m^3)
e = annual volumetric loss to evaporation (m^3)
= $Aw \times e_p$ = average reservoir area x potential evaporation
f = runoff coefficient
R = annual rainfall depth (m)

Example: A village with 60 families, where each family uses 60 litres/day; number of dry days is 180; losses through evaporation are estimated, assuming e_p *is 750 mm/year and a reservoir area of* $20 \times 20 = 400\ m^2$.

Demand: $60 \times 60 \times 180 = 648{,}000$ *litres* $= 648\ m^3$

Evaporation $0.750 \times 400 = 300\ m^3$

Rainfall: 300 mm = 0.3 m

Runoff coefficient: 0.8

Catchment area: $(648 + 300) / (0.3 \times 0.8) = 3{,}950\ m^2$

This is approximately 60 x 65 m: a rather small rock outcrop such as an inselberg. However, a larger or smaller catchment can still be used, although the latter will provide a lower service level.

Storage Volume

To calculate the storage volume of a simple rock catchment dam, the shape of the reservoir is estimated in two halves, giving an approximative storage volume of:

$$V = 1/6 \times L \times Y \times (Xa + Xb)\ (m^3)$$

The real volume might be larger, but it is better to underestimate the volume than to overestimate it.

9.1.3 *General design features*

Table 9.2: Checklist for the design and construction of a rock catchment dam

- A solid foundation, to avoid potential leaks.
- A sound dam construction, which if required, can be built in stages.
- An out-take, gravity pipe and water tap point should be constructed to abstract water downstream from the dam.
- The downstream side of the dam should be protected against erosion in case water overflows the dam.
- The size of the dam and catchment area should be consistent with the available labour force.
- The shape of the reservoir created by the dam should minimize evaporation losses.
- Local construction materials should be relied on.
- Soil erosion should be absent in the catchment area or be easily controlled by simple soil conservation methods.
- The catchment area should be protected against pollution.

9.1.4 *Design of system components*

Catchment area

In general the catchment area will constitute rock outcrops sloping towards the reservoir. However, if the catchment is a rounded inselberg with the dam built on one side, gutters should be constructed around the inselberg to drain the water to the reservoir.

Vegetation and all pockets of soil should be scraped off the rock. This prevents leaves from washing into the water, discourages animals from the area, and prevents soil washing off the surface during rainstorms and into the reservoir. Sediments make the water turbid and can silt up the storage reservoirs thus requiring frequent cleaning.

To demarcate and protect the catchment area, a fence of live thorn bushes or sisal should be planted.

Foundation

Any cracks or fissures near the dam foundation and the reservoir area must be filled with a mix of cement to sand of 1:4. The foundation should be prepared by removing all dirt and loose rock. Weathered rock must be chiselled away, after which the foundation needs to be cleaned with water and a thin layer of cement dusted onto the moist rock surface. Within one hour, a 3 cm thick layer of mortar

(1 cement: 3 sand) is compacted on the thin layer of cement and left with a rough surface to promote good bonding with the next stage of construction.

Dam wall

The design of the stone masonry dam wall is straightforward. It is made up of sections with the general characteristics shown in Figure 9.2.

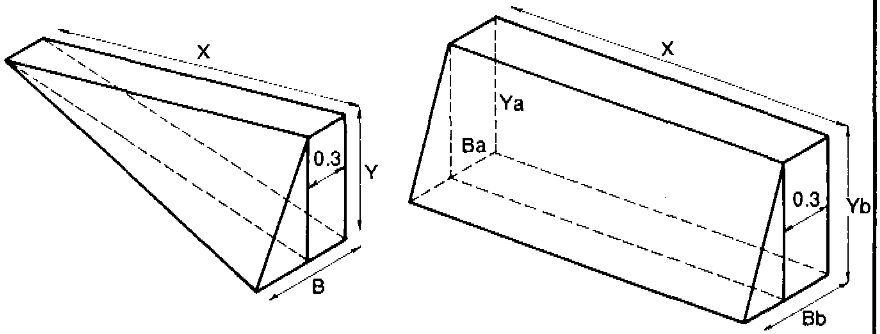

Figure 9.2: Wall types for rock catchment dam

The crest is always 0.3 m. The relationship between dam height (Y) and the base width (B) is given in Figure 9.3.

Generally a 2.5 m high dam, built in steps of 50 cm, is a good size to be completed in one dry season. If a larger dam is required, it is advisable to start off with a small dam and enlarge it upwards and outwards in stages. Another option is to built the dam of reinforced concrete, which sometimes may be cheaper, but involves much more experience and expertise.

Other components

For reasons of hygiene and to protect the dam and catchment area, a tapping point should be situated lower than the dam, and a piping system has to be installed. The out-take point, protected by a filter box, should be located at the lowest point of the reservoir. If necessary, the piping system has to be equipped with a syphon device.

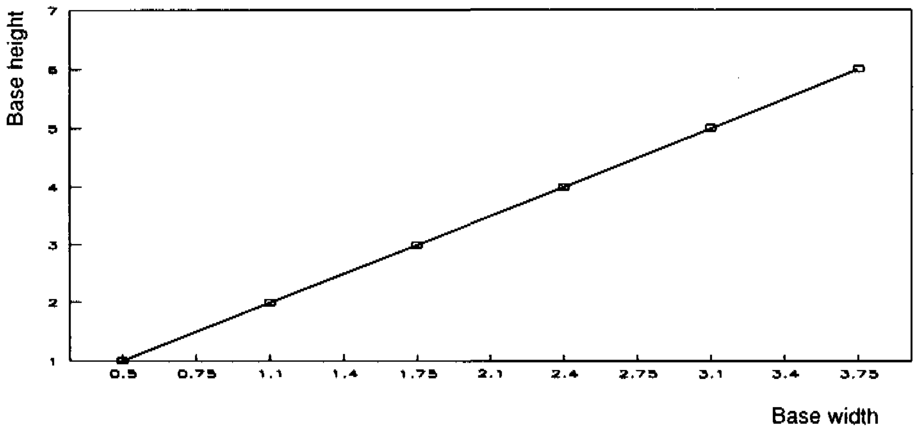

Figure 9.3: Relationship between dam crest height and base width, with a constant crest width of 0.3 m.

A watering trough and a laundry slab should be built at a suitable location downstream away from the tapping station. Donkeys could be watered there and clothes washed (assuming that the stored quantity of water is sufficient for these purposes also).

9.1.5 Costing

Apart from material and labour costs for the actual construction, other costs of the dam that should be considered are planning, digging out soil, filling of cracks, chipping away of stones and the transport of material to the site.

