Water Harvesting for Plant Production

Volume II: Case Studies and Conclusions for Sub-Saharan Africa

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Reflecting the growing interest in water harvesting for plant production, a comprehensive review of the available literature was undertaken and published in 1988 as Technical Paper No. 91. Following on from that review, this report examines specific water harvesting systems in Sub-Saharan Africa. Case studies of thirteen systems from six different countries are presented, and conclusions are drawn under the headings of techniques and engineering, production, socio-economic and project management aspects.

A number of projects throughout the region, set up in the 1980s, have included water harvesting components. However there is a wide range of techniques, approaches and costs – and the impact of these projects varies considerably. The majorities of systems introduced are for crop production, but there are examples of water harvesting to establish trees in dry areas and for rehabilitation of grazing land also. The importance of indigenous systems of water harvesting, and their potential role as a base for planning, is stressed in the conclusions. The need for voluntary participation in all stages of project development is highlighted – it is evident that without this participation there is little or no chance of widespread adoption. The majority of systems introduced are for crop production, but there are examples of water harvesting to establish trees in dry areas and for rehabilitation of grazing land also. The importance of indigenous systems of water harvesting, and their potential role as a base for planning, is stressed in the conclusions.
ACKNOWLEDGEMENTS

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FOREWORD

This document is a valuable record of various attempts made in Sub-Saharan Africa to improve the security of plant production—especially food crops—in very adverse conditions. Supported by detailed case studies, the working paper provides lessons on the viability of various techniques with respect to socio-economic as well as technical aspects.

While strongly advocating water harvesting, the document remains, however, discriminatory in its analysis and clearly points out the limits and weaknesses of the systems observed. A most valuable input for decision-makers is the series of caveats on the "easy" ways, that is, the implementation of earthworks with heavy machinery, and the mobilization of people through the systematic use of food-for-work.

The document indirectly questions the reader on important issues which it does not pretend to tackle such as: should, or must a government invest in those hostile environments where local populations are barely able to subsist? What is the level of investment a government can justify for that purpose? What benefits in terms of economic, social, environmental effects can be expected? How can the creation of assisted human groups with dependent behavior be avoided?

These questions are becoming more and more important as the migratory flows resulting from the misery of adverse economic and physical conditions are increasing in and across Sub-Saharan Africa, causing social and political turmoil in the urban areas.

While this report does not directly address all these problems, its observations and analyses show how crucial it is to reflect deeply on the implications of investment policies in these areas.

Ismail Serageidin
Director
Technical Department
Africa Region
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<td>Water harvesting</td>
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<td>SSA</td>
<td>Sub-Saharan Africa</td>
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<td>C:CA</td>
<td>Catchment: Cultivated Area</td>
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<td>c.s.</td>
<td>case study</td>
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<td>NWADEP</td>
<td>North West Agricultural Development Project</td>
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<td>OXFAM</td>
<td>Oxford Famine Relief Committee</td>
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<td>ITDG</td>
<td>Intermediate Technology Development Groep</td>
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<td>SSWHS</td>
<td>Sub-Saharan Water Harvesting Study</td>
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<td>SSU</td>
<td>Standard Stock Unit</td>
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<td>FYM</td>
<td>Farm Yard Manure</td>
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SECTION A. CONCLUSIONS FOR SUB-SAHARAN AFRICA

SUMMARY

General Issues

There is little knowledge or documentation of small-scale, traditional water harvesting (WH) in Sub-Saharan Africa (SSA), despite the fact that in some areas these systems are of considerable local importance. However, many development projects in semi-arid areas of SSA during the 1980s have included a WH component, reflecting a growing interest in the technique as a potential remedy for drought and land degradation.

Many of these projects have, however, adopted an inappropriate approach, based on high cost techniques which are implemented by machinery or under food-for-work programmes. The more successful projects have promoted simpler, and more sustainable systems based on the involvement of the beneficiaries in both planning and implementation.

Although the poor overall standard of project monitoring makes it difficult to draw conclusions about the effects of WH, it is evident that it can both improve and stabilize yields. It can also have some drawbacks, however, such as waterlogging or increased erosion if bunds are breached.

WH is not a panacea for the problems of drought and resource degradation, and should be viewed not as a freestanding technique, but instead as one element of village land use management.

Techniques and Engineering

Technical design should take into account more than just engineering criteria when planning the ridges and bunds that constitute the physical framework of WH systems. Agronomic and socio-economic factors are integral to the success of WH projects. Where traditional systems exist, they should be the point of departure for project design.

There are no universally appropriate techniques. It is rarely possible to transfer a system that works from one area to another without some modifications. Because of climatic, edaphic and sociological differences between areas, each situation must be considered individually.

Because of the paucity of background data on climate, hydrology and human factors, a "trial and error" approach and built-in flexibility of design can be valuable. Several projects have improved their techniques using the experience of both farmers and project staff.

Stone structures, a feature of West African systems, have several advantages over earth bunds. Because they are semi-permeable they do not easily breach, and neither do they require spillways. Stone is not available in all areas, however, and is not a suitable material for most microcatchment systems that collect runoff in furrows.

In earth-bunded systems, spillways are often a weak point in the design, and are a potential erosion hazard. Where they are necessary, spillways should normally be around the ends of wingwalls.

Structures are sometimes "over-designed" deliberately to reduce the need for maintenance. Over-dimensioning does not always safeguard against breaching however, especially where the calculated ratio between catchment and cultivated areas is large. Furthermore, the increased costs can put construction beyond the reach of local resource users.
Field layout of contours is best done with simple, hand-held surveying instruments such as the water tube level and the line level, which farmers can be readily trained to use themselves.

For crop production, the most common and versatile system of earthen construction is the bunding of three sides of a plot, leaving the top open to accept runoff from a catchment outside the cultivated area. This technique has several variations, including one known as "trapezoidal bunds". A second system – contour ridges – which uses a within-field catchment, has yielded promising results on a pilot basis.

For tree planting, the most common and well-known techniques are "V" shaped microcatchments, or a network of diamond-shaped microcatchments. Contour bunds are more efficient on large, even plots, however, especially when construction is mechanized.

Few WH systems are specifically designed for rangeland rehabilitation or fodder production. However, by-products from crop production systems can make a significant contribution to livestock feed, and grass from afforestation plots is often the most valuable product from tree microcatchments for the first few years.

Production Aspects

WH development should always be accompanied by improvements in plant husbandry, in order to maximize the benefits from the increased moisture available. Such improvements include fertility management, better weed control, and opportunistic planting – aspects often overlooked by projects.

Fertility management is particularly crucial, since soil fertility, after moisture, is often the most limiting factor in plant production. The addition of organic manure or compost is especially important in the maintenance and improvement of soil fertility. One advantage of stone bunds in this respect is that silt and organic matter are filtered out of runoff, and the soil is gradually improved through this "nutrient harvesting".

In afforestation projects, there has been a trend in the 1980s towards planting indigenous multipurpose trees. Prosopis sp is a notable exception, and there are signs of its spreading naturally in several countries from the nuclei of plantations. Although the advantages and disadvantages of this are debated, the introduction of Prosopis may be the main legacy of many tree-planting projects.

Socio–Economic and Project Management Aspects

Little has been recorded, or indeed is known, about traditional WH systems in Sub-Saharan Africa. It is also apparent that simple, field-scale WH systems are often not recognized as such. In anglophone Africa, the term "water harvesting" is commonly understood to imply "water spreading", which usually means relatively large-scale systems that spread floodwaters from "wadis". Indigenous, small-scale WH systems deserve much more attention because of their contribution to production in drought-affected areas.

Most WH systems introduced into SSA are not readily adopted by farmers, and implementation often stops when the project ends. The reasons for this include their labor-intensive nature, their reliance on machinery, their complex design, and their incompatibility with traditional food production strategies.

To be attractive to farmers, WH systems should be as simple and cheap as possible, and should show quick results in terms of crop yields or reliability of production. Even when these
criteria are fulfilled, however, some techniques are still not readily adopted, and research is required to determine the reason.

The costs of WH projects are not easy to calculate precisely because of a lack of data, but rough estimates show a wide range among projects. The highest costs can exceed $US1,000 per hectare, and it seems that the higher the cost, the less likely it is that the system will continue to expand in the post-project phase.

When machinery is used for construction, implementation is taken out of the hands of resource users. Experience shows that maintenance in this case is not carried out voluntarily, nor does construction continue. Nevertheless, there are some cases where mechanization may be appropriate, for example where the procedure is particularly cheap or consists of a one-time operation, such as the transport of stone.

Popular participation is obviously a critical factor in the success of WH projects. The local population should be consulted from the outset, and involved in all aspects of project development, including design, construction, maintenance and evaluation.

Incentives for construction of WH systems are common, and generally are necessary to support the resource-poor farmers. Food-for-work programs are often used to assist farmers, but this can create dependency in certain situations. Unless there is a severe food shortage, other, more productive, inputs (e.g., tools) should be preferred.

WH may have disproportionate effects on different sections of the community. Gender and equity aspects both need to be investigated during project preparation. The workload of women may, for example, be further increased during the construction phase, and rich farmers may benefit more than poorer landowners due to their ability to hire labor.

Land tenure issues affect the popularity of WH. In some situations, the construction of bunds gives farmers a stronger claim to land rights. On the other hand, there are examples of farmers being unwilling to invest in bunds without first having firm tenure.

Farmer training is particularly important to bring WH technology within the grasp of local communities. Without the training of farmers -- both male and female -- large scale adoption is unlikely.

While projects differ markedly in many aspects, inadequate monitoring and weak reporting seem to be common denominators. This not only reduces a project's ability to evaluate its own progress, but also prevents the spread of useful information to other projects.
CHAPTER 1. GENERAL ISSUES

Although there are only a few freestanding WH projects in Sub-Saharan Africa, a number of projects established during the 1980s have included a WH component. This reflects growing interest in the topic, mainly for reasons related to climate. In West Africa, the drop in annual rainfall since the late 1960s has caused emphasis to shift from simple soil conservation towards moisture conservation and water harvesting. Although the same long-term climatic changes have not been recorded in East Africa, droughts during the 1970s and 1980s have stimulated the creation of WH projects in the affected areas.

The techniques used by the projects and the methods of implementation vary widely, as do the costs involved. However, some common features are a general weakness in monitoring and, as a result, a lack of hard information about benefits attributable to water harvesting. Another common factor throughout the region is the close association between WH projects and food-for-work or other incentives.

Despite the limited information available, it is concluded that many WH projects have adopted an inappropriate approach. Their reliance on expensive techniques, often based on the use of machinery or labour rewarded by food-for-work leads to systems which are commonly not even maintained – and which certainly cannot be widely replicated. Where WH projects have shown some success, it is usually where they have promoted simple, low cost technology, often based on traditional systems, and when beneficiaries have fully participated in planning and implementation.

Types of WH systems observed across Sub-Saharan Africa differ in terms of construction materials. Earthen structures tend to predominate in East Africa, whereas stone bunds are more characteristic of West Africa. WH in West Africa is commonly used as a tool in the rehabi-
lication of abandoned and degraded land, in association with mechanical ripping or hand-dug planting pits. This is not usually the case in East Africa, where WH is used to permit crop production in areas where normal rainfed cultivation is not possible—but not for land rehabilitation. The majority of WH, in both East and West Africa, are for crop production rather than for trees, grass or fodder.

While WH makes plant production more reliable by harnessing otherwise destructive runoff, it has certain drawbacks that need to be acknowledged. WH is not effective in all situations or in all years. Because it works by amplifying rainfall, it follows that it will be ineffective in years of no rain, and it can be counter-productive during years of excess rainfall. When rainfall is above average, there is a danger of structural failure and temporary waterlogging unless systems are designed to cope with this situation. Furthermore, increased early moisture availability can, in certain situations, make plants more susceptible to drought later on. WH is most effective in areas where annual average rainfall is between 200 mm and 700 mm and when the rains for a given season are average or below.

The technique of water harvesting also needs to be put into a broader context as one of many possible remedies to the problem of sustainable production in semi-arid Africa. This point is illustrated by the fact that an increase in the amount of water available to plants must be matched by an improvement in the fertility of the soil, which can otherwise be rapidly exhausted. This has implications for grazing management and for the production and use of manure and compost. WH techniques should be regarded as only one part of a wider program of natural resource management. In West Africa, for example, the introduction of village land management plans is an ideal context for making the best of WH techniques.

WH has a rather ill-defined position within many Governments in SSA. Nor is there usually a clear national policy on the topic. From one country to another, WH finds different "homes", ranging from Engineering Departments in Ministries of Agriculture to Forestry Departments in Ministries of Environment. In some cases it is scarcely acknowledged at all. Without a clearly defined niche within a relevant Government department and a clear policy, WH programs are likely to develop in an uncoordinated manner, and remain the province of isolated projects.

Since WH techniques have yet to gain full acceptance at national levels, it is not surprising that it is missing from, or only sketchily covered by, the curricula of universities and training colleges. In a number of countries, WH, in contrast to erosion control, is not even a topic for investigation at national research institutions. It may be worthwhile to investigate the constructive uses for rainfall runoff, as well as the destructive effects.
CHAPTER 2. TECHNIQUES AND ENGINEERING

This section covers the technical design aspects of WH systems. A brief note about terminology and classification is followed by an analysis of design aspects. The analysis then extends to a consideration of the basic WH techniques encountered in the field, and their relative merits. The most widely applicable techniques are identified. Conclusions are drawn about the most appropriate approaches to design and their practical implications.

WH systems are identified as such on the basis of their engineering characteristics. All systems have both catchment and cultivated areas, and there are bunds or ridges to impound or impede runoff. Structures are common to all systems, but these should be the result of design rather than its starting point. A WH system must be more than just the product of technical design - although this is not often the case in practice.

Design should ideally take into account a multitude of factors which are usually specific to particular sites. The end product should be a system that is simple to lay out and construct, as well as durable. Flexibility, i.e., a design allowing for subsequent modification, is also desirable. Several projects, for example, the Kelita Project in Niger (case study #8) and the Turkana WH Project in Kenya (case study #3), have benefited from improving and adapting their techniques in the light of experience.

Local traditions and indigenous techniques, where these exist, should be the take-off point for design where possible. In practice, this tends to be the exception rather than the rule. The most notable exception is the successful Agro-Forestry Project in Burkina Faso (case study #1). Few other projects have paid adequate heed to indigenous techniques or local organizations. Traditional systems in Sudan (case study #12) and Somalia (case study #10) show how effective farmer-managed WH can be.

Terminology and Classification

The terminology used to describe WH techniques is complex. Annex 1 explains the terms used in this document. Some terms are synonyms, others overlap only partially and, to add to the confusion, several English terms have no direct equivalents in French, and vice-versa. Systems of classification are similarly diverse (see Reij et al., 1988). Two important points should be made here about terminology:

A. There is no specific, commonly used French translation for "water harvesting". Techniques are usually referred to as "soil and water conservation" ("conservation des eaux et du sol") or as "land rehabilitation" ("défense et restauration des sols"). The term "collecte des eaux de ruissellement" has only recently been coined as a more literal translation of "water harvesting".

B. There is a widespread, and erroneous, perception that "water harvesting" and "water spreading" are one and the same thing. Water spreading is a particular form of water harvesting; it is essentially "floodwater harvesting". WH also includes a wide range of systems that make use of runoff gathered from overland flow originating from short catchment lengths, usually small scale systems. This is more precisely termed "rainwater harvesting".

In its broadest sense, WH embraces a range of techniques used for various purposes. However, in the context of the Sub-Saharan Water Harvesting Study (SSWHS), WH is defined as "the collection and concentration of surface runoff for plant production before
or perennial streams". It should be restated that the main emphasis of the study is on simple, field-level techniques in drought-prone areas. The study excludes deep ponding of water. In-situ moisture conservation systems, in which rainwater is merely trapped where it falls without being actively concentrated, lies outside the definition of WH; there is acknowledged to be a grey area where the two techniques merge.

**Design (for short slope/long slope systems)**

Where background data exist (for rainfall, runoff, etc.) and designs for systems are available, these should be used to develop project techniques. However, it is characteristic of many WH projects, as well as of traditional systems in SSA, that the design itself is not based on specific criteria, and no design specifications are recorded. A "trial and error" method is common. Combined with farmer participation, this can be workable and should not be derided. An empirical approach gives the flexibility and adaptability needed for design in areas with erratic climate conditions. Nevertheless, simple records of what has been constructed, and with what result, will always be valuable for evaluation.

For any situation, there are various technical alternatives. A basic divergence in approach needs to be highlighted here. At one extreme are the large, relatively costly, "low-maintenance" structures, often associated with mechanized projects, and at the other are the more modest structures emphasizing farmer participation in layout and construction. Evidence from the field demonstrates unequivocally that only the latter category have a chance of being adopted and implemented voluntarily.

![Photo 2 Mechanised Bunding: Keita Valley, Niger](image)

Engineering design for WH systems (except floodwater harvesting systems) should logically begin with the calculation of the requisite catchment-cultivated area (C:CA) ratio. It is thus surprising to find that this calculation is almost always bypassed. An exception is the Turkana Rehabilitation Project in Kenya (case study #3), where these calculations have been considered at length and used in the design of various structures, although experience shows that this does not guarantee success.
The C:CA ratio controls the amount of supplementary "irrigation" through runoff that the crop will theoretically receive, i.e., it reflects the degree to which rainfall will be "multiplied". Because the catchment is the source of the runoff, the quantity of water harvested is related to the size of the catchment, and the ratio between the catchment area and the size of the cultivated plot is critical. The optimal ratio is calculated from the crop's water requirements, a selected level of "reliable rainfall", average rainfall, runoff coefficients and efficiency factors. The calculation is not straightforward, however, nor is it foolproof. There are three basic problems:

(a) Two basic design parameters, namely rainfall and runoff, are highly variable from season to season. In addition, basic data, especially on runoff, are often absent. Incorrect estimates of rainfall and runoff can lead to a doubling (or halving) of the C:CA ratio calculated.