Material requirements:

The volume (V) of a dam wall (Figure 9.2), can be calculated as follows:

Type 1: $V_1 = 0.6\ X \text{ x } Y + 1/6\ (B - 0.3)\ X \text{ x } Y$

Type 2: $V_2 = 0.6\ X\ (Ya + Yb) + 1/8\ X\ (Ba + Bb - 0.6)\ (Ya + Yb)$

Masonry gravity dams are made from a mix of mortar (ratio 1 cement: 4 sand) and rocks (ratio 1 mortar: 4 rocks). One m^3 of masonry thus requires: 2 sacks of cement (50 kg), 0.22 m^3 of sand, 0.88 m^3 of rock and some 200 litres of clean water.

By knowing the volume of the dam wall it is relatively easy to calculate the required quantity of materials.

Labour

Depending on the difficulty of the work site and the commitment of the labourers, it is estimated that 1 artisan with the help of 10 labourers can build an average of 1 m^3 of dam wall a day. For example, a construction team of 2 artisans and 20 labourers would require V/2 days to construct a dam with volume V m^3. Assuming a maximum of 60 working days in a three-month dry season, the maximum volume of dam wall that can be built would therefore be:

Maximum Volume = 60 x 2 = 120 m^3

Each stage in dam construction must be completed in a single dry season. Otherwise, the building site will become partially submerged and unworkable. The dam can be raised in stages each year until it reaches its full design height.

9.1.6 Construction

The construction of a rock catchment dam can be split up in three phases, with specific tasks involved in each. They are listed in chronological order in Table 9.3.

Construction of the dam in stone masonry starts with setting carefully cleaned, large, flat stones in mortar (1:4) along the inner side of the lines marking the sides of the dam. The stones must not touch each other and be kept in place with small sticks until the mortar is strong enough to hold them.

Table 9.3: Tasks for rock catchment construction

A.	**Dam site preparation**
	Bush clearing
	Boulder and soil removal
	Surface inspection
	Fissure/fracture plugging
	Template and builder's lines erection
	Foundation inspection/roughening
	Material collection
	Planting of live fencing around future reservoir
B.	**Construction**
	Draw-off pipe installation
	Dam wall construction
	Plastering
	Pipe, filter box and tapping station construction
C.	**Catchment area improvement**
	Removal of soil cover
	Removal of vegetation
	Filling of fissures
	Construction of catching gutters

When both inner and outer walls have been built up to a height of 0.5 metres and have been cured for some two days under polythene sheet, the space in between them needs to be filled with clean stones and fresh mortar (not older than one hour). When this section is finished, leave it with a rough surface and extend the inner and outer walls by another 0.5 metres, fill the space in between, and continue this step-wise construction until the dam has reached its desired height.

Although skilled artisans can build a water-tight wall in this way, often it may be necessary to plaster the inner wall facing the reservoir with mortar (1:3). Before plastering, the wall should be chiselled and properly cleaned and moistened. Special attention is needed for the corner between the wall and the foundation, which needs proper cleaning and filling with mortar. Keep the plastered wall damp for at least one week, and preferably longer, to ensure a strong waterproof concrete.

9.1.7 Maintenance and management

Maintenance and management requirements are geared towards preservation of the quality of the stored water, optimizing water abstraction and use, and the identification and solution of potential leakage problems.

To avoid contamination of the water, a fence of thorn bush can be constructed around the catchment area or the reservoir edge, discouraging people and animals from entering. The rock should be kept clean of debris and water should always be abstracted at the tapping point. If possible, the reservoir should be emptied at the end of the dry season to remove silt and algae.

To avoid mosquito breeding and the possible spread of malaria, Tilapia fish could be introduced to the reservoir (each year if it runs dry). Fish excrement pollutes a reservoir less than if the reservoir had no fish and organisms were allowed to breed unchecked.

Water use management is required to tackle the problems of over-consumption by the community or use by unauthorized passers-by. Additionally, during the rainy season the dam should be regularly checked for possible leaks. Once spotted, cracks should be marked and repaired when the water level in the reservoir falls below the leak. A watch person who lives and farms near the site could be appointed to carry out the maintenance and to keep track of consumption. With different users, this may not be a simple task. Clear agreements therefore will be required with the users and their community organizations. These will have to focus on the one hand on accepting the authority of the watchmen and on the other establish the required understanding concerning water use. A measurement pole can be placed in the reservoir in order that everyone has an indication how much water is still left.

9.2 Small earth dam systems

The small earth dams discussed in this section are semi-circular or curved banks of earth, generally not more than three metres high and 60 metres in length. They are built by manual labour and/or animal traction using donkey or ox-scoops and can be maintained and if necessary, repaired by the user community. Larger constructions are considered to be beyond the community-based approach described in this document. Large earth dams generally require mechanical earth moving equipment and considerable capital investment.

9.2.1 Site assessment

Successful earth dams need: a suitable catchment and storage area where the dam can be built. The best catchment area is a relatively steep and rocky landscape with no erosion, and from which runoff regularly flows in depressions and streams during rainstorms. The storage area should be an area where water empties onto more gently sloping land in a wide shallow channel or a broad depression.
The following site selection criteria, as listed in Table 9.4, should be observed:

Table 9.4: Checklist of small earth dam siting factors

- Catchment areas with low-density livestock grazing, few agro-industries and low density settlements are preferred, since these minimize the opportunity for sedimentation and contamination by runoff water. There should be a low level of land clearing and no sign of either serious erosion or siltation. This reduces the potential for reservoir silting or dam washouts.
- The reservoir should have a high depth-to-surface ratio and store the maximum amount of water behind the smallest possible dam.
- There should be a sound foundation for the dam and an impervious reservoir bed.
- There should be sufficient runoff to fill the dam each year.
- The site must be accessible to the designated user group.
- There should be a sufficient amount of construction materials in the vicinity.
- There should be a low probability of catastrophic floods, which may overtop the dam and wash it away. Hence rainfall should preferably occur over a period of time, rather than fall in one or more torrential rains.

9.2.2 Calculation of runoff and storage volume

A detailed survey is required to estimate the size of the catchment area and to estimate a runoff coefficient. This survey, possibly in combination with map measurement and aerial photograph analysis, must identify the area from which runoff would drain to the dam site. The drainage divides can be surveyed, or marked on a map or photograph, after which the plan area within can be calculated.

The runoff coefficient is assumed to be 0.25 if the catchment is steep, with many rocky outcrops, but drops to 0.10 when the catchment is made up of gentle hills covered mostly with soil. Normally such hills would respond with low runoff rates. However, when part of the vegetation has been cleared, during construction, runoff may be much higher until vegetation has recovered. Dam's have been washed away because this initially higher runoff was not expected.