(b) The ratio is very sensitive to the chosen level of "design rainfall", i.e., the ability of the system to meet the crop's water requirement on a reliable basis. The more reliable the system is designed to be, the larger the C:CA ratio will be, and the larger the effective magnification of the rainfall. The danger is that bunds will be breached in years of above-average rainfall, as was the case in 1988 with the Turkana Rehabilitation Project (case study #3), despite the calculations.

(c) Where cultivated fields are already established, it is impractical in most cases to increase the size of the catchment outside the plot; the C:CA ratio is thus "fixed". In northwestern Somalia, for example (case study #11), some bunded fields may be said to benefit from a water harvesting system; others have little or no external catchment. Traditional systems in Somalia and Sudan (case studies #10 and #12) have a range of catchment sizes depending on the availability of sites for cropping. This does not apply to short slope catchments, where the catchment strips are sited within the cultivated land and can be simply adjusted by altering the spacing between the ridges (see case study #6, from Baringo, Kenya for example).

Photo 3 A Simple Runoff Plot (Kenya)
A convenient rule of thumb is that a C:CA ratio of 3:1 will approximately double the effective rainfall, assuming a runoff coefficient of 0.33. In practice, this ratio usually suffices to make a significant difference to crop growth without encouraging damaging flows in wet years. In a short slope (microcatchment) system the ratio can be lower due to the greater efficiency (i.e., the higher runoff coefficient) of the short catchment. However, in the more arid areas, such as Turkana District of Kenya or the Central Rangelands of Somalia, larger ratios can be justified, though in these cases a diversion ditch above the plot should be incorporated into the design to protect plots when enough runoff has been harvested.

It is characteristic of tree planting projects in SSA that the size of the catchment supplying each seedling (or the size of the pit to hold the runoff, which is sometimes the basis of design) is determined on the basis of an estimate of the water requirements for seedling establishment (see case studies #3 and #5 from Kenya, #8 from Niger). The catchment sizes range considerably. Surprisingly, in no case studied has there been a calculation of water requirements for mature trees, although this is understandable when most tree species planted are indigenous and hardy once established. Nevertheless, the amount of water harvested will influence the productivity of the mature trees.

**Recommendation 1** There is a need to study and analyze systematically the relationship between microcatchment size and tree performance.

A basic requirement for an earth bund is that a given percentage of its height must be "freeboard", this being the proportion of the bund standing clear of the temporarily ponded water. While 30% of the bund's height is normally acceptable and appropriate as freeboard for the range of bund sizes common in WH systems, some projects deliberately "overdesign" to ensure that the bunds will be longlasting. The most obvious examples of this are in Turkana, Kenya (case study #3) where the freeboard allowed is 65% of the bund's height (for a trapezoidal bund on a typical slope of 0.5%) and in northwestern Somalia (case study #10) where the freeboard allowed is 70% or greater.

While there may be advantages to overdesign in terms of longevity, there are numerous disadvantages. Large bunds are more expensive, requiring massive labor input or the use of heavy machinery. An increase in height also adds disproportionately to the volume of earth and hence to the amount of work involved. Considerable land area is actually lost to the bund and potentially productive top soil is entombed. If breakages do occur, repair is all the more time-consuming, and less likely to be undertaken by the beneficiaries. Earth bunds are at their most vulnerable immediately after construction, before natural consolidation has occurred.

It should be noted that stone bunds, like those in Burkina Faso (case study #1) can be considerably lower than their earthen counterparts since, being semi-permeable and able to tolerate some "overtopping", they do not require a freeboard allowance. However, low stone bunds do tend to silt up quickly and to lose their effectiveness unless increased in height.

An associated advantage of stone bunds is that they do not require spillways or specific overflow structures, due to their permeability. Nor do they cause runoff concentration as artificial spillways do. Short slope (microcatchment) techniques using earth ridges do not usually require spillways either because, while they are not permeable, they are designed to hold all the runoff generated from a given size of rainstorm.

Spillways are the bane of many WH systems. Stone spillways set in contour earth
bunds are particularly vulnerable to erosion and breakage. It is notable that none of the systems described in the case studies uses this kind of spillway, though some projects have tested them. By far the most common type of spillway is the provision for overflow around the tips of up-sloping "arms" or "wings" adjoined to a contour base bund. This is the safest, and most versatile, type of spillway. Nevertheless, any system which concentrates water regularly into a spillway is liable to become an erosion hazard.

The traditional systems in Somalia (case study #10) and Sudan (case study #12) stand in interesting contrast with respect to spillways. In Somalia, there is normally a provision for the discharge of excess runoff, whether around upsloping arms, or in exceptional cases through plastic pipes situated in the main bunds. However, in the "teras" system in Eastern Sudan, bunds are normally breached by the farmer (and later repaired) if water stands for too long.

**Recommendation 2** The most appropriate and effective spillways in earth bunded systems are those in which excess water is drained around the protected ends of upslope arms or wingwalls. Spillways present a potential erosion hazard, however, and stone bunded systems or microcatchment techniques should therefore be preferred wherever possible.

**Survey and Layout**

Of the systems studied, there are three distinct methods of survey and layout. These are:

- (a) traditional systems, in which the implementors use estimates, intuition and experience to determine the contour, sometimes with surprising accuracy;
- (b) high-technology projects that employ sophisticated surveying levels;
- (c) projects using simple water tube levels or line levels.

There is no justification for using sophisticated surveying equipment such as "dumpy levels" for small-scale WH projects. The line level or water tube level are sufficiently accurate and fast, while bringing the technology within the grasp of the farmer, and keeping costs low. Such technology can also be a valuable way to improve traditional systems. The water–tube level favored in West Africa may be more accurate at laying out contours than the line level common in East Africa, especially on low slopes, but it is more difficult to use for the graded contours needed for diversion ditches, for example.

The leading proponent of simple surveying instruments is the Agro-Forestry Project in Burkina Faso (case study #1), in which farmers are trained to use water–tube levels themselves. One drawback is that surveying under this particular project is often done to smaller tolerances than actually required, with the result that contour lines are unnecessarily contorted, require more stone and prevent easy plowing with animals. In contrast, surveying clearly needs to be improved in the Ourhamiza valley of Niger (case study #7): the rigid layout of the "half-moon" microcatchment system leads to inaccuracies on undulating terrain.

**Recommendation 3** Simple surveying instruments such as water levels are adequate for all purposes in WH projects; for rapid expansion in land surveyed, the best policy is to train farmers to use these levels themselves.
Handbooks

Technical specifications (where they exist) are often hidden away in reports with limited distribution, and thus relatively inaccessible. Technical handbooks are rare, almost always project-specific, and are little circulated. Of the projects profiled in the case studies, only the Turkana Rehabilitation Project (#3) has a comprehensive manual describing the techniques used.

Recommendation 4  To facilitate the transfer of information between projects, clear design data needs to be kept in written form by the projects, and distributed widely. A manual describing the most common techniques in SSA would be most useful.

Techniques

A wide variety of basic WH techniques is employed in SSA. These will be briefly analyzed according to (i) the material, earth or stone, and (ii) the production, i.e., crops, trees or grass/fodder. Generally speaking, stone is characteristic (though not exclusively so) of systems in West Africa, whereas earth is normally used elsewhere. Since most WH systems are for crop production, there is no tradition in these areas of planting or tending shrubs or grasses.

Earth-built systems are the most common in SSA, since earth is universally available. Earth bunds have the advantage of being relatively cheap to build and capable of ponding water. They have the disadvantages of being vulnerable to breaching, of settling and eroding if not protected, and of needing a spillway when they are part of a long slope catchment or floodwater harvesting system. The quality of the earth for bund construction can be critical: soil that cracks or develops tunnels (common problems with certain clays, or soils with a high exchangeable sodium...
content) are particularly unsuitable for bund construction. Compaction is very important, but difficult to achieve unless bunds are built during the rainy season, when labor is normally needed elsewhere.

A wide range of earth-built systems are used for crop production, including large diversions for water spreading. The most common field-scale system is one utilizing a long slope catchment to provide runoff to a plot banded on three sides. This is the most versatile and generally applicable system, and the basis of traditional techniques in Somalia and Sudan (case studies #10 and #12) as well as project-implemented systems in Niger (case study #8), Kenya (the "trapezoidal bunds" in case study #3) and Somalia (case study #11).

As previously noted, it is difficult to alter the size of catchment relative to the field where the plot is already established. However, in some projects in which the plots are sited on new land, for example, the plateau of the Keita Valley project in Niger (case study #8), the C:CA ratio can be precisely determined. Ratios for plots banded on three sides range from 2:1 to about 20:1. Ratios between 2:1 and 5:1 are most common, however. For the common system with bunds on three sides, using an external catchment, 3:1 is a widely suitable C:CA ratio. As explained previously, this will approximately double the amount of moisture available to plants.

Bunding on three sides of the plot permits standard cropping techniques within the planted area. Water distribution within the plot tends to be uneven, however, and this can be reflected in plant growth, with the strongest plants towards the lower end of the plot in a poor year, and waterlogging in that area in a wetter year. The Turkana WH Project (case study #3) solves this particular problem through land levelling within the cropped area. This is a labor-intensive operation, however, and a certain amount of levelling occurs naturally in any case after a few seasons.

The second main type of system for crop production using earth structures is contour ridging. Fairly small ridges are formed at intervals of one to three meters, roughly on the contour. The furrows collect runoff from the uncultivated catchment strips between ridges. Crops are planted beside the furrows. This is a within-field catchment system with cropping and catchment strips interspersed within the plot. This type of system is limited to small-scale activities at present, in projects in Baringo District of Kenya, Zinder Department of Niger and at Chiredzi in Zimbabwe (case studies #6, #9 and #13, respectively), but shows great promise.

The advantages of this technique are that it eliminates the need for spillways, allows precise definition of the C:CA ratio, makes use of the high efficiency of the short catchment, and causes even crop growth. However, it is not suitable for the most arid areas with extremely unreliable rainfall, e.g., Turkana District in Northern Kenya, where the quantity of harvested runoff needed from one or two rainfall events to satisfy crop water requirements necessitates a long slope catchment and a larger C:CA ratio. A further disadvantage is that it requires a special tillage and planting system, which may hinder its acceptability.

Tree planting techniques fall into two categories, negarim microcatchments and contour bunds, both of which use short-slope catchment techniques.

(a) Negarim microcatchments (see case study #3) consist of pits or trenches designed to accommodate a given volume of runoff generated from individual microcatchments. The excavated earth is formed into a network of diamond-shaped bunds or individual "V"s. Variations of these "microcatchments", including simple semi-circular bunds around planting pits, are found throughout the region.
This system is appropriate for small-scale tree planting, or for tree planting in uneven land. The amount of earthwork per individual catchment varies considerably, with one example, the arid Turkana District of Kenya (case study #3), clearly topping the others (2.5 cubic meters excavation per pit). The overall system must be designed to impound a defined rainfall event, but individual catchment sizes can vary to meet the water requirements of the seedlings, saplings or trees. Economic considerations normally limit the maximum size of microcatchment per seedling.

(b) In the case of contour bunds (two projects in Baringo District of Kenya — case study #5), the trees are planted in front of bunds, and cross-ties define the individual catchment size per tree. The construction of this system is normally mechanized. It is best suited to large expanses of even land, where it is the quickest and most efficient method, and furthermore allows cultivation between bunds.

**Recommendation 5** For small-scale tree planting, or planting on uneven land, Negarim microcatchments are the best WH system. For larger-scale afforestation on even land, especially where machinery is used, contour bunding is the preferred technique.

WH systems for grass and fodder establishment are few and far between. Three related techniques from Kenya are presented in case study #4. Each is a variation on the semi-circular bund. Dimensions can vary, with the example from Turkana much larger than the others. Because the concept of planting grass or fodder is almost entirely alien to pastoralists or agropastoralists, such systems are unlikely to succeed unless little labor is involved and the need is recognized.
There is some evidence that these conditions are met in Kitui District of Kenya which, significantly, farmers are settled. It must also be noted that the technical aspects of rangeland rehabilitation are usually less problematic than the subsequent grazing management.

Stone-built systems are mainly confined to West Africa because of the availability of stone and a tradition of using it. These systems are normally limited to crop production. Significantly, stone has been the basis of successful WH initiatives in Burkina Faso (case studies #1 and #2). Stone bunds have the advantage of being semi-permeable, and will overtop rather than breach when runoff levels are high. Spillways are not required (except with some examples of permeable rock dams). Stone-based systems do not, however, pond water as effectively as earth systems, and are unsuitable for microcatchment systems where water is held in furrows or pits. Since stone is not universally available, the spread of stone-based techniques is inevitably limited.

Stone lines or bunds (the size depends on the amount of stone available) are techniques developed from traditional practices. The basic improvements introduced by projects introduced are the "contour" concept, that is, the construction of lines or bunds along a contour for greater technical efficiency, and improved construction, e.g., the digging of a shallow foundation trench. Stone bunding is carried out on existing plots or to rehabilitate degraded land. The C:CA ratio is determined by the location of the plot to be treated, but since many plots are commanded by an external catchment, this constitutes a long slope catchment technique, with runoff from the catchment slowed and filtered. The distance between bunds normally ranges from 15 to 30 meters on the 0.5% to 1.0% slopes where the technique is typically used.

Photo 6 Contour Stone Bund: Yatenga, Burkina Faso
The supplementation of stone with a perennial grass (*Andropogon guayanus*) in some sites is interesting, since this living barrier has an effect similar to that of stone, is at the same time self-sustaining, and provides grass for thatching or weaving into mats. This grass can either be planted vegetatively as splits, or directly seeded. Where stone is scarce, this technique is a particularly valuable alternative to transporting stone over long distances. The potential role of vegetative materials in the supplementation, support, or even replacement of WH structures is generally underestimated.

Permeable rock dams are growing in popularity, mainly in Burkina Faso (case study #2) and interest has recently spread to Mali. This is a floodwater harvesting technique. The careful construction of long, low rock dams or walls across valley floors both spreads runoff for improved crop production and heals gullies. A number of projects are involved in such construction, and technical design shows considerable variation at present. By its very nature, this technique is specific to valley bottoms, and its direct benefits are thus limited to those with fields in these locations. The large quantities of stone involved require transport to the site, which is generally provided by the projects.

**Recommendation 6** Where loose stone is available, it should normally be preferred to earth as a material for bunding.
CHAPTER 3. PRODUCTION ASPECTS

WH is used to improve plant performance in areas where moisture deficiency limits production. Its potential benefit can be subdivided into particular components: initial establishment may be improved through the concentration of early showers, the crop may be helped to weather a mid-season dry spell, or rainfall may be multiplied at critical periods when the season ends prematurely. Still, there can obviously be no control over the timing of the water harvested, in contrast to most irrigation systems.

However, improved moisture availability must be accompanied by associated improvements in husbandry to reap the maximum benefits. Improvements in varietal and species choice, and general husbandry, will tend to bring benefits of their own, which can be amplified by the additional moisture made available under WH. Since fertility issues are rather more complex, they will be discussed in detail.

Improved husbandry is essential to exploit the additional moisture made available by water harvesting. Indeed, the value of WH can be questionable without associated improvements in husbandry. This is exemplified in northwestern Somalia (case study #11) where, despite considerable investment in WH structures (around $1,000/ha), the poor yields recorded (average of 190 kg/ha in 1987, an admittedly dry year) reflect the very low level of general crop management by farmers.

Careful timing of planting is essential in order to optimize the plant's use of the available (or potentially available) moisture. Different strategies are used according to the rainfall characteristics of the area. For example, in the arid Turkana region of Kenya, crops are planted into residual moisture after a heavy runoff event (case study #3). In less arid Baringo (also Kenya – case study #6), the advice is to dry-plant crops to await the rains after a given date. Where rainfall is still more reliable (e.g., Zimbabwe – case study #13), planting is recommended into soil thoroughly dampened by early rains, once a threshold date has passed.

Clean weeding, especially in the early stages of plant growth, is particularly important where moisture is a limiting factor. Weeds act like holes in a bucket, "leaking" moisture out of the soil and undoing the effects of WH. Weeds also rob the crop of nutrients. However, improved soil moisture from water harvesting can itself make conditions more favorable for weed growth – a problem that has been noticed by farmers.

Reduced plant populations in themselves often improve yields in dry years. In two examples (Kenya – case study #6 and Zimbabwe – case study #13), lower plant populations, associated with a novel planting configuration, are an integral part of the recommended system. However, this departure from conventional techniques of planting and tillage may limit the popularity of a WH system.

A further husbandry technique that deserves mention is the opportunistic exploitation of available extra moisture by planting a "relay" crop. This is recommended in Zimbabwe (case study #13) and can be observed in the "Teras" of Sudan (case study #12) where watermelons are planted on the bunds in response to the temporary ponding of water.

Recommendation 7: Improved standards of husbandry must be introduced at the same time as investments are made in WH structures.

Fertility is often the second limiting factor after lack of moisture. This is not
Photo 7 Early Weeding – essential for good yields Burkina Faso

Photo 8 "Fosse Fumière" (compost pit), Burkina Faso
always the case, however. In Baringo District of Kenya, for example, the colluvial soils around the lake are highly fertile (case studies #5 and #6). Nevertheless, maintenance and improvement of fertility status is usually of vital importance in areas where WH is carried out. Several aspects of fertility and its management should be noted:

(a) The improved water availability and higher yields under WH lead to greater exploitation of soil nutrients, and it is thus vital that fertility status be improved, or at least maintained, if sustainable production levels are to be ensured.

(b) The return of organic matter — both plant debris and manure — to fields is important and constitutes part of the extension message under some projects (e.g., Burkina Faso — case study #1).

(c) Inorganic fertilizers are rarely used or recommended due to uncertainties about yields and markets, though the improved moisture status under WH makes the use of chemical fertilizers more viable in some situations.

(d) Crop rotation and the inclusion of legumes in cropping mixtures are well known methods of managing fertility. They are not much in evidence, however, under WH systems where monocropping of cereals predominates.

(e) The use of large quantities of relatively fertile top soil for bund construction should be a concern in areas where land is not abundant. This is an issue in northwestern Somalia (case study #11), where no productive use is made of the large piles of soil.

(f) Wherever water is harvested, so too are organic and inorganic materials, although this does not apply to short slope catchment techniques. Waterborne nutrients are then deposited by the runoff when it infiltrates. Examples of this are the siltation behind stone bunds in Burkina Faso (case study #1) and the wash lines encrusted with goat droppings on earth bunds in Turkana (Kenya — case study #3). While these effects have not been quantified, soil is built up and fertility can be improved.

(g) The same process can wash sands into the cultivated area, but this only occurs when catchments are long and sandy. This is sometimes welcomed by farmers, especially where soils are heavy. Some new water spreading schemes in Sudan, for example, are only cultivated once sufficient sand has been deposited.

**Recommendation 8** Fertility management is usually the most crucial aspect of crop production where WH is used. Fertility must be improved, or at least maintained, for WH systems to be productive and sustainable.

**Annual Crops**

Crop and varietal choice is important. Sorghum (Sorghum bicolor) is the typical grain crop of WH systems. Sorghum is characteristic of the traditional systems in Somalia and Sudan (case studies #10 and #12), and is promoted under projects as diverse as those in eastern Niger (case study #9) and northern Kenya (case study #3). The advantages of sorghum are its drought resistance and its tolerance of temporary inundation — useful attributes under WH systems. A wide range of cultivars exist and there would certainly be benefits from exchanging planting material between projects and countries. For example, one variety considered highly suited to the arid
conditions in Turkana (Kenya) matures in less than three months, and has produced yields after being planted in the residual moisture of a single flood.

Pearl millet (Pennisetum typhoides) is also common under WH systems, mainly in the drier cultivated zones of West Africa. Maize (Zea mays) is generally ill-suited to areas where WH is practiced or promoted, as it is intolerant of drought or waterlogging. However, it is the preferred cereal, in terms of diet and husbandry, in most of Kenya and Zimbabwe, and WH can help make it a more reliable crop (case studies #6 and #13).

Legumes are included only in a minority of planting schemes. Cowpeas (Vigna unguiculata) are by far the most common both in traditional systems (e.g., Somalia – case study #10) and under project guidance (e.g., in Kenya – case study #6). Other promising legumes include green grams (Vigna radiata), lablab (Lablab purpureus) and tepary beans (Phaseolus acutifolius).

Photo 9 Sorghum – the typical crop of water harvesting, Kenya

Trees

Tree planting in dry areas can be assisted by WH, especially in the phase of seedling establishment. A number of projects in several countries are using WH for tree planting, and several basic similarities emerge. However, there is considerable variation in the cost of the WH structures associated with afforestation, and the more expensive systems are difficult to justify, especially in the face of rather speculative benefits.

The primary objective of most projects is domestic or commercial fuelwood production, often associated with the secondary objective of fodder production. Control of environmental degradation is frequently cited as a further benefit (Niger – case study #8; Kenya – case study...
Nevertheless, it is evident that objectives are not always clearly thought out, one possible reason being that it is widely assumed in development circles that tree planting is invariably beneficial.

In the 1980s, the trend in species selection has been to plant an increasing proportion of indigenous trees. This is in contrast to the policy of the 1970s and earlier, when exotics predominated, often with disappointing results. Despite the rather slow initial growth of indigenous species, their ability to survive once established is now generally preferred to the potentially greater biomass production of the exotics in favorable situations. *Acacia* spp is widely favored, as are *Cordia* spp, *Balanites* spp and *Ziziphus* spp.

One exotic, *Prosopis*, is still commonly planted, however. *Prosopis juliflora* (sometimes termed *P. chilensis* - which is identical for practical purposes) is being planted by projects in several countries, including Kenya, Somalia and Niger. Intriguingly, *Prosopis* is the only example of an introduced tree species that shows significant evidence of having "gone wild" in several parts of semi-arid SSA. This shrubby tree is drought-tolerant, only lightly browsed and grows readily from seeds deposited in animal droppings. Its main uses are as fuelwood from its readily coppicing stems and as fodder from its seedpods. The major contribution of many afforestation projects is likely to be the naturalization of *Prosopis* into the local ecosystem. Where there is severe degradation and tree cover is scarce, this could be a substantial benefit. There is evidence from several countries that *Prosopis* can even seed itself in areas where there are no indigenous trees remaining. However, where natural bushland is rich or irrigated land close by, the potential invasion of *Prosopis* may constitute a menace.

There are few examples of WH being used to support trees that yield a more valuable economic product than fodder or fuelwood. Relatively high-value trees, such as *Acacia senegal* for gum arabic or *Balanites aegyptiaca* for seed oil extraction, could more easily justify the costs of structures. But, such tree crops are dependent on market structures that do not exist in all countries, and they may take up to ten years to reach full productivity.

Direct seeding is a technique employed by only a few projects (e.g., Niger - case study #9). Since it eliminates the nursery stage, the potential cost saving of direct seeding is immense. This technique may not work in all areas or for all species, but the preliminary evidence is that it deserves further testing and field trials.

A technique used by several projects (e.g., Kenya - case studies #3 and #5) is to plant more than one seedling (or seed) in a planting station, and to thin later if necessary. This makes good sense, since the incremental cost of planting extra seedlings is relatively small and survival rates per hectare can normally be improved considerably. However, there are few data to quantify these benefits. Sometimes multiple planting is carried a step further: one seedling is planted in the bottom of the planting hole, and another next to the hole.

**Recommendation 9** Multiple planting should be a standard practice under WH systems.

Weeding, if any, is usually done only in the immediate vicinity of the seedling. It is significant that the grass and weeds growing between the trees are the most important output of afforestation in the first few years. Some projects actively promote this production by planting grasses and low-growing fodder species. Without such immediate returns, afforestation projects are much less attractive.
Recommendation 10  
Planting grass amongst trees should always be considered in afforestation projects as a means of obtaining quick benefits.

Range and Grassland

The main contributions of WH to fodder production are the by-products of grasses and herbs grown in association with trees, and the plant residues from cropping systems. Small-scale WH systems are rarely designed specifically for grass or fodder, simply because of the greater potential return from crops and the difficulty of justifying the costs of WH for grass and fodder in dry areas. A further constraint is that the planting of grass or fodder is an alien concept in the areas where rangeland is an abundant resource.

Rangeland rehabilitation by grass planting in association with WH has been tested in three locations in Kenya (case study #4). In Baringo, grass planted in small "hoops" yielded spectacular improvements over the adjacent unprotected, untreated rangeland. Much larger and more expensive hoop-shaped structures in Kenya's Turkana District have also been designed for fodder (no performance data available). However, the best combination of performance, cost and acceptability is the example of the higher-potential Kitul District, where the objective is the re-establishment of productive pasture.

One technical point specific to systems promoting grass and low-growing herbs is that the ground coverage and root systems of these plants protect structures and reduce maintenance requirements, although structures are still vulnerable in the initial stages.

Integrated Systems

Integrated production systems associating annual and perennial crops are still more talked about than actually implemented by projects. There are few examples of agroforestry being tested in the context of WH. Part of the problem of agroforestry is the difficulty of identifying tree species that farmers are prepared to plant in association with crops. While farmers will leave certain naturally occurring trees of particular value in fields (e.g., A. Albida in Niger, Terminalia spinosa in Somalia), most trees are considered a nuisance, because they compete with annual crops for nutrients, and harbor grain-eating birds.

The greatest potential for integrated systems in WH is probably the establishment of vegetation, grasses, leguminous shrubs and trees, on or near earth bunds in cultivated land. In addition to the positive effects on fertility, earthen bunds are stabilized, a by-product is produced, and the otherwise unused soil of the bunds exploited. Where it is difficult to justify the cost of microcatchments for trees, one alternative is to plant seedlings on or near the bunds. In some projects (e.g., Niger – case study #8), it is indeed standard to plant trees in association with bunds, although this is a project practice rather than a case of voluntary adoption. In the Central Rangelands of Somalia, project trials using WH (case study #10) are testing a fully integrated production system of crops, trees, fodder legumes and grass, with cuttings from Commiphora spp used to develop live fences. This type of approach should be a model.

Recommendation 11  
The incorporation of legumes, trees and live fences can yield longer-lasting benefits and should always be considered when planning a WH system.
CHAPTER 4. SOCIO-ECONOMIC AND PROJECT MANAGEMENT ASPECTS

While it is important to perfect the technical aspects of WH, experience shows that unless adequate attention is paid to the socio-economic context in which it is promoted or introduced, a project runs considerable risk of failure. To use an analogy from information technology, the software (i.e., the socio-economic aspects) is as important as the hardware (the technical aspects). This chapter will touch on a range of socio-economic aspects, including the adoption of WH techniques, the methods of construction, popular participation, individual and collective approaches to WH, women’s issues, equity aspects, land tenure, incentive policy and support systems, costs and benefits, lessons from traditional techniques, transfer of WH techniques, monitoring and evaluation, and reporting. Although treated separately for practical purposes, most of these subjects are closely linked and some overlap is unavoidable.

It should be noted that socio-economic data on WH are scarce, and when available, rather unreliable. Many WH projects simply do not bother to build up knowledge on the socio-economic situation of the local resource users, or to evaluate the impact of their activities. This aspect will be treated in more detail in the paragraph on monitoring and evaluation.

Adoption of Water Harvesting Techniques

Experience indicates that in most cases WH and other soil and water conservation activities come to a complete standstill as soon as a project withdraws. Farmers sometimes maintain the structures and, in that case, what has been constructed (sometimes at considerable cost) continues to function. But adequate maintenance of WH structures is the exception rather than the rule. Rarely do farmers continue in the post-project phase to apply these techniques on their own fields.

The reasons for non-adoption are varied, and can include:

(a) Incompatibility of WH techniques with traditional food production strategies;

(b) high labor requirements for construction and maintenance;

(c) heavy reliance on machinery, which is often unavailable in the post-project phase, while farmers are discouraged from using their own equipment, if they have any;

(d) lack of farmer training in simple land surveying methods for design and construction of WH works. Farmers remain dependent on technicians and are unable to treat their lands when and where they want to;

(e) technical design parameters, e.g., rainfall intensity and runoff coefficients, too complex for local resource users.

If WH techniques are to be adopted, they should be simple enough to be mastered by farmers and should produce attractive and immediate yield increases. However, experience shows that not all simple and efficient WH techniques are automatically adopted by farmers. This is demonstrated by the low rate of adoption of simple techniques such as "half moons" and trenches in the Tahoua Department (Niger – case studies #7 and #8) and contour ridges in the Baringo District (Kenya – case study #6):

(a) Although the "half moons" make it possible to cultivate degraded gentle slopes under low rainfall conditions, they have not yet been adopted spontaneously by
farmers, for reasons that have not been really studied. It may be that most agropastoralists in the region use to plant their crops in sandy, easily cultivated soils with minimal land preparation; the construction and maintenance of "half moons", often laid out on more clayey, hard-to-cultivate soils, deviates considerably from this pattern.

(b) Trenches are another illustration of simple techniques not automatically adopted by farmers, although they increase the survival rates of trees planted in 300 mm rainfall areas. Their non-adoption is most likely due to the quantity of work involved in their construction (one cubic meter per trench), as well as to uncertainties about land and tree tenure.

![Photo 10 Trenches, Keita Valley, Niger](image)

(c) Contour ridges produce substantial yield increases, compared with flat cultivation, but few farmers in Baringo District have adopted them. Where they have been adopted, they tend to be spaced at smaller intervals than originally proposed, since farmers do not fully understand the reason for leaving so much land uncultivated between ridges.

(d) In the Tahoua Department in Niger, farmers tend to increase the size of the "half moons" at the expense of the size of the catchment area. The vital role of the catchment area as a multiplier of rainfall seems not to have been fully grasped by the local resource users in these areas.

If simple techniques are not always easily adopted by local resource users, the chances that more complicated techniques will be taken up are even more remote: the contour earth bunds in northwestern Somalia (case study #11) and the stone-reinforced earth bunds in the Keita region of Niger (case study #8) illustrate this point. Although farmers in these
areas have been exposed for several years to these techniques, they have not applied them voluntarily on a single hectare. It is true that these projects had different purposes, and that adoption of techniques was not an objective. However, unless techniques are adopted by local resource users, they will always be limited in coverage.

Do we have then replicable WH technologies? The answer is a qualified yes. An analysis of the case studies shows that traditional techniques as the "teras" of Sudan (case study #12) and the "caag" and "gawan" systems of Somalia (case study #10), and the contour stone bunds in Burkina Faso are replicated spontaneously by villagers on a sizeable scale (case study #1):

(a) In the Yatenga region, the number of hectares treated annually by farmers with contour stone bunds increased from about 150 in 1982/83 to about 5,000 in 1987/88. Men and women in the Yatenga region practice bund construction with an almost religious fervor. Impressive results can be observed in or near every village: farmers have rehabilitated degraded land, and obtained cereal yields twice as large as the average on existing cultivated lands. However, probably fewer than 10% of rural households have now adopted contour stone bunding, but little is known about the socio-economic characteristics of adopters and non-adopters.

(b) Some permeable rock dams (case study #2) are constructed in the Kongoussi region of Burkina Faso by farm families using their own resources. It is unlikely that this will be done on a large scale, however, since great quantities of stone are needed for construction of rock dams, and its transport over distances of over one kilometer requires the use of vehicles.

Although the case of contour stone bunding in Burkina Faso is particularly encouraging and instructive, the fact remains that there are at present no other conspicuous WH success stories. And since no project has conducted systematic research on why farmers do or do not adopt WH techniques, one often has to guess the reasons.

Recommendation 12  Research on reasons for adoption and non-adoption of WH techniques is urgently needed. 1/

Construction Methods

The use of machinery can permit quick and effective implementation of WH works, as well as tangible results for donor agencies, governments, the press and perhaps the farmers. In Somalia's Northwest Region Agricultural Development Project (case study #11), bulldozers are used to construct bunds to a height of one to two meters at a horizontal interval of 30 meters. The Keita and Damergou projects in Niger (case studies #8 and #9) rely on tractors. The Baringo Fuel and Fodder Project (case study #5) uses a motor grader for bund construction.

1/ The quality of the information is more important than the quantity. This kind of information is also needed in the short-term in order to permit timely adaptation of techniques and support packages. Therefore, conventional surveys using detailed and highly structured questionnaires with partly precoded answers should be abandoned in favor of "Rapid Rural Appraisal" techniques (see McCracken et al., 1988 for a general introduction to RRA techniques in agricultural development).
Photo 11 Bunding by Bulldozer, NW Somalia

Photo 12 Ridging with Specially Designed Implement, Damergou, Niger
One example of machinery use deserves explicit mention here. The Damergou Project in Niger (case study #9) uses specially designed tractor-drawn implements for the construction of tied contour furrows and curved mini-trenches. Implementation is rapid, efficient and relatively inexpensive. This kind of technical innovation is most interesting, and it is not surprising that several projects in Niger have already shown a serious interest in procuring this equipment. However, caution is needed as the technical success needs to be matched by participation of the local population.

But, more often, the use of machinery present disadvantages, such as:

(a) a lack of farmer involvement, since the activities are designed, planned and implemented by outsiders;

(b) the creation of an imbalance, due to the scale of WH works, between maintenance requirements and what beneficiaries are willing and able to invest;

(c) the difficulty of continuing operations in the post-project phase, since in most cases neither Governments nor beneficiaries can afford to operate a fleet of machines after withdrawal of the funding agency.

When machinery has been used for construction, WH works are not adequately maintained by the beneficiaries, and spontaneous adoption of the techniques by the farmers is virtually nil. Once heavy earth-moving equipment is introduced, it is unrealistic to expect farmers to maintain bunds by hand or with ox-drawn equipment. Over-dimensioning of structures (NWADP in Somalia), or the carpeting of earth bunds with stones (Keita Valley Project, Niger) to reduce or eliminate the need for maintenance is not a solution, since all systems need some adjustments repairs and maintenance. Deliberate "overdesign" may at best delay short-term maintenance needs, but at considerable cost.

Two opposing schools of thought exist about the use of machinery in WH. Some conservation specialists advocate heavy reliance on machinery, as they do not believe in the ability of local resource users to rehabilitate and manage their own environment. They believe that the problem of environmental degradation is simply too big for local resource users to handle. Others reject machinery for reasons already mentioned and prefer to rely as much as possible on local "participation".

A more useful distinction could be made between WH on individual farmers' fields, which directly benefits them, and interventions benefitting groups of farmers or entire village communities. In the first case, the use of machinery should be avoided as it will discourage farmers from applying the techniques in the post-project phase using their own means. The OXFAM/ITDG-funded Turkana WH Project in Kenya is the only WH project known to the authors that has made an effort to introduce animal-drawn scraper boards for levelling, as well as scoops for bund construction (case study #3). The use of animal-drawn equipment could reduce labor requirements for construction, a particular advantage in regions where labor is scarce.

**Recommendation 13** For WH on individual fields, the provision of donkey carts, animal plows and other tools to farmers should be preferred to the use of heavy machinery.