The dam design should be such that earth is more deeply excavated adjacent to the dam with a gradual shallowing of the reservoir upstream. This will minimize seepage and evaporation, because as the water level falls, so do the surface and bed areas. The maximum depth should be more than two meters. Because of this pattern of excavation, the reservoir can be assumed to have a volume roughly equivalent to a cylinder sliced diagonally in half, and can therefore be calculated by the following formula:

$$V = {}^{1}/_{2}\ \pi \ \times W/2 \times W/2 \times D_m$$

with:

W = Width of cross section of reservoir from one end of the dam to the other

D_m = Maximum depth of reservoir

π = 3.14

Table 9.5: Approximate volume of reservoirs (m^3)

		Dam length (m)				
		10	*20*	*30*	*40*	*50*
Maximum Depth (m)	2.0	78	315	707	1257	1965
	2.5	98	393	884	1572	2455
	3.0	118	472	1060	1886	2947
	3.5	138	550	1238	2200	3438
	4.0	157	628	1415	2514	3929

9.2.3 General design features

In designing manually constructed simple earth dams, the design features given in Table 9.6 have to be taken into account:

Table 9.6: Checklist for the design and construction of a small earth dam

---

- A sound foundation has to be assured to avoid seepage under the dam, which not only results in losses in storage volume, but also could lead to destruction of the dam.
- The dam construction must be large enough to ensure stability.
- An out-take pipe system and water tap point should be constructed to abstract water downstream of the dam.
- Two stone spillways have to be constructed to avoid over topping and erosion of the dam walls.
- The upstream wall should be protected from wave and runoff damage by covering it with stones.
- Clay should be used as the primary construction material. Care should be taken in selecting and compacting the clay, producing an impervious dam and avoiding seepage.
- The dam should be fenced off, using live thorn fencing or cut thorn bush to keep livestock from walking on the dam sides and damaging the structure.
- The size of the dam should not exceed the capacity of self-help labour the users are willing to provide.
- No soil erosion should be present in the catchment area or else it should be controllable by simple soil conservation methods.
- The catchment area should be protected against pollution.

9.2.4 Design of system components

Earth dams should be built during the dry season and scheduled to be finished before the first flow occurs. The clay material should include some sand and silt. Cracking clays known as montmorillonite, which is found in black-cotton soils, should be avoided. Compacting material in the foundation trench and dam can be done either by walking animals over it or by using a tamper such as a heavy log with two handles attached. The soil should be moistened to help compaction.

In the standard design presented here, the width of the crest section is 2 m, while the dam side slopes are built with a slope of 2:1 horizontal to vertical ratio, to give the dam weight and stability. The ideal dam height is about 3 m. The height of the dam crest above the spillway/maximum water level should be at least one meter. To avoid seepage of stored water underneath the dam, a 1.2-1.5 m wide trench, 50 cm deep, should be filled up with 5-10 cm layers of compacted, impermeable clay. It should be directly under the line of the crest of the dam.

The approximate volume of the earth dam is:

$$V = (L/3 \times 2H \times H) + (L \times H) \text{ m}^3$$

with: L = length along the crest (m)
H = maximum height (m)

While constructing, increase the height H by 1/3 to allow for settlement. Thus the volume of material needed will be roughly V x 1.33.

Two stone-protected spillways (Figure 9.4) should be constructed to release excess water and avoid over topping of the dam. Since the dam is built of clay, it is more vulnerable to erosion by over topping than a masonry dam. Erosion can easily lead to dam failure. In practice, spillways are situated at the ends of the dam and should each be around one-sixth of the dam crest length.

The course of the spillway downstream should be planned carefully. It should discharge well clear of the dam downstream, not cut in across the downstream slope of the dam, be protected by a boulder-lined channel with grasses, and have a good slope to ensure rapid discharge and prevent the backing up of water.

For protection the dam wall should be covered with stones on the upstream side to prevent damage by wave action. Shallow rooting, creeping grasses should be