If the scale and dimensions of WH works require a collective commitment from villagers to implement certain specific large structures, some form of support with heavy equipment may be necessary. For example, the most efficient way to rehabilitate gullies can
Photo 13 Donkey Carts, Yatenga, Burkina Faso

Photo 14 Transport of Stone for Permeable Rock Dam, Burkina Faso
be to construct a number of permeable rock dams in the same valley in one dry season. Each
dam requires the transport of several hundred cubic meters of stone over distances of 1
kilometer or more. The exclusive use of wheelbarrows and donkey carts would prolong the
construction period considerably, reduce the efficiency of the works and risk disillusioning
villagers. The use of vehicles for transport of stones is necessary under such conditions,
as the dimensions of permeable rock dams practically preclude voluntary construction outside
the project phase.

To create tree plantations (case study #9), using heavy machinery may be
justified in regions of low population density, provided that the local resource users are
involved in the planning, management and exploitation of the plantations. Population numbers
as well as local and sub-regional needs for fuel, fodder and poles for construction require
that a ceiling be imposed on the size of such plantations. Arrangements should be made in
an early phase for sharing of costs and benefits between beneficiaries as well as for cost
recovery.

Recommendation 14 As the use of heavy machinery can only be justified under certain
conditions, it is recommended that the local situation is studied carefully
before promoting this option.

The maintenance of WH works constructed collectively should, of course, be
discussed before construction begins. If such works are exploited individually, their
maintenance will have to be assumed and organized by the direct beneficiaries. Where a limited
number of individual farmers benefit from collectively constructed WH works, as is the case
with permeable rock dams (case study #2), at least partial cost-recovery should be considered.
For example, a percentage of the increased agricultural production could be siphoned off and
used to create a local cereals bank or sold on the market and the proceeds invested in the
village.

Construction by hand can be a slow and cumbersome exercise: construction of contour
stone bunds on one hectare can take 50-150 man/days depending on the availability of stones
on or near the fields (Begemann, 1986; Wright, 1982). The construction of contour ridges
on one hectare in Baringo, Kenya takes 90 man/days per hectare, compared to 50 man/days
per hectare for conventional tillage (Hogg, 1986). Trapezoidal bunds in Turkana (Kenya)
require an investment of 380 mandays for construction. One trapezoidal bund impounds 0.32
ha. The construction of "half moons" in Ourihamiza, Niger requires 40-80 man/days per hectare
(4 to 8 half moons/day; approximately 313 units/ per hectare).

High labor requirements for construction of WH works during the dry season are
an important constraint to large scale WH projects. Semi-arid regions usually show a strongly
skewed sex ratio during the dry season, since many young men are herding cattle or have
migrated to urban areas or plantations in search of cash income. The remaining men try to
earn some money with trade, cottage industries or vegetable gardening. Many projects try
to remove labor constraints by offering such incentives as food-for-work. The risk, of
course, is that the local population is motivated by the incentive instead of by their
appreciation of the importance of water harvesting.

Although construction by hand is often slow, this need not be a constraint where
many hands are available. The challenge is to create a situation in which a steadily growing
number of local resource users become motivated to treat their fields. An additional advantage
of works constructed voluntarily by hand is the automatic balance between maintenance needs
and the local capacity to carry out this work.
Photo 15  Construction by food-for-work, Turkana, Kenya

Photo 16  Traditional Technique of Stone Lines, Yatenga, Burkina Faso
Popular Participation

Local resource users are rarely involved from the beginning in the selection of WH techniques, the choice of vegetal material, or the kind of incentives offered. The initial phase of the Agroforestry Project in Burkina Faso provides useful insights: in 1979, the project started with the plantation of trees in microcatchments. It soon became apparent that the villagers were not interested in planting trees that they could not protect against uncontrolled livestock grazing in the dry season and that showed no immediate benefits (Wright and Bonkoungou, 1985). Their priority was to grow more food, since the region was drought-stricken and the total harvest considerably below annual family needs. For this reason, the project decided to change its course, and chose to test several WH techniques at farm level ("half moons", microcatchments, earthen contour bunds and stone contour bunds), and get the villagers to evaluate them. As they expressed a clear preference for contour stone bunds, the project decided from then on to promote them. This responsiveness to farmers' priorities partly explains the success of the project; the permeable rock dam construction in the Kongoussi region of Burkina Faso (case study #2) recorded similar results for the same reasons.

Recommendation 15 Farmers (both male and female) should be involved from the outset in the planning and development of WH projects.

Substantial training programs for farmers (male and female) and field staff in simple land surveying methods and in basic design and construction principles are important factors in encouraging adoption of WH techniques. Without adequate training of most farmers, large-scale adoption of the techniques will not be possible. Men and women trained by the Turkana WH Project now need only minimal technical advice and supervision. On the Central Plateau of Burkina Faso, thousands of farmers have been trained in stone bund construction and many of them now treat their fields when they want. They are proud of their new skills, which enable them to operate with little technical support. Most WH projects pay little attention to farmer training, a situation which urgently needs to be remedied.

A large-scale training program for large numbers of farmers requires a change in the attitudes of governments and donors, who usually want quick, tangible results. Developing such training is a slow process; trainers must first be trained and some fields treated during the training sessions. Experience shows that it takes between five and ten years to develop a technical package and a substantial training program. Thus, governments and donor agencies should be aware that if they opt for a participatory approach, tangible results cannot be expected quickly.

Recommendation 16 More effort should be made to train farmers (male and female) in order to create favorable conditions for large-scale adoption of WH techniques.

Individual and Collective Approaches to WH

According to conventional theory, watersheds need to be treated as a whole, starting from the top and working downward. In fact, as illustrated on the Central Plateau of Burkina Faso, farmers generally prefer to treat their own fields before treating common lands (Wright and Bonkoungou, 1985). In this way, they know they will reap the benefits of their own efforts, which is not always the case in community enterprises. It is now accepted, at least in parts of West Africa, that the villagers decide how to organize themselves: farmers wishing to treat their fields individually can do so, but they can also organize work parties. In specific situations, such as relatively flat lands, WH can be practiced by individual farmers independently from the rest of the watershed without undesirable
Recommendation 17  Local resource users should decide how they want to organize themselves for the construction of WH works, and which fields they want to treat on a priority basis.

In some cases, such as the use of water spreading techniques, the dimensions of WH systems are such that they cannot be constructed on an individual basis. The most common solution has always been to organize villagers, often with food-for-work as an incentive (see case study #3). Again, experience shows that, for various reasons, what is constructed in this way is usually not maintained. As WH works normally benefit a limited number of local resource users, the solution may be to organize these direct beneficiaries, rather than a largely uncommitted group of villagers, for construction and maintenance.

In a growing number of Sahelian villages, a land use management approach is promoted: experiments are conducted with cattle enclosures, rotation of grazing areas, etc. In some cases, these experiments have been imposed from above, while in others they are the result of a dialogue between projects and villagers. Contracts now exist between some projects and villages; they define the activities carried out by villagers and the conditions for project support. The attribution of exclusive rights to the village on a defined grazing and fodder-collecting territory can be part of the contract, if the government officially supports this initiative. Such village activities require:

(a) adequately functioning local organizations;
(b) locally-defined priorities for resource management;
(c) rules for the exploitation of non-arable lands;
(d) sanctions or some type of community pressure when individuals do not respect the rules.

In most villages, however, there are at present no adequately functioning local institutions that could develop and implement village land use management plans, and they will thus have to be created.

Recommendation 18  WH is not a freestanding technique, but should be treated as part of a village land use management plan.

Women's Issues

Women constitute more than 50% of the rural labor force in most semi-arid regions. Women are heavily over-represented in the 17–40 age range, because many young men have migrated to regions where they can earn a cash-income during the dry season. According to Monimart (1989), however, men are more often staying away not only in the dry season, but for much longer periods that sometimes extend to several years. Consequently, the number of female-headed households is on the increase in semi-arid regions. Since the construction of WH works is limited to the dry season, it is not surprising that women play an important role in this activity, and often carry out the hardest and most demanding tasks. In the Kelta Valley Project in Niger, for example, 75%–95% of works (collection of stones, carpeting of earth bunds with stones, and trench digging for tree plantations) are done by women attracted to the work sites by the food-for-work incentive.
In many cases, WH has undoubtedly increased the workload of women. One might therefore ask whether the benefits they derive are commensurate with the labor they provide. The benefits are direct and indirect. Direct benefits are: (a) food-for-work rations, which women use partly to feed their families and partly to sell for cash; and (b) the possibility, in a limited number of cases, of constructing WH works on their own private fields. Indirect benefits are: (a) yield increases resulting from the construction of WH works on family fields, which enable women to contribute less from their individual fields to the family food supply; and (b) under some projects, the training and improved skills in survey techniques and bund construction. Globally, women do not seem to benefit adequately from their efforts. According to Monimart (1989), although women play a major role in desertification control activities, they derive only limited benefits from them.

The decline in the economic status of women is closely related to their limited access to land and to the degradation of the natural resource base, and is not compensated by new income-earning opportunities such as handicrafts (Monimart, 1989). In many regions, individual women have access to small plots of marginal lands, with usually no permanent land use rights. Married women in certain parts of West Africa are allocated some land (often 0.25 to 0.52 hectare) by their husbands for an indeterminate period. On this land, they may grow crops of their choice, within the limits of the soil quality, since the best land is reserved for the family fields. Given the marginality of their plots, women would certainly benefit from applying WH techniques on them, but few do so: their husbands have the right to withdraw and reallocate these parcels, and the resulting uncertainty on the right of use makes WH treatment of these plots unattractive. When women are in groups, however, things are different: in an interesting development, women in some regions of Burkina Faso have organized themselves to rehabilitate degraded land collectively.

Given their important role in WH, women should benefit greatly from material support to alleviate their workload, and from training to improve their skills. Although the need to train women in WH techniques is increasingly recognized, the number of trained women is still much smaller than that of trained men; this is an anomaly considering their significant contribution to the activity. The Turkana WH Project in Kenya (case study #3) has trained women, and it is not unusual to see them leading work groups for bund construction, a task that they often perform as well or better than men.

Recommendation 19 To increase the benefit women derive from WH developments, a major effort should be made to provide them with systematic training in techniques and material support (tools, donkey carts, etc.), and help them get access to land.

Equity Aspects

Traditional African society is not very equitable, although inequality is less pronounced than in many other societies. While the objective of WH is not necessarily to reduce inequality, one would hope that it does not aggravate it, either. If techniques are more easily adopted by richer farmers, inequality could increase and extra steps should perhaps be taken to facilitate adoption by poorer farmers. The case studies show that, since reduced little attention has been given to equity aspects, little information is available:

Contour stone bunding would seem to be a "neutral" technique, meaning that every farmer (including poor ones) can apply it. In practice, however, the relatively affluent farmers adopt stone bunding more quickly and treat bigger areas in a shorter time than the smaller farmers. Some of the richer farmers have commercial interests, hire vehicles to transport stones and employ laborers to construct the bunds. But, in the Yatenga region, contour stone
bunding has, on a modest scale, created a new form of wage employment, as village groups, including women's groups, construct stone bunds on individual farmers' fields for payment in cash per meter.

The Turkana Water Harvesting Project in Kenya (case study #3) is a rare example of a WH project with a clearly defined target group. This project works with poor Turkana who still have some livestock, but not with the very poorest, who lost all their livestock during recent droughts. The rationale is that WH alone is not sufficient to make a livelihood, since a good harvest will only be obtained two years out of five. The Turkana who still have a few animals are the target group because the combination of WH and some livestock guarantees a livelihood. (WH activities alone would only perpetuate the Turkana's dependence on food aid). The project is also funding a restocking program in the region to help the poorest group.

Other projects may inadvertently favor particular groups as a result of the technical package they promote, which is not necessarily unacceptable to those who do not immediately benefit. The construction of rock dams in valley bottoms (case study #2) is a case in point: for historical reasons, mostly village chiefs and a few villagers belonging to the traditional warrior caste would have access to land in valley.

**Recommendation 20** During the design and implementation of WH projects, specific attention should be paid to access of poor farmers to the technology in order to prevent greater inequality at village level.

**Land Tenure**

In many African countries, all uncultivated land officially belongs to the State, which does not mean that customary land use rights are no longer recognized by the local population. Land tenure can often be subject to great uncertainty and insecurity, but strikingly little research has been done on this subject. For example, what happens when projects rehabilitate substantial portions of degraded land that have not been cultivated for two decades or more? There is considerable speculation about the effects of the development of WH works on land tenure, but these effects can still be unpredictable, for example:

(a) In northwestern Somalia, it has been suggested that one of the reasons for the popularity of bunding is the perceived insecurity of tenure, and the fact that bunding is thought to confer a stronger claim to the land.

(b) In Niger, in the Keita Valley project, exactly the opposite situation was found where farmers were not interested in treating fields already under cultivation because they feared that bunding might jeopardize their land use rights (Rochette, 1989). In theory, the decision was made to allocate rehabilitated lands on first to the former owners, and then to those who had done most of the work. In practice, this meant that very little land was left for the latter. Women in particular, who constituted more than 75% of the labor force, expressed their dissatisfaction. Although they had done most of the work, only about 10%, most of them single, were granted land (Monmart, 1989). The decision was reversed in 1987.

**Recommendation 21** Attention should always be given by WH projects to the interactions between their activities and land tenure.

**Incentive Policies and Support Systems**

The case studies show few examples of voluntary participation in WH projects.
Projects usually provide some form of Incentive, most often food-for-work, given the recurrent food shortages in many semi-arid regions. In these regions, many men who are needed for the construction of WH works and other environmental rehabilitation activities are absent, because they migrate in the dry season to other regions to earn cash. For example, men from the Keita Region in Niger migrate to the coastal countries for seasonal cash earning jobs. But paradoxically, the opportunity to work for food to do deter their migration: nowadays, they leave their village with a sense of relief, knowing their families will have food, obtained by women and children on the WH sites under construction (Rochette, 1989). The payment of cash-for-work has been tried by at least one project (case study 7). This kind of incentive could dissuade young men from migrating and thus reinforce local capacity for environmental rehabilitation, but could also distort motivation even more than food-for-work, and increase dependence on donor support.

Food-for-work can also be a disincentive (as documented by Jackson and Eade, 1982): in some cases, farmers will not continue to build or maintain WH works without food aid; food distributions in years with good harvests can have similar effects. The policy should be to diversify incentives: for example, to replace food-for-work by other incentives such as fertilizer-for-work, tools-for-work or community infrastructure-for-work (wells, village shops, etc.). However, recent experience in Niger shows that diversification of incentives is not automatically accepted by the villagers. Once projects embark upon food-for-work, it is very hard to backtrack.

In order to increase farmers’ capacity for construction of WH works or to decrease their workload, projects provide various kinds of support: (i) tools (water tube levels, shovels, pick axes, etc.), subsidized, donated, or sold under credit (case study 1); (ii) equipment (donkey carts, wheelbarrows, etc. – case study 1); (iii) vehicles for the transport of stones either free or for payment in kind (case study 2); and (iv) training and extension services (case study 3). In fact, the type of support provided determines to a large extent whether farmers will be able to continue WH in the post-project phase. But donor agencies sometimes seem to sacrifice long-term goals for short-term success, and projects often use their own vehicles for free transport of stones to individual farmers’ fields, instead of providing donkey-carts and wheelbarrows to farmers’ groups.

Most often, the projects select the kind of support to provide, and the conditions under which farmers can get it. Instead, some form of dialogue could be initiated between projects and farmers, and could result in a contract defining the respective roles and contributions of farmers and projects in a village land use management program. The accent could be on equipping small groups of farmers with tools, donkey carts, etc. The groups would lend these equipments to group members, women’s associations, or other users’ associations, for daily fees high enough to cover maintenance, repair, etc. This approach would prepare farmers to further actions requiring a collective behavior, and to the management of group activities.

**Recommendation 22** Incentives and support should be defined in close consultation of local resource users in order to improve chances for post-project expansion of WH activities, and proper maintenance of works.

Lack of coordination between projects is a major cause of confusion among beneficiaries, projects, administration and government. It sometimes occurs that four or five projects, funded by different donor agencies, implement WH activities using entirely different incentive and support systems: food-for-work vs. voluntary participation, tools provided on credit vs. free tools, free transport of stones vs. a contribution in kind, etc.
Recommendation 23  A coordination of WH support programs and incentive systems must be set up at national level to prevent confusion among beneficiaries, and disincentive effects on future voluntary participation.

Costs and Benefits

The available data on costs and benefits of WH systems is approximate at best, and should therefore be regarded with skepticism. Examples of major weaknesses are:

(a) Available cost estimates do not always take into account the costs of labor for construction, maintenance costs of the water harvesting structures, depreciation of equipment, etc.

(b) The calculation of benefits is at best limited to the measurement of yields on selected plots, which are compared (or not) with yields on control plots. However, where control plots are included, they are often unrepresentative of the conditions on the experimental plot. This makes a systematic comparison of "with" and "without" situations impossible. Cultural practices (timely weeding, plant density, use of inputs, etc.) have a clear impact on yields, but they are rarely the same for different plots belonging to different cultivators. For that reason, too, a comparison between experimental and control plots is risky unless those plots are researcher-controlled.

(c) The value of important by-products, such as stover, is usually omitted from the calculation of benefits.

(d) Downstream effects of WH, such as less damage to crops, or upstream effects, such as accelerated growth of trees in the area treated, are difficult to quantify and therefore not considered.

(e) It is not always clear from reports whether the yield data are expressed per gross hectare (including the catchment area), or per hectare actually cultivated.

The financial costs of constructing WH can vary from less than $100/ha to over $1000/ha, but the basis of the cost calculations is highly variable and not always known. Cost estimates are therefore difficult to compare. For example:

(a) The Agro-Forestry Project in Burkina Faso divides its annual project budget by the estimated number of hectares treated and arrives at an average cost well below $100/ha. But farmers' participation spent on collection and transport of stones and on construction is not taken into account.

(b) The Keita Valley project in Niger includes the number of workdays per hectare and uses the cash value of food–for–work rations as a basis for calculation. Total costs per hectare for construction of trenches for tree planting is 544,880 CFAF, or US$1,758 (US$1 = 310 CFAF). Food–for–work rations account for 55% of these costs. Bunds with wingwalls constructed on the plateaux in the Keita region cost 177,378 CFAF/ha (US$572). In the latter case, one-third of a hectare is used as agricultural land and two-thirds as catchment area. This means that the cost of creating one hectare of cultivated land on the plateaux is US$1,716, of which 37% is for food–for–work (FAO, 1988).
(c) Projects carried out with machinery can be cheap: the Damergou Project in Niger (case study #8) indicates average costs per hectare of less than US$50 for construction of curved mini-trenches and tied contour furrows. Costs are low, because the construction is done in quick, one-time operation. In contrast, the cost of the food-for-work rations for construction of trenches in the Keita project amounts to about US$967 per hectare.

(d) The Northwest Region Agricultural Development Project in Somalia (case study #11) uses bulldozers to construct bunds over one meter high, with about 300 linear meters per hectare. The costs per hectare were about 10,000 So.Sh. in 1987 (US$1,250).

It should also be mentioned that, at an average cost per hectare of around US$1,000, the financial costs of a modest 100,000 ha program is already US$100 million. Funding WH programs of that magnitude could well be impossible. As a general rule, one can say that the higher the costs per hectare, the slimmer the chances of adoption.

Concerning the benefits of WH, the available data are also scanty and unreliable. At present, no reliable time-series data exists for yields measured over periods of four or five years on the same fields, so it is difficult to make any statement about the evolution of yields. In Somalia, estimates of average grain yields on NWADP (case study #11) range from 820 to 1,750 kg/ha for bunded land, and from 840 to 1,220 kg/ha for equivalent unbunded land. However, a yield survey commissioned in 1987 (a drought year) found no differences between bunded and unbunded lands. Improved agronomic packages should obviously accompany bund construction; otherwise, the high financial costs (about US$1,250/ha) cannot be justified.

Photo 17 "Teras" System in Eastern Sudan – harvested sorghum in foreground

The benefits, in terms of yield increase and sustainability of yields at a higher
level, could theoretically justify a high investment per hectare, but experience shows that high
investment per hectare does not always lead to correspondingly high outputs. It is even assumed
that yields on treated fields will decrease after some time, because higher yields lead to increased
nutrient extraction, which is insufficiently compensated with manure or fertilizers. This assumption
has not materialized, as yet, on the fields treated with stone bunds in the Yatenga (case study #1).
On the contrary, it appears that yields are increasing over time. But utmost caution is needed in
the interpretation of these figures, as increases can result from different causes, such as
improved land husbandry practices.

Recommendation 24  WH projects should improve the quality of data collection with regard to the
costs and benefits of WH techniques.

Lessons from Traditional Techniques

Little is known about traditional WH techniques, such as the "teras" system (case study
#12) in Sudan, the "caag" and "gawan" systems in Somalia (case study #10), the pit farming system
in Mali, etc. These traditional techniques have not been studied systematically, nor have they been
used as a starting point for new programs. However, they continue to be partially maintained, and
even expanded, by the local population. Although conservation experts in the last few years have
increasingly recognized the potential importance of these traditional WH systems, little research
has been done in the countries covered by the Sub-Saharan Water Harvesting Study (SSWHS)
referred above (p.111).

Why are traditional WH techniques in some cases maintained and even expanded, and
partially abandoned in others? In the absence of adequate research, some speculation is possible.
For example, observations during SSWHS field missions indicated that the efficiency of some of the
traditional WH techniques is too limited to cope with the changing climate. Elsewhere, migration has
evidently been an important factor in abandonment.

Recommendation 25  More research is required on traditional WH systems: (i) to determine the
extent to which they can still be used as a starting point for new programs;
and (ii) to identify ways to improve their efficiency.

Transfer of WH Techniques

Several studies have shown that examples of successful natural resource management
can be found all over the West African Sahel, but that their scale is small and their success very
site-specific. Rarely do successful techniques spread spontaneously to neighboring regions. In
the case of water harvesting, would it be possible to transfer successfully WH techniques, for
example contour stone bunds, planting pits and permeable rock dams popular on parts of the Central
Plateau in Burkina Faso, to other parts of the West African Sahel or East Africa? For contour stone
bunds, the basic conditions for success are: (i) an abundant supply of stones; (ii) a tradition of
using stone in the area, if possible; and (iii) high population density and land pressure. Such
conditions can be found in the Ader Douchi Maggla as well as in some areas north of Niamey in Niger,
on the Dogon Plateau, around Bamako and in several other regions in Mali. The potential for transfer
of stone bunds is not restricted to semi-arid Sub-Saharan Africa: using the Burkina Faso experience
as inspiration, the technique has recently been introduced to Gujarat (India). Such transfers are
already taking place, but on a limited scale: limited efforts have been made to transfer contour
stone bunds and rock dams to some regions in Mali.

Recommendation 26  A systematic effort should be made to identify the necessary conditions for
successful transfer of specific WH techniques from one region to another.
Monitoring, Evaluation and Reporting

Most WH projects have only a vague idea of the costs and benefits of the techniques they promote. They usually have little data on rainfall characteristics, runoff, farm typology, farm budget, cultural practices, etc. They seem hardly interested in finding out why local resource users do not voluntarily adopt and maintain the WH techniques identified as appropriate for their zone of intervention. They make only a modest effort to monitor and evaluate the socio-economic impact of their programs (sometimes for lack of funds and skilled personnel). They may struggle along for years without adjusting their technologies and extension strategies, and rarely do they reorient their activities during implementation.

However, data on rainfall characteristics and runoff can improve the design and modelling of WH techniques. Cost-benefit data can be used to convince donor agencies to fund more WH projects. A record of cultural practices (land preparation, sowing, weeding, use of manure and fertilizers, etc.) is needed to allow comparison of results. A more systematic exchange of experience between projects, as well as some comparison of technical packages, would greatly facilitate the selection of relevant techniques, and the diagnosis in case of non-adoption.

Monitoring and evaluation (M/E) is indispensable to rationalize WH actions, and all WH projects should collect a range of basic data, and, for example, investigate systematically the reasons for non-adoptions of technologies by local resource users. This information would make it possible to adjust techniques and extension approaches, and to identify appropriate support packages.

Recommendation 27 All WH projects should make arrangements for monitoring and evaluation in order to obtain basic data and information on the socio-economic impact and acceptability of their technical packages.

Improved M/E of WH projects would result in better reporting. At present, many WH projects do not even produce annual reports stating targets or giving basic data on achievements such as the number of hectares treated under the project. Deductions are never made for the number of hectares of WH works deteriorated because of lack of maintenance by beneficiaries or due to rain damage. And field experience is usually not reported and analyzed in projects annual reports.

At the national level, the responsibility for WH is not always clear. In some cases, project "A" sends its reports to the Ministry of Environment, project "B" to the Ministry of Agriculture, project "C" to the Ministry of Home Affairs and project "D" to the Ministry of Planning. This confusion of responsibilities is thwarting WH policy development, and frustrates the creation of a national WH data bank, which should be easily accessible to all projects with current or planned interventions in the field. The creation of this data bank would not be costly, would facilitate coordination, and increase opportunities for new projects based on past experience.

Recommendation 28 At the national level, WH should be entrusted to a definite institution, responsible for the coordination of all programs, and the creation of a WH data bank.
SECTION B. CASE STUDIES

N.B. The case studies are resultant from field visits to the 7 countries by the authors during 1987-1989 under the SSWHS. Information given in the studies is based on the date of the visit, which is noted at the end of each case study.
BURKINA FASO

General background

Area: 27.4 million ha
Population: 7.9 million (est. 1990)
Population Growth Rate: 2.9%
Climate: about 60% semi-arid
Staple grain: sorghum and millet

The Central Plateau of Burkina Faso is characterized by high population density and high land pressure. In years with below average or erratic rainfall food shortages at family level are substantial. In those years many families migrate to regions in the West and Southwest, which have a more favorable climate, better soils and lower population densities. Spontaneous migration to these areas causes enormous environmental degradation.

Water harvesting


Soil and water conservation based on graded earth bunds, which was the major thrust of the SWC activities in Burkina Faso in the second half of the 1970s and the beginning of the 1980s, was not very successful. The earth bunds were not maintained by the farmers and often deliberately breached in years of erratic rainfall to allow runoff from outside to enter the treated fields. Contour stone bunding was introduced in the Yatenga region of Burkina Faso in the beginning of the 1980s and it quickly became a success story. After training, farmers applied the techniques on their own fields and used a combination of contour stone bunding and pitting to rehabilitate degraded land. Numerous projects on the Plateau Central now promote stone contour bunding.

In 1981/82 the first level permeable rock dam was built in the Kongoussi region to rehabilitate a gully. The gully quickly filled up with sediments creating fertile land. The level rock dam constituted a water spreading technique and the crop yields, which resulted, were well over 1 ton/ha. Since then, hundreds of rock dams have been built in different parts of the Plateau Central, and the projects have adapted the basic design to the conditions of the region in which they are working.

Contour stone bunding (water harvesting) and permeable rock dams (water spreading) have become very popular techniques in Burkina Faso. The major challenge now is to design techniques acceptable to farmers in areas without stones.
Case Study 1
Contour Stone Bunding
Yatenga, Burkina Faso

artist's impression

Detail of Stone Bund

Water Tube Level

slope (0-2)

up to 25 cm

35 - 40 cm

level of water

plastic tube

pole

5-10 cm

level of water

plastic tube

pole
Case study 1

CONTOUR STONE BUNDING
YATENGA PROVINCE

INTRODUCTION

The Agro-Forestry Project (PAF) developed and popularized contour stone bunding in the Yatenga Region in the beginning of the 1980s. Contour stone bunding is a simple technique and each year an increasing number of farmers are adopting it. Whereas about 150 hectares were bunded by farmers in 1982/83, the number of hectares treated in the dry season of 1987/88 had risen to an estimated 5000 hectares. Farmers trained in the use of a water tube level for surveying of contours, as well as in rules of thumb for the construction of contour stone bunds, engage voluntarily in the treatment of their fields. Other projects, in and outside the Yatenga region, have also started to promote contour stone bunding. All adds up to make this a water harvesting success story.

WATER HARVESTING SYSTEM

Techniques and engineering

The PAF project started in 1979 as a forestry project. Microcatchment techniques from the Negev desert in Israel served as a source of inspiration. But it quickly became clear that farmers were not interested in planting trees, because they felt that they could not protect them adequately. They were mainly interested in improving food production. For that reason the project decided to change its course. Different techniques were tested at farmer level and evaluated jointly by farmers and project staff. Farmers had a clear preference for stone bunds.

The farmers construct stone barriers on their fields. Whether they opt for a single line of stones or for a stone bund depends on the quantity of stones available on or close to their fields. The stone bunds are laid out on a contour. They are up to 25 cm high, and the base width is up to 35 - 40 cm. They are set in a trench of 5 -10 cm, which increases stability. The spacing between stone bunds varies in most cases from 15 - 30 m. The contour stone bunds do not concentrate runoff, but keep it spread. They reduce the speed of the runoff allowing infiltration.

Farmers use stone bunds on fields already under cultivation, and to expand the cultivated area also. To rehabilitate barren and crusted soils, which no longer regenerate spontaneously, they use a combination of stone bunds and planting pits. Farmers dig planting pits ("zay") between the bunds. The spacing of these "zay" is approximately 80 cm, which corresponds to the usual planting density. The "zay" are about 20 cm. wide and 20 cm. deep. Runoff is concentrated in these pits.

Contrary to the recommendation of conservation experts, farmers often start treating the fields at the lowest point and work upwards, rather than treating the lands from a high point in the catchment and work downwards. Stone bunds however are not easily destroyed by runoff and by starting low down the slope farmers can be certain to harvest sufficient runoff for producing a crop in a year of below average or irregular rainfall.
Production system

The main crop grown in the bunded fields is sorghum, but also planted are pearl millet and peanuts. During the dry season farmers put some organic material in the "zay", which attracts termites. The termites "fertilize" the soil and their holes increase the infiltration capacity of the soil.

Stone bunding is particularly attractive to farmers, because on fields already cultivated, it increases the yields directly in the first year by an estimated 40%. Where barren land is rehabilitated, yields can attain even 1200 kg/ha in the first season. It is commonly assumed that yields on treated fields will decrease after some time, because higher yields imply an increased extraction of nutrients, which is insufficiently compensated by farmers with manure or fertilizers. There are indications that this is not yet so on the bunded fields in the Yatenga (Relj, 1988), but it should be kept in mind that the quality of these data is debatable.

<table>
<thead>
<tr>
<th>Year of treatment</th>
<th>1984</th>
<th>1985</th>
<th>1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cereal yield/ha in 1987 (kg)</td>
<td>1112</td>
<td>883</td>
<td>777</td>
</tr>
</tbody>
</table>

The population of the Yatenga was originally not really interested in tree planting. This has changed slowly. A growing number of farmers in the region are becoming interested in planting trees on their fields and have requested the project for seedlings.

Since 1988 PAF has not only promoted the construction of bunds and the planting of trees, but has also emphasized the need for village land use management. One important element is improved grazing control. It has created village land use management committees in three villages. In one village (Longa) the population is now enclosing their livestock (Ouedraogo, 1989).

Implementation and extension

From the beginning considerable attention was paid by PAF to the development of an extension and training methodology.

The first step is to discuss the state of the environment with the villagers. The second step is the organization of a visit to farmers in other villages, who have already treated their fields. In December 1989, ten farmers from the Yatenga were even taken to Mali to visit traditional SWC techniques on the Plateau Dogon as well as to the region of Sofara where pitting systems are better developed than in the Yatenga. The third step is the organization of training courses at village level. Usually farmers from 3 - 5 villages participate in these training courses.

Farmers are trained to operate water tube levels and to lay out a contour on their fields. It takes only a few hours to train them how to handle a water tube level. At these sessions farmers are also stimulated to reflect about how to organize the treatment of their fields. During the 1987-88 season 1006 farmers were trained by PAF in the Yatenga region (788 men and 218 women) and another 205 outside the Yatenga. Since 1985 the project has also trained women, but the number of women still lags far behind the number of men. PAF
not only trains farmers, but also extension agents. All extension agents of the Yatenga region have been trained and they in turn now play a crucial role themselves in farmer training.

In all the villages where the project intervenes a management committee is created, which assists farmers in the organization of the conservation activities and which manages the limited material support provided by PAF (water tube levels, wheelbarrows, etc.) (Ouedraogo, 1989).

Monitoring, evaluation and reporting

PAF has produced annual progress reports since 1979/1980. From the beginning the project has measured yields on a number of treated and untreated plots. However, none of the reports provides a description of the physical characteristics of these plots and therefore the figures should be regarded with caution.

DISCUSSION

Techniques and engineering

Some farmers in the Yatenga as well as on other parts of the Central Plateau traditionally use stone lines on their fields, but the efficiency of these stone lines leaves much to be desired. Contour stone bunds are basically an improvement of existing traditional techniques. Stone bunds are easy to construct, furthermore diversion ditches and spillways are not needed and little land is lost to the bunds. The major limitation of course is the supply of loose stone.

A particularly attractive aspect of stone bunds is that land can be treated "piecemeal". Stone bunds can be constructed on individual plots without too much risk of destruction by runoff from the catchment. If a farmer concludes that the spacing between stone bunds is too large, he can easily put in an extra bund or replace an existing bund.

Silting up of stone bunds presents a potential problem. Though the silt is welcomed, the stone bund no longer slows the runoff. This has not yet happened in many cases, but since 1987 PAF has recommended farmers to associate the planting of a perennial grass (Andropogon gayanus), with bund construction. This grass will take over the function of the stone bunds when these silt up.

Production system

Fertility maintenance and improvement is important, otherwise the higher yields cannot be sustained. PAF seems fully aware of this issue and promotes the introduction of compost pits ("fosse fumière") as well as the enclosure of livestock, which facilitates the production and collection of better quality manure.

The "zay" system is an excellent method of further concentrating water and nutrients, but construction requires a considerable input of hand labor. Farmers who use "zay" to rehabilitate degraded soils, also use manure. Wright (1985) who surveyed 313 fields treated with stone bunds observed that chemical fertilizers were used on only 2% of these fields. Field observations show that stone bunding in combination with "zay" and a systematic use
of manure considerably improve the physical characteristics of the soil already after one or two years. Because of improved land husbandry and increased moisture availability a limited use of fertilizers seems now justified.

Implementation and extension

The project has an excellent all round approach – from training farmers in surveying the land and in the principles of bund construction, to the provision of some material support. Furthermore the project is now evolving from a WH project into a village land use management project.

In the Yatenga thousands of hectares have now been treated with stone bunds and in a growing number of villages stones are becoming increasingly scarce. The effort and costs to collect and transport stones increase correspondingly. A solution could be to use dynamite to create quarries in each village. This would be a much cheaper solution than introducing lorries for the transport of stone. Dynamite is already used in road construction and in some cases in well digging, so why not for the construction of stone bunds and rock dams.

BACKGROUND DATA

Project/authority

Projet Agro-Forestier,
B.P. 200,
Ouahigouya,
Burkina Faso.

Important references include:


Socio-economic factors

Standard data for the Yatenga and other parts of the Plateau Central indicate that
virtually all the fields are cultivated permanently, about 90% of the cultivated area is cropped with cereals (sorghum and pearl millet), the average area cultivated per person is about 0.5 ha, the average family has 8 to 10 persons, etc. Although such generalizations are helpful, they hide considerable regional and local variations.