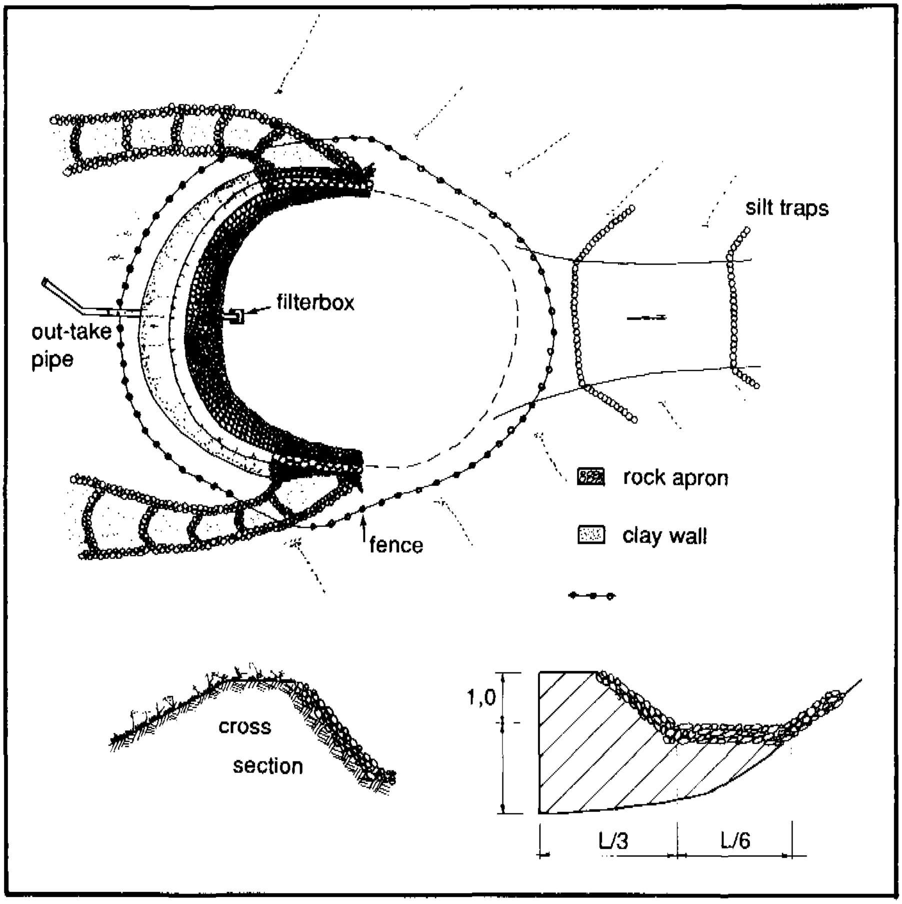

Figure 9.4: General design of a small earth dam including two spillways

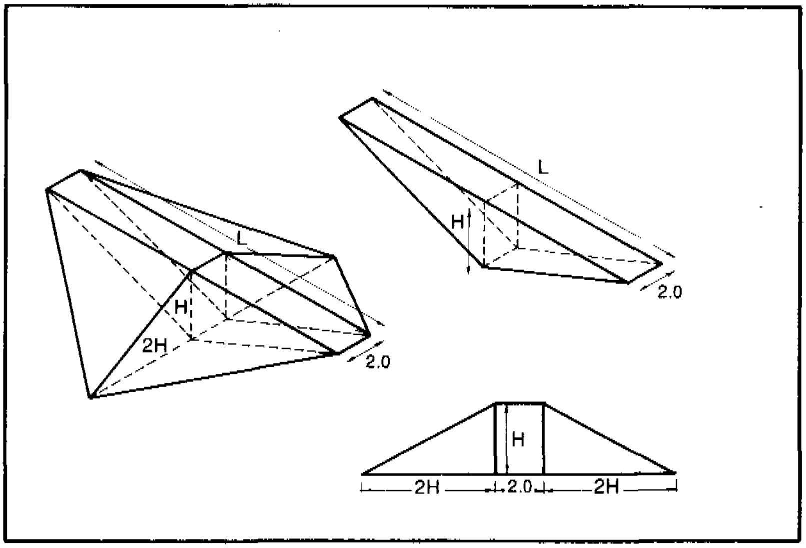

Figure 9.5: Dimensions of a standard small earth dam design

planted on the earthen parts of the dam to minimize potential erosion from rain impact.

Because of the lower water quality potential, small earth dammed reservoirs are most suitable for livestock watering. However, in some rural areas, many people will find the water perfectly acceptable and more convenient than having to travel longer distances to cleaner water points. Water should therefore be piped to both a tapping station and a cattle watering trough at a downstream location. This also prevents people and animals from walking over and damaging the dam walls. The taps can be opened at times of very high runoff to increase the outflow from the dam and prevent over topping.

9.2.5 Bill of quantities

Material

The materials to be used are mainly clay for the dam wall and large stones for protection against erosion. The quantity can be calculated from estimated dam wall dimensions (see Section 9.2.4).

Labour

Given a conservative estimate, each labourer can build approximately 0.5 m^3 of dam on average per day with hand tools or about 2.5 m^3 per day with an ox-scoop. Therefore, the number of person-days required to build the dam is equal to the volume divided by this daily work capacity.

9.2.6 Construction

There are various stages involved in earth dam construction: trench digging, out-take pipe laying, wall construction, wall protection and spillway reinforcement. The careful selection of the soil for the dam construction is essential. If the local soil satisfies the following three conditions, then the material is likely to be suitable:

- Clayey, rather than silty soils are required for dam construction, since silts are unstable in the presence of water. Wet, clayey soils feel sticky when rubbed between the fingers. Also, wet clays can be rolled easily into a flexible ribbon 1.5 mm thick and 4 cm long, without breaking. There should be little gritty bits in the soil, showing the presence of some coarse particles, which help prevent cracking.
- The clay soils should have good moisture retention capacity, which can be assessed by the bottle test. A 0.75 litre bottle with its base removed is turned upside down, compacted one-third full with the soil to be tested and then filled with water. If water drains out through the open neck in 24 hours, the dam is likely to loose water through seepage.
- Non-dispersive clays should be used, otherwise the dam may fail. They can be identified by taking 10 grams of dried soil and putting it gently into 100 ml of distilled water. If, after an hour of sitting undisturbed (do not shake), the water is cloudy, the soil is a dispersing variety and should be avoided.

9.2.7 Maintenance and management

In order to keep the quality of the water as high as possible and maintain the dam walls, the following guidelines should be adhered to:

- erosion control should be implemented in the catchment area;
- silt traps should be used in the inflow channel;
- bacteriological and chemical contamination of the catchment area and reservoirs should be prevented;
- the dam and spillways should be protected by fencing to exclude people and livestock;
- the pipe and tap should be maintained;
- bank and spillway maintenance should take place by regular examining for cracks, settlement and slides;
- cracks should be filled immediately with compacted clay, and embankment erosion should be rectified by planting grass and filling rills.

Concerning management of water use, the same applies as with rock catchment dams (9.1.7) requiring supervision and agreements among the users.

10. Groundwater Dams

Groundwater dams are used to retain seasonal groundwater flows and facilitate the abstraction of water through lined shallow wells. The objective is to place an impermeable barrier, made from either clay or masonry, across the river bed from the surface down to an impermeable layer below (Figure 10.1 and 10.2). Another type, the raised-sand dam, can be made from masonry. This dam actually raises the level of the river bed, catching sand from upstream and creating a larger groundwater reservoir (Figure 10.3). The dam is raised in successive 50 cm stages to achieve this effect.

The clay dam is best built where a layer of clay underlies the sandy river bed. A masonry dam can be built where a bedrock layer occurs between 2 m and 4 m below the surface of the river bed. The raised-sand dam is built where bedrock is exposed at or very near to the river bed surface, and raised in 50 cm increments after each rainy season.

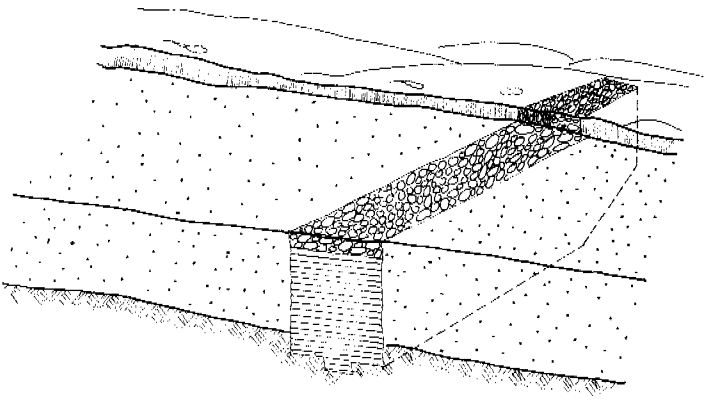

Figure 10.1: Sub-surface clay dam

10.1 Site assessment

A site assessment for the placement of groundwater dams should include the considerations given in Table 10.1.

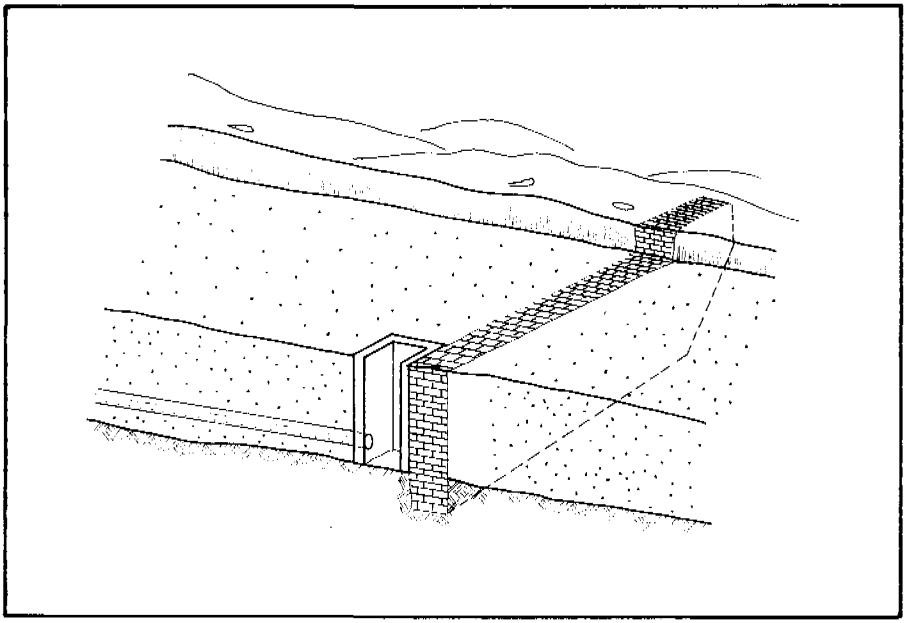

Figure 10.2: Sub-surface masonry dam

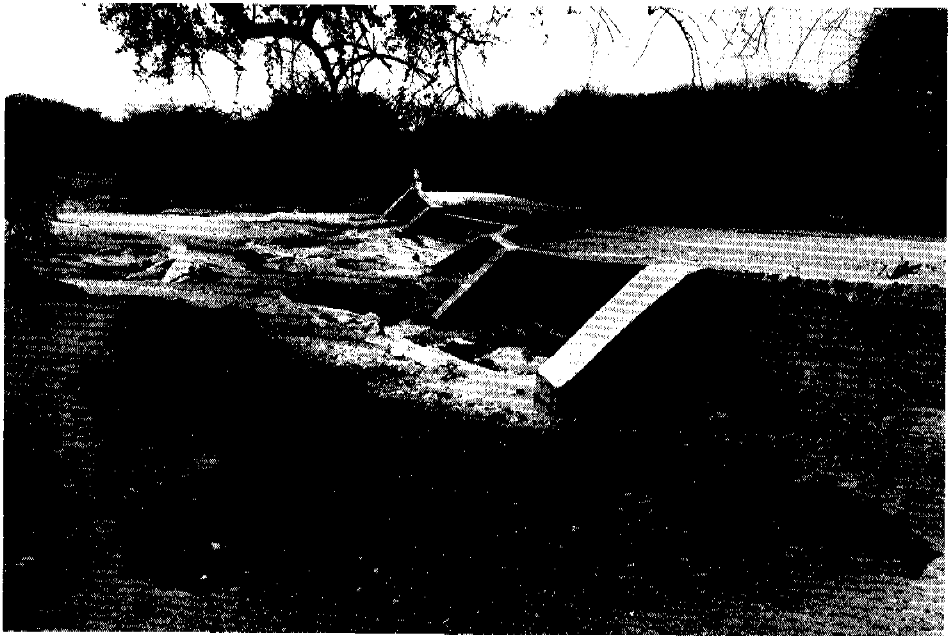

Figure 10.3: Raised-sand dam, Kenya (Photo Jørgen Schytte)

Table 10.1: Site selection considerations for groundwater dams

- Check if the river flows a number of times each year.
- The river bed should consist of coarse sand for maximum storage capacity and recharge of wells. A layer of saturated sand yields around 340 l/m^3 and a layer of clay may yield only 190 l/m^3. Water in coarse soil flows up to 100 times faster than in a fine soil.
- The bottom of the river bed should be solid rock, without fractures. Clay can also serve to avoid the loss of stored water by seepage.
- By making use of simple iron rod or auger depth penetrations upstream and cross stream, a rough estimation of the dimensions of storage can be determined.
- A good site for the location of the dam would be where the river narrows between steep stable banks, since here the maximum storage will be achieved for the minimum dam size.
- Building a dam downstream of a natural depression in the river bottom provides a good basin.
- Locations which are subject to frequent and serious bank erosion and subject to channel course changes should not be selected. Preference should be given to sites that are in a landscape zone between hills and plateaus, since here there is most likely to be sand transported in the water and runoff events will be more significant during the rainy season.
- The river bed should have a slope of between 1 and 5 %.
- For a masonry groundwater dam, a good location is where impermeable bedrock rises up towards the river bed surface.
- Construction materials should be locally available.
- The site should be selected in cooperation with the local user group who must be satisfied with the choice made.
- Observation of traditional wells at rivers can give information on the water flow in riverbeds and the site potential. For example, if the water level rises quickly after rainstorms this shows that there is considerable and rapid sub-surface flow. However, if the water level falls very quickly after the runoff has passed and the well is once again dry or low-yielding, then this might indicate seepage through fractures.

Depending on facilities and resources, a more systematic survey could be made using aerial photographs, a geo-electrical survey or piezometric tests. Aerial photographs and maps show where underlying impermeable bedrock is close to the surface along seasonal rivers and stream channels. Alternatively, the position of impermeable clay-rich soils can be detected which may be overlain by river sands. Geo-electrical surveys can give details on the depth of river beds, thickness and type of underlying layers and the presence of fractures. Piezometric tests map sub-surface water conditions and flows through wet and dry periods and indicate the geohydrological potential of a site.

10.2 Storage volume

It is difficult to estimate the amount of increased water supply resulting from these dams. The amount of extra water available to well users at the dam location depends on the depth, width, length and hydraulic gradient of the sand river.

For raised-sand dams, it is possible to make an estimate of the minimum increase in supply that can be expected by locally raising the sand volume in the river bed, and hence the water storage capacity in the vicinity.

$$V = H/2\ (100\ H/s) \times W$$

with:
H = height of dam (m)
W = river width (m)
S = slope of river bed (%)

For example: River width W = 15 m with a slope of 3%. A raised-sand dam of height H = 3 m, should result in an increase of sand volume of:

$$V = 3/2 \times (300/3) \times 15 = 2250\ m^3$$

The increased sand volume consisting of saturated coarse sand and a porosity of some 0.34% can provide a storage volume of $0.34 \times 2250 = 765\ m^3$.