The population density in the central part of the Yatenga varies from 70 to 100 persons/km², but is much lower in other parts. In the northern part of the Yatenga, the average population density is in the order of 20 persons/km².

Different population densities, variations in soil conditions, differences in access to valley bottoms, etc. cause considerable spatial variation in farming systems. Furthermore land is not equally distributed amongst the villagers.

Although the annual average national population growth is officially in the order of 2.9%, there are some indications that in at least some villages in the Yatenga the population is actually decreasing. In particular in years of bad rainfall, numerous villagers leave and settle permanently in the more fertile and better watered parts of the country.

Natural resources

Climate

The long-term average annual rainfall (1920 – 1970) for Ouahigouya, the capital of the Yatenga Province, is well over 700 mm., but the average for 1973 – 1983 is down to 562 mm. However, rainfall in 1984 and 1985 were well below these figures. On the basis of rainfall the Yatenga is now part of the Sahel zone and no longer of the North Sudanian zone with over 600 mm. rainfall.

Soils

The soils and the vegetation vary along with their position on the toposequence. Soils on the plateaus are lateritic and gravelly whereas clayey loams are found in the valley bottoms. Soils on the upper, middle and lower slopes are (usually) sandy loams or loamy sands. From the beginning of the 1970s drought conditions make agriculture on the upper parts of the slopes virtually impossible and agricultural activities "move down the slope". The valley bottoms, which used not to be so important for cultivation because they were waterlogged, suddenly became more important with decreasing rainfall. One interesting phenomenon that can now be observed in the Yatenga is that stone bunds are used to rehabilitate the middle slopes. Bunding allows agriculture to "move up the slope" again.

Vegetation

Karité (Butyropermum parkii), néré (Parkia biglobosa) and Acacia albida are amongst the most important tree species. The expansion of cultivated land, the growing pressure of livestock, the increased need for fuelwood and recurrent droughts have all led to a degradation of the vegetation cover. The plateaus are devoid of trees and the grass cover on the upper and middle slopes has in many cases disappeared or changed in composition (more annuals). Almost every village now has its extent of barren and crusted soils ("Zipelle" in Moré).
Related water harvesting systems

Many projects and organizations in the region promote contour stone bunding:

Government Agencies: CRPA/FEER

NGO's: Six S, Projet Agro-Ecologie, Association Française des Volontaires du Progrès

Research on stone bunds and related issues is carried out by ORSTOM (Serpantié and Lamachère, 1989) and by the Research and Development Project based at CRPA (Rodriguez, 1989).

Date visited: December 1987 and March 1989
INTRODUCTION

The permeable rock dam project under the "Association Française des Volontaires du Progrès" (AFVP) began in 1981/2. Between 1982 and 1987, 148 permeable rock dams were built in the region between Kongoussi and Tikare on the Central Plateau of Burkina Faso. Permeable rock dams are long low structures across valley floors, which have the simultaneous effect of controlling gully erosion while causing deposition of silt and spreading of runoff water for improved plant growth. This is a floodwater harvesting technique. Although these structures are labor intensive and require provision of mechanized transport for stone, they are particularly popular in this area. They have led to both considerable crop yield increases behind the dams and effective control of gullies.

WATER HARVESTING SYSTEMS

Techniques and engineering

Permeable rock dams are usually constructed across relatively wide and shallow valleys. Some dams may require central spillways where the watercourse is incised, but the majority consist of a long, low rock wall with a level crest along its full length. This then causes the runoff to spread, and if overflow occurs, the whole dam is overtopped evenly.

Permeable rock dams under AFVP are usually constructed as straight walls where the topography allows – in the lower valley for example. Where the sides of the valley slope more sharply the wingwalls/spreading bunds may arch away from the center, following the contour (see artist's impression). Each dam is usually between 50 and 300 meters in length. Ideally the spacing between permeable rock dams is such that the top of one dam is level with the foot of the dam above it. In practice however, spacing is generally wider than this. Contour stone bunds are sometimes constructed in association with permeable rock dams, especially where the dams are widely spaced. Where a gully extends downstream from a dam, its sides are protected with stone bunds, to prevent overflow from the dam causing the gully sides to "eat back" towards the dam.

The dam wall may be above one meter in height for a short length within the gully, but the main part of the wall is usually between 80 cm and 150 cm high. The dam wall is flatter on the downslope side (at least 2:1 horizontal:vertical) than on the upslope side, (1:2 horizontal:vertical) to give better stability when the structure overtops. During construction a shallow trench may be excavated for a foundation. Large stones are used for the outer layer of the wall, and smaller stones for in-fill. The dam wall is designed to be semi-permeable, allowing water to permeate slowly through the structure, while silt is retained.
Case Study 2
Permeable Rock Dams
Bam, Burkina Faso

Typical Cross Section, Spreading Bund
Production system

Not only do permeable rock dams improve the moisture available for crops, but they also have a significant impact on the depth and quality of soil, especially immediately behind the dam, due to deposition of fertile silt. Sorghum is commonly planted, but permeable rock dams are planted with other crops also, according to the soil type and the proximity to the moister areas behind the dam. For example, where soils are heavy, and inundation with runoff is frequent, rice may be planted. Sorghum is the most usual crop on medium textured soils and pearl (bulrush) millet and groundnuts are grown on lighter, sandier soils. A succession of crops may be found upslope of a single permeable rock dam, according to the different zones of soil types and moisture availability (Berton, 1989).

Yields from land treated with permeable rock dams and planted to sorghum in the Risslam region are given as 1.9 tons/hectare compared with 1.0 tons from equivalent land untreated (CIEH 1987). Yields are said to increase with the age of the structure.

Implementation and extension

The permeable rock dam project was formed in response to the requests of 13 villages in the Risslam region. The manner of implementation and management of the project was agreed with the villagers. Manual work, for collection of stones and construction of dams, is carried out voluntary by the villagers. The project lorry is used to transport stone and the agreement is that the villagers will meet 50% of the running costs of the lorry. Where cash is not available, a contribution of millet is accepted. The introduction of the 50% contribution has tended to encourage smaller structures and a preference for structures to be built on an individual basis.

Each village within the group has one official who is trained in, and responsible for, the technical aspects of site selection and construction. Two other officials are responsible for materials and finances respectively. Ultimately the objective is for the group of villagers, the "Risslam Group" to become an autonomous development organization.

Costs for a typical permeable rock dam which improves cultivation on 2 - 2.5 hectares total about 160,000 - 200,000 CFA (approx. US$ 500 - 650) for transport. Additionally the labor requirement is between 300 and 600 person-days (for 200 - 250 m3 of stone) (Dezilleau and Minoza: 1988).

Monitoring, evaluation and reporting

CIEH (Comité Inter Africain d'Etudes Hydrauliques) has worked in close collaboration with the project to study various aspects of permeable rock dams. This research has been carried out since 1986 and has covered the following:

- runoff from small catchments;
- the hydraulics of permeable rock dams;
- the effect of permeable rock dams on cultivation and yields;
- the socio-economic aspects of the programme.
The various reports produced (see "important publications"), together with AFVP's own reports give a broad and clear picture of the strengths of the programme and the areas which need improvements.

DISCUSSION

Techniques and engineering

Permeable rock dams permit water spreading while simultaneously controlling gullies. This has proved a much more effective and popular technique than simply controlling gullies with gabion drop structures – which in any case often fall by cutting around and collapsing.

Design can be tailored to particular situations. Where gully control is the priority, for example towards the top of a valley, a defined spillway can be incorporated. Lower down the valley, where water spreading is the priority, the dam can be level throughout its length. Where dams have collapsed or otherwise failed it has usually been due to poor siting or construction. Four points about design need to be highlighted. These are:

a. avoidance of gully heads as sites for dams;

b. design of an appropriately low side-slope on the down-stream side;

c. careful placement of stone, and using large stones as a "casing";

d. incorporation of a shallow foundation trench to prevent tunnelling beneath the dam wall.

Also important is the spacing between dams. If this is too wide, or the dam wall itself too high, there is a danger of piping by runoff in the center of the dam, thereby undermining the structure.

There are two principle technical limitations to the applicability of permeable rock dams:

a. the dependence on large quantities of stone (an average requirement is slightly over one cubic meter per meter length of bund);

b. the technique is only appropriate for particular sites – valleys, where there is a source of water to spread.

Production systems

To best exploit the growing conditions provided by permeable rock dams, a careful planting plan needs to be devised. As outlined previously, it is important to match the crop and the varieties with the conditions – and to grow a range of crops in a single field if necessary. Above all it is important to exploit the section of the field where accumulated silt is deepest, and moisture supply best. Here, rice may be suitable if water stands too long for other crops. If waterlogging is not a problem in this zone, a plot of cotton can be grown as an alternative to sorghum.
Implementation and extension

The implementation system of the programme is based on the agreements between the village groups and the project authorities. Because demand originates from the villagers themselves, and the technology is well appreciated, there is a platform for sustainable development. The contributions to the running costs of the lorry demonstrate a firm commitment by the villagers, and represent the first stage in the possible take-over of responsibility by the people themselves.

Monitoring, evaluation and reporting

Collaboration between the project and CIEH has proved an effective way of gathering and analyzing information about technical performance, which is too often lacking in other projects.

BACKGROUND DATA

Project/Authority

"Projet de Digues Filtrantes de Risslam" (The Permeable Rock Dam Project of Risslam)
Association Française des Volontaires du Progrès,
B.P. 947
Ouagadougou
Burkina Faso

The programme started at the end of the 1970s as "Projet Petits Barrages" but changed its emphasis from water supply dams to permeable rock dams in response to village priorities.

Important references include:

AFVP/FAC (1988) "Aménagement de Digues Filtrantes dans la Région de Risslam". (Annual Report for '87-'88), Kongoussi


Socio-economic factors

The Central Plateau of Burkina Faso is inhabited by the Mossi and the Peul peoples. The Mossi are peasant farmers with both crops and livestock, whereas the semi-nomadic Peuls are agropastoralists. In Bam province, where the permeable rock dams are being constructed, the
average population density of 45/km² exceeds the ecological carrying capacity of the land. As a result, a large percentage of the young male population migrates for the dry season, or even the whole year, to seek work.

Agriculture is subsistence oriented, with about 15% of the land cultivated on the Central Plateau, and of this up to 90% is cultivated with sorghum and millet, often undersown with cowpeas. Six hectares of land is a typical holding for a family consisting of 10 members. Most of the work is carried out by hand. Crop rotation is not usually carried out, and mineral fertilisers are not used.


Natural resources

Climate

Permeable rock dams are implemented on the Central Plateau of Burkina Faso which is situated in the Sahelo-Sudanian zone. The average annual rainfall in this zone ranges between 350 mm (to the north) and 600 mm (to the south). In common with much of the Sahel, there has been a significant drop in annual rainfall over the last 20 years. The rains occur from mid-June until mid-September, with maximum precipitation in August and September.

Mean minimum temperatures during the coolest season (December to February) are between 14 °C and 15 °C. Mean maximum temperatures during the hottest period (April and May) range between 39 °C and 41 °C. Potential evaporation for the region is about 2000 mm/year.

Soils

Most of the cultivated soils are more or less leached ferruginous tropical soils. These are generally sandy clays or loamy sands, becoming more clayey with increasing depth. Lack of fertility is characteristic of most soils on the plateau, and rapidly becomes a constraint to plant growth when the moisture requirement is satisfied. Soils on the valley floors are heavier, and tend to be relatively more fertile.

Vegetation

The natural vegetation can be classified as a degraded tree savanna. Dominant tree species are Butyrospermum parkii, Parkia biglobosa, Khaya senegalensis, Acacia albida and Adansonia digitata. The perennial grasses include Andropogan geyanus and Cymbopogon ssp. Towards the north of the zone, the vegetation becomes sparser. The Central Plateau of Burkina Faso has become degraded due to the combination of overstocking of livestock, a high human population and the droughts of the last two decades.

Related water harvesting systems

Permeable rock dams are also implemented on the Central Plateau by other organisations, which include:

FEER (Fonds de l’Eau et Equipement Rural).
Design is similar to AFVP, but most labour is supported by food-for-work.

**PEDI** (Programme et Exécution du Développement Intégré).
Design normally incorporates a spillway, and the structures are referred to as "chutes" (in French).

**PATECORE** (Projet Aménagement des Terroirs et Conservation des Resources dans le Plateau Central).
Recent project with design based on the AFVP model, but dams tend to be larger, wider and lower.

KENYA

General background

Area: 56.9 million ha  
Population: 20.4 million (1985)  
Population Growth Rate: 4.0%  
Climate: 85% arid/semi-arid  
Staple Grain: Maize

Kenya has the fastest rate of population growth in Africa. The overspill of population from the humid highlands is leading to increased settlement and agriculture in the marginal and dry areas. Despite the high levels of production obtained in small and large scale farming sectors of the more favoured zones, Kenya is not immune to food scarcity in years of drought.

Water harvesting

Place in Government: Soil Conservation Branch  
Agricultural Engineering Division  
Ministry of Agriculture

There are no extensive areas of traditional WH in Kenya. Some flood retreat agriculture is practised, but on a very small scale: for example in Turkana District. Where long traditions of semi-arid area cropping exist, there is often evidence of irrigation (by gravity flow) such as in Baringo and the Kerio Valley. Soil conservation technology for the wetter areas is well developed, and the infrastructure for implementation is institutionalised. The "fanya-juu" method of developed bench terraces is particularly well known, especially where self-help women's groups are active in eastern Kenya.

WH technology is comparatively little developed. However a number of projects in the semi-arid and arid areas have instigated WH programmes, some experimental, some implementational, in recent years. These projects have arisen as a result of the Government's new emphasis on developing the drier zones. The most notable of these projects are in the arid Turkana District of north-west Kenya, where considerable WH works have been carried out, principally on a food-for-work basis. The semi-arid zones of Baringo have also seen a number of trials. Nevertheless WH in Kenya has not yet become widespread or popularised.
Case study 3

 WATER HARVESTING SYSTEMS
 TURKANA DISTRICT

INTRODUCTION

Turkana District differs from most areas in SSA where WH is practised, being generally more arid and having a predominantly pastoral population. A distinctive feature of the WH programmes is their reliance on food-for-work in the construction phase. WH structures in Turkana are characteristically large and relatively expensive. Although various flood diversion schemes have been tried in Turkana District over the last 40 years, it was not until 1983 that water harvesting was introduced on a wide scale by the Turkana Rehabilitation Project (TRP). In 1984 “trapezoidal bunds” replaced contour bunds as the principle system for food crops, while microcatchment techniques have been used for a number of years for tree planting. It is estimated that just under 150 trapezoidal bunds had been constructed to the end of 1987.

Working within a limited area in the north of the District, the Turkana Water Harvesting Project (TWHP) seeks to demonstrate appropriate WH systems while simultaneously introducing animal draught. TWHP has developed a close relationship with the local population, and emphasises the importance of building on the traditional system of sorghum “gardens”. A range of WH techniques are utilised, according to site characteristics.

WATER HARVESTING SYSTEMS

Techniques and engineering

TRP

The current design for trapezoidal bunds was formulated in 1984, and was based on an original design proposed in 1982. Trapezoidal bunds were designed to replace a technically imprecise contour bunding programme which failed in its objectives, technically and otherwise. The trapezoidal-shaped structure (when viewed from above) consists of a bottom earth bund, straight, but approximately on the contour, with wingwalls extending upslope at an angle of 45 degrees. Dimensions vary according to land gradient, but for a typical slope of 0.5% the bottom bund is 60 cm high with a base width of 5.8 metres, and total earthwork is 260 cubic metres. The area impounded for cropping is 3,200 square metres.

The trapezoidal bund collects runoff from a long slope catchment external to the cultivated area, and impounds water to a maximum depth (for a 0.5% slope) of 20 cm before allowing excess to discharge around the wingtips. The area within the bund is not levelled. The size of catchment required is calculated according to a design formula relating crop water requirement to probable rainfall and an estimated runoff factor. Typical catchment : cultivated area ratios are calculated to be in the region of 20 : 1 for reliable sorghum and legume crops in the relatively more favourable areas of the district.
Case Study 3
Trapezoidal Bunds
Turkana, Kenya

artist's impression

Trapezoidal Bund for 0.5% slope
(from Min Ag 1986)

"V"-shaped microcatchments for trees
TWHP

Traditional sorghum gardens are modified by bunding and levelling in order to improve production by an even impounding of runoff. 500 - 1000 cubic metres of earth are moved in the construction of each garden. Techniques are tailored to the individual situation, and engineering details therefore can only be summarised generally. The basic technique uses a long slope, external catchment with varied catchment : cultivated area ratios.

A typical garden is between 0.5 and 0.8 ha in size and is treated by being surrounded on three sides by earthen bunds. Bunds are up to 100 cm in height and have a base width of approximately 5 metres. Within the plot, land is levelled. Excess water, over and above the design impounding depth of 25-30 cm, is allowed to overflow around stone protected spillways on the upslope tips of the side bunds. An original technique, now largely superseded because of problems associated with the spillways, was "level flooded terraces". These comprised a series of plots on different levels, each having a stone spillway of 8-9 metres width centrally sited in the bottom earth bund. Spillway height was about 35 cm.

Production systems

TRP

Trapezoidal bunds are intended for crop production. The major crop of the area is sorghum and the local sorghum variety, with its rapid maturity (60 days), is recommended for planting under WH. Planting after initial flooding is the usual practice, and a crop can even be taken, in some circumstances, after a single flood. Ratooning is not advised because of the possibility of pest and disease build-up. Various drought tolerant legumes are recommended, including cowpeas and green gram. No details of crop yields are available.