10.3 Design

Each of the groundwater dams has a different design and construction method. However, the steps involved in deciding what size and shape of dam to build is relatively straightforward. Tables 10.2, 10.3 and 10.4 and Figures 10.4 and 10.5 give the main design features. The design should take into account the expected speed of construction in relation to the available time and the possible effects on the river.

The design should take into account the expected speed of construction in relation to the available time and the possible effects on the river.

With clay and masonry groundwater dams, there is little or no damming of surface flow. The majority or all of the structure is positioned below the river bed surface, which implies that construction should take place in the dry season.

The design of a raised-sand dam is different as it must allow for building in stages. Constructing a raised-sand dam to a height of 2 to 4 m in one stage, would result in the ponding of water upstream and allow fine particles to settle out. If this happened, there would be three negative effects:

- the yield and permeability of the increased storage reservoir would be lower;

- the evaporation from the reservoir would be higher;
- the recharge rates from the surface flow into the shallow aquifer would be considerably reduced (Nilsson, 1988).

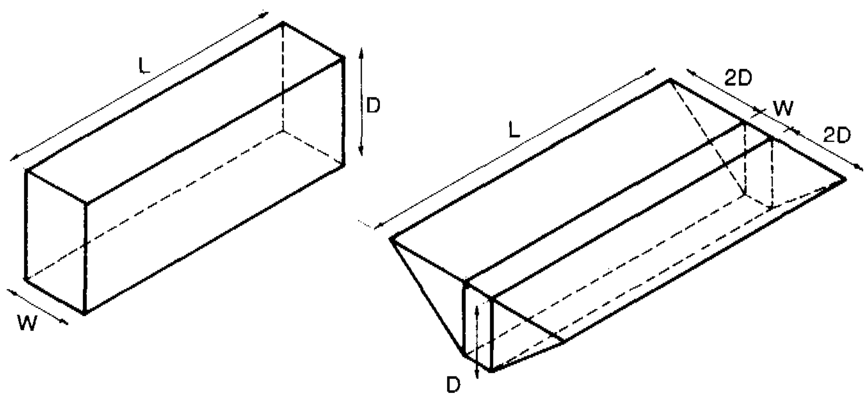

Figure 10.4: Outline design of a sub-surface clay or masonry dam

Table 10.2: General design features for a sub-surface clay dam

- A clay dam should be built in one season.
- Clay is used as the primary construction material. Care should be taken in selecting and compacting the clay to achieve an impervious dam and to avoid infiltration through fissures and cracks.
- A sound and watertight foundation has to be constructed to avoid seepage under the dam, leading to a loss of stored water.
- The dam should have a width of 2 metres all the way down to the foundation.
- The height of the dam depends on the depth to the clay layer.
- The top of the dam needs to be protected against erosion from stream forces.
- An extension of the clay dam into the river banks should be made to prevent seepage and erosion between the river banks and the dam.
- Rocks should be piled against the banks upstream and downstream to protect them from erosion.
- The dam should be located where the river bed is narrower and the sand layer becomes thinner.

Table 10.3: General design features for a sub-surface masonry dam

- A masonry dam should be built in one season.
- The dam should be 50 cm wide.
- The height of the dam depends on the depth to the bedrock layer.
- The dam should be located where impermeable bedrock rises up towards the river bed surface to within less than 5 m.
- A sound foundation must be constructed to avoid seepage under the dam.
- A spill-over apron must be constructed to protect the downstream side of the dam from erosion caused by flowing water, which would remove material behind the dam.
- The dam should be extended with two wing walls into the river bank to prevent seepage between the river banks and the dam.
- The top of the dam and side walls must be protected against erosion from flowing water.

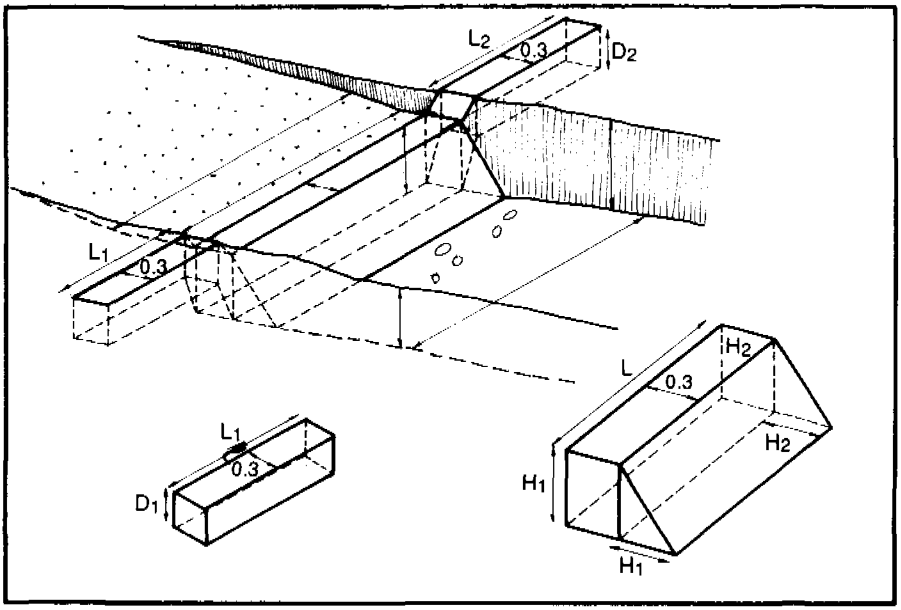

Figure 10.5: Design of a raised-sand dam

Table 10.4: General design features for a raised-sand dam

- The raised-sand dam is built in seasonal stages of 50 cm.
- A filter box and draw-off pipe should be constructed as well as a tapping station with a watering trough and laundry slab.
- The dam wall should not be increased in height until floods have deposited a bed of coarse sand up to the level of the present dam wall.
- The dam should not cause water to flood out over the river banks, creating erosion.
- 30 cm thick masonry wing walls should be added once the dam wall has reached its maximum height. They help to protect the bank from erosion.

10.3.1 Material and labour requirements for clay or masonry dams

The cost of a sub-surface clay or masonry dam in labour and materials depends on the average depth and the length of the trench and the widths (W) of the dam being 2 m for a clay dam and 50 cm for a masonry dam.

Given the volume of dam (V) m^3, the material requirements for compacted clay fill or masonry is given by:

$$V = L \times W \times D$$

with:
L = dam length (m)
W = dam width (m)
D = average depth (m)

When digging a trench in dry sandy soil, the sides of the excavation will collapse in the centre, resulting in a trench much wider than it is deep. For instance, a 4 m deep trench will be around 16 m wide. Hence, the volumes of sand to be dug out (V_{out}) and back-filled (V_{bf}) are given by:

$$V_{out} = L \times (W \times D + 2D \times D) \qquad V_{bf} = L \times 2\,D \times D\ m^3$$

The quantity of cement, sand, rocks and water for the masonry dam can be easily calculated, given that 1 m^3 of masonry requires 2 sacks of cement of 50 kg, 0.22 m^3 of sand, 0.88 m^3 of rocks and 200 litres of clean water.

The number of working days for the construction of a dam can be derived from the following estimates, each for one working day:

- a labourer can dig out 2 m^3 of sand;
- a labourer can back-fill 4 m^3 of sand;
- a labourer can fill and compact around 0.5 m^3 of clay;
- a skilled artisan with the aid of 10 labourers, can complete 1 m^3 of masonry wall.

10.3.2 Material and labour requirements for masonry raised-sand dams

As shown in Figure 10.5, the complete raised-sand dam is composed of the dam and two side walls.
The maximum height of the sand dam depends on two factors:

- the height, steepness and stability of the river banks;
- the known height (and frequency) of floods.

If the elevation of the river bed is raised too high by the dam, the river channel will not be able to contain the flood flows and widespread flooding and erosion of the river banks will result. For example, in a steep sided sand river bed with 3.5 m high banks and flood flows of up to one metre deep, the maximum sand dam height should not be more than 2 m. This gives the river sufficient capacity to handle most flood flows safely. The depth of flood flows can be estimated by asking local people to describe flows they have seen and by looking for evidence of scour or debris deposition on bank sides. As the dam is built in stages each of some 0.5 m in height, the ultimate crest level does not necessarily have to be determined in the planning stage. Depending on the effect of the stages already constructed a next stage may be initiated.

The dimensions of the dam vary in direct proportion to the height. Therefore, a simple survey of the site is needed to arrive at the data required to estimate the volume of the dam (Figure 10.5).

The following formulae give the full total volumetric measurements for the dam materials, from which a bill of quantities and labour can be completed.

$$\text{Volume of wing wall 1} = L_1 \times 0.3 \times D_1$$

$$\text{Volume of wing wall 2} = L_2 \times 0.3 \times D_2$$

$$\text{Volume under crest} = [(H_1+H_2)/2] \times 0.3 \times L$$

$$\text{Volume of sloping face} = [(H_1+H_2)/4] \times (H_1+H_2)/2 \times L$$

with:
H_1 = height of the dam crest above the river bed at side A
H_2 = height of the dam crest above the river bed at side B
D_1 = average depth of the wing wall on side A
D_2 = average depth of the wing wall on side B
L = length of the dam across the river from bank A to B
L_1 = length of wing wall on side A
L_2 = length of wing wall on side B

The same principles used to calculate the material and labour requirements for the masonry sub-surface dam are also used for the raised-sand dam (Section 10.3.1).

10.4 Construction

Site preparation

When digging a trench, the sand should be moved far enough away upstream so that the diggers will not have to move it again as the surrounding sand collapses into the digging (de Nooy, 1977). Groundwater dams should be constructed in the dry season, when sub-surface water flow levels are at a minimum and flood damage of surface structures can be avoided. Nevertheless, with clay and masonry groundwater dams, water may drain into the trench during construction. The water must be drained out, either by syphon, pump or bucket and can be used in mortar making and curing.

Clay wall groundwater dam construction

This type of dam is built on top of an impervious layer of clay, to a depth of 2 to 4 m below the river bed. A trench of 50 x 50 cm is dug into the layer of clay and is filled with more compacted clay in order to create a watertight connection between the dam and its foundation. This prevents water loss under the dam (see Figure 10.1). It is very important that all sandy material is removed from the trench. If a sand-filled layer is still present, water will leak under the clay wall. The compacted clay dam is a consistent 2 m width down to the foundation, while its length depends on the width of the river bed.

The trench should be backfilled with the excavated sand. To protect the dam against erosion by streaming water, the top 50 cm of the dam should be made of a layer of large, heavy boulders. The spaces in between the rocks should be filled with small stones and sand. The extension of the dam wing walls into the river banks are also made of compacted clay. Rocks should be piled against the banks a short distance upstream and downstream of the dam to help prevent erosion.

Masonry wall groundwater dam construction

To prepare the foundation, all sandy material should be cleaned from the rock layer at the bottom of the trench and loose and weathered rock must be removed. Afterwards, a mixture of cement and mortar should be painted on the foundation area as described in Section 9.1.4. The masonry wall should be constructed to a height that projects 50 cm above the river bed. The trench should be back-filled with the excavated sand. For protection from erosion, the downstream side can be filled with large, heavy boulders to prevent any scour cutting back up the channel, exposing the masonry wall and reducing the strength of the dam construction. The side walls should be raised to 50 cm above ground level and 50 cm above the crest of the dam. The top of the dam and side walls are plastered with mortar to protect them from erosion.

Raised-sand dam

The preparations for the foundation are the same as for the masonry wall dam described in the previous section. As part of the first stage, a pipe and filter-box should be installed at the lowest part of the wall from where water will flow under gravity to a tapping station. This should be constructed downstream of the dam. Preferably, it should be on a solid section of the bank to avoid being flooded. The height of the water tap must be lower than the bottom of the dam, so that all the available stored water will flow out.

The crest level of the first stage should not be more than 50 cm above the sand bed. The dam should not be heightened until floods have deposited a bed of coarse sand behind the dam, up to the level of the crest. If it is built higher, fine sand or silt will be deposited. After the first and subsequent stages, place plenty of large stones against the downstream side of the dam and against both sides of the dam wall by the river banks. These large stones prevent the flood water from flowing over the dam, causing erosion and under cutting the river bed on the downstream side.

Each extension adds 50 cm to the height of the dam wall. The two wing walls are built when the dam has reached its maximum height. If there were no wing walls, the flood water might erode the bank away and the water might flow around the dam, causing it to collapse and release the stored water.

The dam wings are simple vertical stone masonry walls. They are carefully joined to the sand dam to prevent leaks. The wing wall should be built 50 cm higher than the surrounding land surface and large rocks should be placed against the downstream side.

10.5 Management and maintenance

The water quality in groundwater dams is generally the highest of all water harvesting systems, since water is stored in the ground and filtered as it moves through the sandy soil. However, opportunity does exist for shallow groundwater contamination by seepage of pollutants from the surface. The precautions listed in Table 10.5 can help to reduce the risk of contamination to a low level.