TWHP

Local sorghum varieties are produced under the WH systems, and planting basically follows the traditional pattern. It is reported that a "reasonable" harvest can be expected two years out of five and the best yield recorded is 1,300 kg/ha.

Implementation and extension

TRP

All work is carried out by hand and is linked to a food-for-work programme. On a typical land gradient of 0.5%, a trapezoidal bund requires 260 cubic metres of earthworks (rising to 380 cum on a 1% slope). The food ration per m3 of earthwork is 2.25 kg maize, 80 g beans and 40 g. oil with a market value of approximately US$ 0.85. One m3 of earthwork is assumed to be equivalent to one man-day of labour. The cost of earthworks is therefore approximately US$ 700 per cultivated hectare on a 0.5% slope, and US$ 1,000 on a 1% slope.

Although there are no exact figures for achievements in terms of numbers of units constructed, it is reported that 100 trapezoidal bunds were completed in 1984, but a total of less than 50 were built in the following three years. As yet, there is no evidence of voluntary construction of WH techniques. Some instances of small repairs carried out voluntarily have been reported, but these are the exception. There are no data available
about adoption of improved husbandry.

Both training and extension systems are well developed under the Turkana Rehabilitation Project. Training courses are held regularly for the field staff most of whom are locally recruited, and local “area co-ordinators” are well versed in the various techniques. Manuals have been prepared, periodically, for the use of field staff.

TWHP

Construction work is carried out by hand under food–for–work. A contract system has been introduced to facilitate the distribution process and to engender a sense of responsibility. No group is permitted a continuous contract, so that dependence on food–for–work is discouraged. The original cost per hectare of land treated, in terms of the cash value of the food allocation was US$ 750, but by 1987 the ration, and thus the cost, had been halved. In some instances, during 1988, when supplies of food–for–work became scarce, work was implemented successfully on greatly reduced rations. All repairs and maintenance are now carried out by the plot owners.

TWHP is testing draught animal systems as a means of reducing labour inputs. Oxen and donkey teams with scoops and ploughs are available for hire from the project, and while this programme is still at an initial stage, some use has been made of the teams for construction and repairs. Regular training courses have been organised for the local staff. These courses cover leadership skills, animal draught systems and monitoring as well as WH techniques. An extensionist works with each of the three project staff committees, and acts as the primary contact with the local people. To avoid male bias in extension, the project has appointed women staff, and the majority of group representatives selected for training are women.

Monitoring, evaluation and reporting

TRP

There is no systematic monitoring of construction and performance other than basic records of food distributed and volume of earthwork completed. Data on a number of basic parameters such as number of structures utilised, crop yields and bund breakages, have yet to be collected.

TWHP

While it has previously been acknowledged that little monitoring was carried out in the early stages of the project, it is reported that good progress is now being made in these areas.

DISCUSSION

Techniques and engineering

TRP

Trapezoidal bunds in Turkana are one of the few examples in SSA of a system for which
a catchment: cultivated area ratio has been calculated, based on agronomic and hydrological parameters. By avoiding a stone spillway within the bottom bund a potential weak spot in design is avoided. The dimensions of the bunds have been deliberately "overdesigned" (the main difference between this design and the 1982 model) capitalising on the plentiful labour, thus attempting to reduce maintenance.

Nevertheless there are a number of examples of bunds which have failed – probably due to poor siting or poor construction and breaches in such large bunds take a considerable amount of labour to repair. It may be expedient to reduce the catchment area in the light of the damaging flows which have occurred in several instances. The C:CA calculation used may be based on an underestimation of the problems associated with above average rainfall – and often imperfect construction.

TWHP

TWHP has demonstrated flexibility in its approach to technical design, exemplified by the movement away from overtopping spillways (which proved vulnerable to damage). Furthermore the "individually tailored" designs for existing gardens imply a site-sensitivity seldom found elsewhere. Another rather unique feature is land levelling.

Production systems

The reliance on local, quick maturing sorghum varieties under both projects is sensible in light of the unreliability of the rains – and this variety's ability to mature, in some circumstances, on a single flooding.

Implementation and extension

TRP

While labour intensive methods are the most suitable for Turkana, the reliance on food–for–work means that voluntary replication of techniques is unlikely in the foreseeable future, and even voluntary maintenance may not be readily achieved. However where food–for–work programmes are necessary, which has been the case in Turkana, WH programmes can be a valid use of this labour. But it is questionable whether the deliberate design of structures to be larger than strictly necessary is the best approach, especially when maintenance may not, in reality, be negligible. Although designed with social considerations in mind, it may be that trapezoidal bunds need modification in design and application before becoming socially acceptable on a wide scale.

TRP has a good infrastructure of field agents, needed originally to ensure effective food distribution. However the District is very large and the population scattered. Training sessions, arranged for the staff, have been held regularly and both principles and practices covered in detail. Despite this, technical supervision is still not up to an acceptable standard throughout. The scarcity of Ministry of Agriculture extension agents is reflected in the practical difficulty of following up construction with advice on agronomic techniques.

TWHP

Though construction work has been closely linked with food–for–work, the project has made considerable efforts to reduce the people's dependence on the food, and to encourage
a more responsible attitude through a contract system. While costs have been reduced recently to levels of around $150 - $375/hectare, this is still a considerable input for a system which may give a reasonable yield only two years out of five. Nevertheless, there are positive indications that by developing a close relationship with local groups, an awareness of the benefits of WH is being generated and a responsibility for maintenance as well as participation in construction is being engendered. The steps taken to address women's issues, as outlined, are a positive move. TWP has recognised the importance of training to build up the skills and capability of local staff. Extension is being tackled through specific personnel in each area of action, and attention is being given to the problem of a potential male bias.

Monitoring, evaluation and reporting

TRP admits monitoring to be a weakness at present; post-construction follow-up is weak. There is an urgent need to capture at least the basic data from the field. Until this is accomplished, there is no accurate basis for evaluating the programme. TWHP also acknowledges that data collection could be improved, and recently considerable progress has been made.

BACKGROUND DATA

Project/Authority

TURKANA REHABILITATION PROJECT
P.O. Lodwar, Kenya

The Turkana Rehabilitation Project, under the Ministry of Energy, funded by the EEC and other donors, was set up in 1980 in response to the severe food scarcity in Turkana. TRP was initially concerned almost exclusively with food distribution, and the establishment of camps where up to 80,000 people (40% of the population) were fed. In 1983 TRP became involved in water harvesting projects, on a food-for-work basis, and the majority of the food is now distributed for this purpose. The level of food has now diminished considerably due to favourable rains in recent years, but it is acknowledged that at least a small amount of food-for-work is likely to continue to be required for the foreseeable future. TRP is the main implementing agency in terms of WH within Turkana District, though technical advice comes from the Ministry of Agriculture and Forestry Department, or is acquired through consultants.

Important reports include:

"Turkana Water Harvesting Manual" (1985, NORAD)

TURKANA WATER HARVESTING PROJECT
P.O. Lokitaung, via Lodwar, Kenya

The Turkana Water Harvesting Project (TWHP) was initiated in late 1984 and follows on from an original Salvation Army project in the same area, which was assisted by Voluntary Service Overseas. TWHP, an OXFAM supported project, uses food-for-work supplies which are channelled through the Turkana Rehabilitation project. Its self-stated objectives are:
a. to develop appropriate rainwater harvesting systems;
b. to establish food-for work norms;
c. to investigate concomitant social and economic aspects;
d. to introduce animal draught systems.

Important reports include:

coverage in: "Rainwater Harvesting" ITDG Publications (Pacey and Culilis, 1985)

Socio-economic factors

The approximate population of Turkana District is 220,000 and the average population density only about 4 people per km². The great majority of the population are pastoralists, though a number supplement their income with activities such as opportunistic cropping and fishing. Traditional cropping consists of planting rapidly maturing sorghum varieties in natural depressions which are prone to temporary flooding. The Turkana are very vulnerable to the exigencies of climate, disease and food shortages as highlighted in 1980 when up to 80,000 people received food aid.

The major development initiatives in Turkana in the last few decades have been the construction of irrigation schemes on the main river in the district. These have not however been very successful, either economically or sociologically.

Natural resources

Climate

Most of Turkana District is classified as being within the L6 agro-ecological zone according to the FAO/Kenyan system. This is termed the "Lowland Ranching Zone" and typically has a r/Eo ratio of 15 – 25. Annual average rainfall for most of the District ranges between 200 mm and 450 mm, but it is very erratic. Design annual rainfalls used for water harvesting calculations, with a 33% probability of being equalled or exceeded, range mainly between 230 mm and 370 mm. Mean temperatures are high. Figures for Lodwar show a mean maximum of 36°C and a mean minimum of 22°C.

Soils

Most of the soils are loamy sands or sandy loams formed of colluvium or developed in situ from grits, gneisses and schists. The soils are young and unleached, and fertility is moderate to good. There are many minor areas of alluvium near the main rivers, and also considerable patches of land are covered by lava flows. The majority of the area is a sandy rocky plain with slopes below 1%. The land rises gently towards 1,000 m a.s.l. in the west, from a height of 370 m a.s.l. on the lakeshore.

Vegetation

Apart from strips of thickly wooded riverbanks, much of Turkana is only sparsely
covered with trees. Much of the dry interior plain has very little tree cover at all, though in better areas the canopy, formed mainly of Acacia spp., reaches a level of 20% cover. As well as a wide range of Acacias, common trees include Balanites spp., Salvadora persica, Ziziphus mauritiana, Dobera glabra, and, by the lake, Hyphaene thebaica.

Related water harvesting systems

The Turkana Rehabilitation Project also constructs microcatchments for trees, semi-circular bunds (see case study 4) and spate diversion schemes.

Microcatchments for trees

The standard design for tree microcatchments under TRP is a "V" shape, with arms extending upslope – tips on the contour – for 10 metres. The excavated pit, in the angle of the V is 2.5 m³ in capacity. Structures are offset, but there is no precise spacing between individual microcatchments, and thus no standard, defined, catchment area. In practice, the catchment area is up to 150 m² in the driest areas. However, in certain more favourable zones, an alternative design sometimes used is an enclosed grid with individual catchments of 5m x 5m and pits of 1.2 cubic metres capacity. Tree planting is intended to increase the amount of available browse. In the case of the standard design three tree seedlings are planted behind each pit, immediately after the beginning of the rains. Species recommended for the drier areas include Prosopis chilensis, Salvadora persica, Cordia sinensis, Acacia tortills, Balanites aegyptiaca, and B. Orbicularis.

The total cost of earthwork per hectare covered by microcatchments is U.S. $150 based on individual catchments of 150 m², equivalent to a cost of $0.65 per seedling. (Based on KSh. 12 = $US 1 ration of 6 kg maize per microcatchment, and 3 seedlings per hole). The total amount of earthwork involved in making microcatchments in 1987 was 120,000 cum. It is expensive to raise trees in such an environment, and neither establishment nor survival can be assured. Rather than digging microcatchments specifically for trees it may be a better strategy to plant trees on, or near, bunds prepared for crop production. The only widespread significant effect on the environment of tree planting would occur if one of the species becomes naturalised – as indeed seems possible in the case of Prosopis juliflora/chilensis.

Spate diversion

TRP has been engaged in a number of spate diversion (water spreading) schemes. These consist of earthen embankments which divert part of the flow of wadis into channels, leading the discharge to plains where bunds spread, and impound, the flow. Some of these schemes are for fodder, others for crops. While there is a considerable range, the schemes are generally very expensive (approx US$ 1,000/ha) to construct and bund breakages are a continuous problem. The different characteristics of each site make engineering design particularly problematic.

Date visited: April 1988.
Case study 4

SEMI-CIRCULAR HOOPS
FOR RANGE AND GRASSLAND DEVELOPMENT
VARIOUS DISTRICTS

INTRODUCTION

The three Kenyan projects cited have all tested semi-circular hoops as a water harvesting technique for improving regeneration of grass or fodder species in dry areas. In the arid Turkana District, hoops are intended for grass and fodder production, whereas in semi-arid Baringo, rangeland rehabilitation is the objective. Similar structures have been tested in Kitui District for re-establishing pasture on overgrazed land in marginal areas. The size of the structures and the costs differ considerably from District to District. Technical performance has been mixed, though each District has examples of dramatically improved vegetation within the hoops. Adoption of the techniques by local people however only seems likely, in the short term, in the relatively prosperous Kitui District.

WATER HARVESTING SYSTEMS

Techniques and engineering

Turkana District

The structures used in Turkana are relatively large and intended to be maintenance free. Each impounds an area of approximately 300 m². The "semi-circular hoops" are in fact semi-octagons, each with a total bund length of 46 metres. Bund size depends on land slope. For a 0.5% slope, the highest point of the bund is 27.5 cm and the base width at this point is 240 cm. 15 m³ of earth are excavated for such a structure. For a 2.0% slope, the highest point of the bund is 50 cm and the base width at this point is 420 cm. Tips are sited on the contour. Appropriate catchment: cultivated area ratios have been calculated to be between 6:1 and 12:1 for grass and fodder in the drier parts of the District. This ratio is achieved in the field by siting lines of hoops the requisite distance apart to achieve the full catchment between lines. For example to achieve a ratio of 10:1, lines of hoops are sited approximately 100 metres apart. A distance of five metres is left between tips of the hoops to allow for drainage of excess runoff.

Baringo District

The semi-circular hoops tested in Baringo are considerably smaller than those in Turkana, having a radius of six metres and a maximum bund height of only 15 cm. Soil is excavated from below the bund to allow a better spread of the impounded runoff within the structure. Hoops are sited on the contour, with 6 metres between hoops in the same line and about 6 metres between rows.

The structures are staggered in successive lines. Approximately 25% of the land is impounded by these hoops and thus the effective catchment: cultivated area ratio is approximately 3:1. The system is a within-field or microcatchment system. Any significant flow
Case Study 4
Semi-Circular Hoops
Turkana, Kenya

artist's impression

contour

Turkana Example

earth bund 20 cm
earth ridge

down-slope furrow

Baringo Example

contour

earth bund 20 cm

down-slope furrow

35 cm

a' 

300 cm
from an external source would be damaging and needs to be excluded by the use of a cut-off drain where necessary.

Kitul District

The structure tested in Kitul District are termed "pits" though they are similar to semi-circular hoops. Soil is excavated from a curved trench and thrown downslope to form a ridge. The ridge is banana shaped rather than a full semi-circle, and about 2.5 metres long. The trench varies from 15 cm to 30 cm in depth. There is no set spacing for these structures, but in practice they are sited very close to each other – a distance of about two or three metres apart on average. Once again, this is a microcatchment system.

Production system

Turkana District

Hoops are used for production of "pasture and browse". Grasses such as Cenchrus ciliaris and Echinocloa sp. have been tested with success. No data are available on production. In some cases the local people have planted the hoops with sorghum.

Baringo District

Grasses such as Cenchrus ciliaris, Eragrostis superba, Cymbopogon sp. and Heteropogon machrostachyus have been used for rangeland rehabilitation. In one trial on the Njemp's Flats near Lake Baringo, a dry biomass of 1,215 kg/ha was recorded from the treated land, compared with 17 kg/ha from land which was fenced but not otherwise treated. Results were reported to be spectacular.

Kitul District

In the relatively more favourable conditions of Kitul, Chloris guyana and Eragrostis superba have been planted for the re-establishment of pasture under the pitting system, and though no data are available for production, impressive growth has been observed.

Implementation and extension

Turkana District

As with other WH systems in Turkana, construction of semi-circular hoops is tied to food-for-work, and payment is made on a volumetric basis. The volume of earthwork is 15 cubic metres for structures on a 0.5% slope and 35 cubic metres on a 2% slope. The value of the food ration is approximately US $ 0.85 per cubic per metre of earthwork. Construction of hoops began in 1985 and though there are no precise records of numbers of structures completed, project authorities estimate a total of over 2,500 hoops have been established to the end of 1987. Training sessions have been held for staff on construction aspects of hoops, and technical handbooks prepared.

Baringo District

Semi-circular hoops are made by hand, with the local hoe, and one hectare can be treated (with 40 – 50 hoops) in ten man days. Implementation has almost exclusively been on
a trial basis, under the project, using paid casual labour. Approximately 10 hectares have been treated in total. There has been negligible adoption of the practice by local agropastoralists. Field days have been organised for local farmers in Baringo.

**Kitul District**

No precise date are available yet about work rates or area covered. However, it is reported that over 100 sites have been treated by pitting, the majority on a self-help basis by groups, with provision of free tools as an incentive. In Kitul the extension effect of involving self-help groups in over 100 sites has been considerable.

**Monitoring, evaluation and reporting**

Few detailed data covering implementation or production are available from any of the projects, although there are some useful production related details from Baringo.

**DISCUSSION**

**Techniques and engineering**

**Turkana District**

The size of the hoops used in Turkana is very considerable, but despite this, the hoops are not always to cope with large volumes of runoff. This may be an argument for a reduction in the catchment size – essentially changing the system into a microcatchment design with little or no overflow expected. In at least one site, this modification has been implemented successfully in response to breakages.

**Baringo District**

In contrast to Turkana, the structures used in Baringo are minimal in dimensions, and though working well on very even land, they are vulnerable to breakage wherever any runoff concentrates in rills, however small. This system does not have the capacity to overflow safely and thus the ratio between catchment and cultivated area needs to be kept low.

**Kitul District**

The pits in Kitul are designed for uneven, eroded terrain – often on hillsides – and their strength is that excavation storage forms a large proportion of the storage for runoff and thus some water harvesting effect is retained even if damage occurs to the ridge. To ensure consistency and improve efficiency it would be appropriate to develop a standard technical design based on projected rainfall and runoff.