Once a clay wall groundwater dam is built, there should be little maintenance. After each large flood however, members of the user group should be designated to check the dam site to see if the channel has started to erode away the dam. Any erosion should be corrected by refinishing the clay wall and protecting it again with large rocks, too heavy for the smaller flows to move. With masonry groundwater dams, any channel erosion that might undermine or expose the dam should be arrested by filling with large boulders and using silting traps to catch sandy material. This is similar for raised-dams. With the raised dam, the gravity pipe should be checked frequently along its length for signs of damage or leaks and the tapping station kept in good order. Also with groundwater dams there may be a need to control water use, thus requiring supervision, clear agreements between users and monitoring of storage still available. For the latter a piezometer may be installed which allows a caretaker or watchman to estimate how much water is left and if rationing has to be made more strict.

Table 10.5: Checklist of precautions that help to manage and maintain water quality and reliability in sub-surface and sand dams

- No open defecation in/near the river bed upstream.
- No tethering of donkeys at the well.
- No bathing/laundry upstream of the dam.
- No pit-latrines on the bank upstream.
- No unprotected wells in the river bed near the protected well.
- Regular maintenance of the protected well-site and handpump.
- Use and maintenance of a downstream gravity out-take.
- No use of pesticides/chemicals upstream of the dam site.

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Annex 1 Runoff farming systems

Runoff farming systems, although not used for drinking water, are a natural complement to domestic household and livestock water harvesting in ASA regions. Their main aim is to control runoff water in an agriculturally productive manner, raising infiltration in farmer's fields and improving soil moisture conditions for crops. At the same time, this prevents soil erosion by reducing runoff volume and velocity, causing any suspended soil particles to be deposited on the fields. Runoff farming is necessary in most arid and semi-arid regions where rain-fed farming is unreliable because of insufficient or unreliable rainfall.

Runoff farming stabilizes soils, increases soil moisture, and therefore increases the probability of attaining good and reliable harvests under difficult agricultural conditions. The majority of systems are simple to understand, plan and construct. They also can be developed by farmers themselves after a period of instruction and supervision. Runoff farming is particularly appropriate on recently cleared sloping fields before erosion sets in. Perennial crops with deep roots adapt well to runoff farming because they can use water stored deep in the soil. Some drought-tolerant fruit trees grow well when planted downstream of bunds or in the depressions of micro-catchments. The best staple crops are grains that mature quickly and need only one major rainstorm. They are planted as soon as the rains have moistened top soil layers. With maize, it has been observed that a 5% increase in soil moisture will increase yields by more than 15%. The overall effect of runoff farming with fanya-ju terraces in the Machakos district of Kenya, for example, was a 50% increase in yields.

The main disadvantage of runoff farming is that unlike irrigated agriculture, the water supply is not controlled, but depends on the timing and magnitude of rainstorms. Even though runoff farming makes more water available over the growing season, its timing may be poorly distributed, leading to low yields because of poor germination and short periods of moisture stress and waterlogging. Systems are labour intensive and usually require annual maintenance to rebuild earth bunds and strengthen check lines. Some external catchment systems require hands-on management during rainstorms to prevent waterlogging and direct water to different areas by controlling spillways.

There are a range of different runoff farming systems. Some collect and concentrate water within the confines of a single field. Other collect water from external catchments, diverting water from streams or drains and onto adjacent fields.

Micro-pits and micro-catchments - micro-pits are small water collection pockets that fill with surface runoff and into which manure is placed and a few seeds can be sown. Micro-catchments are small earth banks, usually diamond shaped, with the apex pointing downslope. Water drains into the interior of the diamond or to the lowest point in the apex, where it is used to water a tree or a small clump of maize or millet. If the land is almost flat, these micro-catchments can be created by excavating a basin and using the spoil as a bank around the downslope edge. Alternatively, micro-pits can be dug at regular intervals and water will collect in them during rainstorms. Micro-catchments are usually made on slopes of less than 3°, so that runoff depths and velocities are low, ensuring that the earth embankments are not eroded and gullying does not occur. They are therefore, confined to lower slopes.

Small check-barriers - are comprised of stone lines, debris strips or earth contour bunds, and are built at intervals descending gradual slopes. The first two are made along contours by raking crop residues or stones from the field into lines. These act as permeable barriers, allowing runoff water through, but at a reduced velocity, thus preventing gullying and enhancing infiltration. Small earth contour bunds are built by digging shallow ditches along the contour line and piling the soil upslope into a low bank 20 to 30 cm high. In Kenya, these are widely built by farmers and called the fanya-ju or "built-up terrace". Water is retained behind the small bund and infiltrates in the field surface. Trees can be planted in the ditch and grass grown to help stabilize the bund. If soil is washed down it will collect behind the bund and can gradually build up the land, forming a terrace. Bunds are generally spaced between 5 and 20 metres apart, depending on slope gradients. Where rainfall is low, the interval between consecutive bunds acts as a runoff zone and is left bare and unploughed. The runoff feeds the bund and the flattered area may be contour-ploughed and planted with crops.

Larger earth contour bunds - are sometimes built to trap more water, and use spillways made of stones to allow heavy runoff water to safely discharge onto the field without erosion. Unless these bunds are perfectly level, runoff water can flow over the bund at its lowest point, creating erosion. Larger bunds and stone-walled terraces can be built on the steeper slopes if these are being cleared for farming. These also can be used as a form of erosion control to prevent gullying into the lower slopes below.

Semi-circular bunds - are built in a half-moon across part of the field, trapping surface water. The two ends of the semi-circle are positioned level with each other on the same contour. Runoff flows from the area upslope and is caught in the half-moon. Any excess water flows out around the edge of the tips. Semi-circular bunds can be as large as 3 metres in radius and are built in staggered formation along contours and down a sloping field. Hence, the water running out of or around upper bunds is captured by the lower bunds.

Trapezoidal bunds - are similar to the semi-circular bund except they have a straight bottom and angled sides. The bottom of the trapezoid is built along a contour and the ends terminate level on a higher contour. Again, excess water flows out around the wings and not over the top of the bank. These bunds are generally 0.8 m high with a width of 40 m across the field at the lower end and around 80 m open between the two upper ends of the wings.

External catchment systems - a number of different external catchment systems have been applied in Africa. They vary from large barriers built across a valley bottom to check flood flows and cause temporary inundation over farmland, to small deflection barriers placed across a ditch or stream to direct water onto an adjacent field where it is dispersed as spate irrigation. For example, a plank wedged between large rocks can act as a deflection dam. This can be removed to prevent excessive flooding on the field. By having a series of deflections at several points along a stream or drain, water can be diverted onto several fields during a rainstorm. Large permeable rock barriers or filtration dams have been used in some countries, such as Mali and Burkina Faso, to slow water moving down alluvial valley bottoms, reducing its erosive force, depositing sediment and enhancing infiltration. Elsewhere, barriers such as masonry or earth dams are used to hold back the water in a reservoir, and crops are planted around the margins as water gradually recedes.

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