**Production systems**

It is questionable whether in the Turkana situation, pasture and fodder will be the people’s priority under such water harvesting systems. Given the level of input involved, food crops may be a better alternative, especially if sorghum is grown – with its potential to produce significant amounts of fodder from stover. Choice of grass species is appropriate in Baringo and Kitul, though grazing may lead to some damage to the structures in Baringo;
and possibly to animals in Kitul, in places where trenches are as deep as 30 cm.

Implementation and extension

The size and expense of the hoops in Turkana are very much a function of the ample availability of food-for-work rations and the lack therefore of a labour constraints. Voluntary replication is not an objective; these structures are justified by the project as an appropriate investment in the circumstances. This case does not apply in Baringo and Kitul, where structures and systems have been designed with replicability as a priority. Though the Baringo treatment is particularly cheap and also effective, the poor response in terms of adoption reflects a lack of popular interest in rehabilitation of communal grazing land. More hopeful is the situation in Kitul where the system is being introduced into an atmosphere of vibrant soil conservation activities, active groups and perceived land pressure.

Although training and extension efforts could be expanded and improved in Turkana and Baringo, these may not lead to significant improvements in adoption rates, as they are probably not the limiting factors. When technical recommendations are clarified for Kitul, training and extension can be readily absorbed by the well established “Training and Visit” system in the District.

Monitoring, evaluation and reporting

In Baringo, records of input and production parameters have been kept, for at least sample situations, and this is of real value and needs to be kept up. Both in Turkana and Kitul, systematic monitoring systems should be developed so that basic information, at least, is captured.

BACKGROUND DATA

Projects/Authorities

Turkana Rehabilitation Project
P.O. Lodwar

Kitul Arid Semi-Arid Lands Development Project
P.O. Box 642
Kitul

Baringo Pilot Semi-Arid Area Project
P.O. Marigat
via Nakuru

The three projects are District based, supported by external donors and implemented by the Government of Kenya with some technical assistance. The Turkana Rehabilitation Project is funded by the EEC and was established in 1980 in response to the severe deprivations that year. The Baringo Pilot Semi-Arid Area Project is supported by an IDA credit from the World Bank, and began field operations also in 1980. The Kitul Arid and Semi-Arid
Land Development Project is supported by USAID and began field work in 1981. Although water harvesting is a major part of TRP's work, it forms only a small portion of the programme of BSAAP and Kitul ASAL.

**Important reports include:**

**Turkana:** Turkana Water Harvesting Manual (1985, NORAD)

**Baringo:** BSAAP Interim Report (1984, Ministry of Agriculture)


**Socio-economic factors**

The vast majority of the Turkana people are pastoralists, though a proportion carry out opportunistic cropping of sorghum. Drought and animal disease within the last decade have led to as many as 40% of the population being destitute at times and in need of food aid – though the last few years have seen a marked improvement in rainfall.

In the lowlands of Lake Baringo, the population are generally agropastoralists. Population pressure is relatively high and overgrazing a serious and increasing problem. Grazing land is common and only land which is used for crops is respected as "belonging" to an individual.

Kitul has a very much higher population density than the other two districts and in the area under review, all families grow crops and the majority own at least some livestock. While land adjunction has covered much of the area, any uncropped land is used communally for grazing.

**Natural resources**

**Climate**

Most of the relevant parts of Turkana and Baringo Districts are classified as being within the IL 6 ecological zone (FAO/Kenyan system) with an r/Eo ratio of 15–25. However, the annual average rainfall in Turkana ranges mainly between 200 mm and 450 mm, whereas in the lowlands of Baringo the average is around 650 mm. Kitul is wetter and the area where much of the pitting activities take place is in the LM 4 zone, where the r/Eo ratio is 40–50 and average annual rainfall is in excess of 800 mm.

**Soils**

In Turkana, most of the soils are loamy sands or sandy loams formed of colluvium or developed in situ from grits, gneissses and schists. The area where hoops are constructed in Baringo is a colluvial plain, with a high silt content and which disperses on wetting giving rise to considerable runoff. Fertility is high. Slopes in the relevant areas of both these
districts are low. In Kitul the major part of the central area is a non-dissected sedimentary plain with soils of low fertility. The pitting exercise is largely confined to areas of compacted, eroded overgrazed land on hillsides.

Vegetation

Much of Turkana has very little tree cover at all, though in better areas, the canopy, formed mainly of Acacia ssp. reaches a level of 20% cover. On the colluvial flats in Baringo, ground cover is extremely poor with the exception of a flush of largely unpalatable herbs at the beginning of the rains. In the cultivated highlands of Kitul few trees are seen and the eroded grazing land between farms is denuded apart from stunted bushes.

Dates of visits:
Turkana: April 1988
Case study 5

CONTOUR RIDGES FOR TREE PLANTING
BARINGO DISTRICT

INTRODUCTION

Two projects, the Baringo Fuel and Fodder Project and the Fuelwood Afforestation Extension Project are using a basically similar technique for tree planting in the basin of Lake Baringo, Kenya. Contour bunds are formed by motor grader or tractor and trees planted within the upslope furrows. This system is quick to implement and technically effective. The long term objective of both projects is to involve villagers in the planting and management of trees for fuelwood and other benefits, while simultaneously rehabilitating degraded land. BFFP especially stresses large scale expansion and eventual management by local groups. At time of reporting (1987) most activities are confined to plots directly controlled by the projects and notwithstanding initial technical success, the critical test will be the ability of the projects to devolve management effectively to local people.

WATER HARVESTING SYSTEMS

Techniques and engineering

Both projects refer to their techniques as "microcatchments". The basic techniques are similar: earth bunds are constructed on (or approximately on) the contour, with the furrow upslope, to collect runoff from the catchment between bunds. Trees are planted in the furrows.

**Baringo Fuel and Fodder Project:**

Bunds are constructed by a standard road maintenance motor-grader to a height of approximately 20 cm and spaced normally at a 10 metres horizontal interval. A relatively wide furrow is created upslope, reportedly to avoid the potential danger of waterlogging and to minimise damage to bunds in the case of heavy runoff. Ties are sited in the furrows at a distance of 10 metres apart to prevent lateral flow. This system is a one-time operation which reportedly does not require maintenance.

**Fuelwood Afforestation Extension:**

A disc plough with one of the three discs removed, pulled by a wheeled tractor, is used to construct bunds. As the plough is not reversible, the tractor must make an "empty" return trip for each effective one, as the system demands the soil is thrown downslope. The original spacing between bunds of 10 metres apart has been reduced to 5 metres. Bunds are constructed to about 20 cm in height and the furrow is narrower than that of BFFP.
Case Study 5
Contour Bunds for Tree Planting
(Baringo Fuel and Fodder Project)
Baringo, Kenya

artist's impression

Baringo Fuel and Fodder Project

Fuelwood Afforestation Extension
Production system

Baringo Fuel and Fodder Project:

Trees are planted one to two metres apart, in holes dug in the furrows, giving effective individual microcatchment sizes per seedling of 10-20 m², though this can be later adjusted by thinning where felt necessary. The most successful tree species grown are said to be Prosopis chilensis, Acacia tortils and Combretum aculeatum though a wide range of species, both indigenous and exotic, have been tested. An important component of the afforested blocks is grass - species such as Cenchrus ciliaris are planted amongst the trees for fodder and thatching. The plots were opened for utilisation of the grass for the first time in 1984.

Fuelwood Afforestation Extension:

Trees are planted at two or three metres apart in the furrows, making the effective microcatchment size 10-15 m² per tree; formerly it was double this size. Species preferred by the project include Cordia sinensis, Prosopis ssp., Balanites aegyptiaca and Acacia tortills.

Implementation and extension

Baringo Fuel and Fodder Project

Construction of bunds by motor grader is considered a quick and efficient method in these soils, which are easy to work when dry. Cross-ties are made by hand. Solar powered electric fencing surrounds each afforested block or "field" (of sizes normally between 10 to 50 hectares). Watchmen are employed to guard the fields, maintain the fences and keep records. Land preparation costs are given at a minimum of $100 per hectare (1986 figures). By the end of 1987 just over 130 hectares had been planted, using the microcatchment system on the Njemps Flats. Although the project authorities control the establishment and management of the blocks, they keep close contact with local groups. This takes the form of discussions both prior to and during the land development phase. The ultimate objective is to hand over management of the blocks entirely to these groups. This is not an extension project as such, but its stated aims include "creating an awareness" amongst the local people. Adoption of techniques is not an objective at present, though people are encouraged to plant trees in their homesteads.

Fuelwood Afforestation Extension:

The project uses its own machinery to construct bunds. Plots are protected by wire fences and watchmen. By title an extension project, most work to date in the Njemps Flats area has been on the project's own demonstration/trial plots. Approximately 150 hectares have been planted using WH methods. However, a package for tree planting on 0.1 to 0.2 ha. plots around homesteads by local farmers is proposed for 1988. Construction of microcatchments would be done either by tractor or by hand with possible use of food incentives. Trees are to be planted in an agroforestry system.
Monitoring, evaluation and reporting

Baringo Fuel and Fodder project:

This project produces periodic progress reports with details of physical accomplishments. Few data on tree growth, other than survival, or on grass production were available at the time of the visit, though project authorities say that a wide range of records are being maintained.

Fuelwood Afforestation Extension

Detailed monitoring of establishment, growth rate and other parameters is beyond the capacity of the project at the moment, though its importance is acknowledged.

DISCUSSION

Techniques and engineering

These two afforestation projects in the same area, have developed basically similar WH techniques: that of closely spaced mechanised contour bunds with upslope furrows. This is a microcatchment technique which is very well suited to large scale afforestation on relatively even land; and as such is a more efficient method than "V" shaped microcatchments in this situation. Although design of catchment size has been developed more largely by estimation than fine calculation, results in the field indicate that the sizes chosen are within the correct range.

Production system

Visual evidence suggests that the two projects have developed effective skills of raising seedlings through to establishment. Choice of tree species has been thoroughly considered by both projects and a wide range tested. The Prosopis spp. which are the most conspicuously successful tree will almost certainly become naturalised in the area, with mixed (though on balance positive) benefits, judging from experience elsewhere in SSA. It is of interest that both projects have sought to increase short term productivity and the appeal of tree planting by either incorporating grass into the system or proposing that trees be mixed with crops.

Implementation and extension

Neither project has yet evolved out of the project-controlled planting/management phase, and the expansion of tree planting activities outside direct project involvement will be a test of long term viability. Both projects rely on mechanized WH techniques, and this implies a commitment to relatively large scale enterprises, and means that post project expansion may be jeopardised. When significant harvesting of fuelwood becomes possible, benefits may theoretically be conferred on the women of the area whose role it is to collect domestic fuelwood – though experience from other countries has demonstrated otherwise. However it may require the introduction of a cash earning enterprise such as charcoal making for the large scale planting of trees to become attractive to local communities and this may then become male dominated.
Monitoring, evaluation and reporting

Monitoring systems designed particularly to record and report, production data could be useful improvements to both projects, although it is acknowledged that BFFP is now recording a range of parameters. Such information is vital for evaluating the extent to which tree planting is likely to have an impact on the local fuelwood situation, as well as such technical aspects as the effectiveness of different microcatchment sizes and the comparison of species.

BACKGROUND DATA

Projects

Baringo Fuel and Fodder Project
P.O. Box 1051
Nakuru

Fuelwood Afforestation Extension
FAO, P.O. Box 30470
Nairobi

The Baringo Fuel and Fodder Project, based at Kampl ya Samaki, Lake Baringo, began tree planting in 1982. It is funded by the Netherlands Government and falls under the Kenya Government’s Ministry of Energy.

Important reports for BFFP include various progress reports and a sociological tract: “Socio–Economic Changes in the Kampl ya Samaki Area, Baringo” (E. Meyerhof, 1988).

The Fuelwood Afforestation Extension (Project) is based at Marigat. It is an FAO project, funded by the Australian Government and implemented through the Forestry Department of the ministry of Environment and Natural Resources. The project began in 1983.

Socio–economic factors

The inhabitants of the area are generally agropastoralists though there are some families who have no livestock and others who do not crop. Estimates of average stock holdings vary widely from 5.6 SSU/family to over 20 SSU, though there is a very uneven distribution of stock between families. Smallstock predominate. Some irrigated agriculture is carried out, though the majority of fields are rainfed. Population density is 20 – 30 people/km² and the population growth rate is between 1.2 and 1.5% per annum. Land is held in trust for the people by the government and is used communally for grazing, though unofficial individual rights to land for cultivation are acknowledged. Much of the agricultural work is carried out by women and the provision of firewood is a female responsibility.

Natural resources (extracted from Baringo Pilot Semi–Arid Area Project – Interim Report, Min. Agric. 1984).

Climate

The mean annual rainfall at Marigat (broadly representative of the area) is 655 mm with a range of 376 – 1086 mm and a coefficient of variance of 28% (based on records from 1958 – 1980). Rainfall is seasonal and occurs principally from April until August, though rain can fall at any time of the year. Mid–season droughts are often severe. Rainfall intensities of up to 100 mm/hour for 5–10 minutes have been informally noted, though the recorded
maximum value is 77 mm/hour. A recording rainguage sited at Radat, some 20 km distance from Marigat demonstrated that intensities of 20 - 40 mm accounted for 18% of total rainfall.

Class "A" pan evaporation readings (uncorrected) average 2576 mm/annum. The calculated value for open water evaporation after Penman by Woodhead is 2274 mm. Under the FAO Agro-Ecological Zone system used in Kenya, the Lake Basin area is partially in zones IL6 and LM5 representing rainfall: open water evaporation ratios of 15 - 25 (arid) and 25 - 40 (semi-arid) respectively. The temperature varies little throughout the year; mean monthly maxima range between 31 and 34 °C. Wind speeds increase in strength during the dry season to a mean daily figure of 1.46 m/sec in March at which time considerable dust storms occur.

Soils

The two projects are active (though not exclusively so) on the "Njemps Flats" area around the shores of Lake Baringo. The soils are generally Eutric Fluvisols which are deep and fertile. Irrigated maize yields of up to 5 tonnes per hectare, without fertiliser, have been recorded in this area. There is, however, a serious and renowned problem of sheet and gully erosion. Textures are usually silty loam or silty clay loam and soil structure is poorly developed. The pH range is 7.5 - 8.0. A relatively high exchangeable sodium percentage leads to dispersal on wetting and as the surface layer is also easily compacted during rain, the cap which results leads to high rates of runoff despite the low slopes. Runoff from small experimental plots (2m x 2m) in the area on a 0.5% slope have given the following results:

<table>
<thead>
<tr>
<th>Rainfall (mm)</th>
<th>Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>trace</td>
</tr>
<tr>
<td>20</td>
<td>45 %</td>
</tr>
<tr>
<td>30</td>
<td>53 %</td>
</tr>
<tr>
<td>40</td>
<td>60 %</td>
</tr>
<tr>
<td>60</td>
<td>68 %</td>
</tr>
</tbody>
</table>

Vegetation

Ground cover on the Njemps Flats is extremely poor with the exception of a flush of largely unpalatable herbs at the beginning of the rains. *Acacia tortilis* is the dominant tree with *Balanites aegyptiaca*, *Acacia seyal* and *Salvadora persica* also common. There is very poor natural regeneration of trees. Fuelwood use is estimated at 0.18 cum/person/year in the Njemps Flats area, indicating a shortage of supply.

Date of visit: September 1987
Case study 6

CONTOUR RIDGES FOR CROP PRODUCTION
BARINGO DISTRICT

INTRODUCTION

The Baringo Pilot Semi-Arid Area Project has been testing systems of water harvesting potentially suitable for small scale farmers since 1981. Contour ridges, made by hand, have proved the most appropriate and have become the interim recommendation for extension. Contour ridges gave considerable yield advantages over control plots at little extra labour cost. Trials and demonstrations have continued. However by 1986 the technique had been adopted by only 75 farmers, i.e. 15% of the target population.

WATER HARVESTING SYSTEM

Techniques and engineering

Contour ridges are small earthen ridges, 15 - 20 cm high, with an upslope furrow which accommodates runoff from an uncultivated catchment strip between ridges. Ridges are sited on the contour and spaced at approximately 1.5 metres apart. Small earthen ties are made within the furrow at 4-5 metre spacing, to prevent lateral flow. The objective of the system is to concentrate local runoff and store it in the soil profile in the vicinity of the plant roots. As this is a microcatchment or within-field catchment system, runoff from an external source is not required and may be damaging as no provision is made for overflow within the system. A cutoff drain is therefore provided where necessary. Contour ridges may be used on a range of slopes, though dimensions need to be increased as the gradient increases, but are principally recommended on the plains around Lake Baringo where slopes average 0.5%.

The design of contour ridges has been arrived at empirically. The height of the ridge is designed to prevent overtopping while minimising labour input, and the size of the interridge catchment is a compromise between runoff volume and farmer acceptability. The resultant effective catchment: cultivated area ratio is 2:1.

Production system

Contour ridges are designed for small scale production of food crops. A cereal intercropped with a pulse is the recommended system. The cereal of choice is sorghum, while cowpeas are the most appropriate legume for the area. However many of the local agropastoralists prefer to attempt to grow the less well adapted crops of maize and beans (Phaseolus vulgaris). The planting configuration differs from standard practice. The cereal is planted on the upslope side of the ridge and the legume immediately in front of the furrow. The advantage of this system is that each plant receives an equal amount of moisture from the uncultivated catchment between rows.

Compared with a conventional recommended spacing of cereal lines at 90 cm apart, bisected by a line of legumes, the advised system under contour ridges gives a considerably wider spacing. Overall population densities are approximately two thirds of the normal
Case Study 6
Contour Ridges for Crop Production
Baringo, Kenya

artist's impression

cut-off drain

lope .5%

1.5m

ties

15-20 cm

ridge furrow 1.5m

cultivated area

catchment

a

a'
recommendation. This may be beneficial in itself in a dry year. Records of yields are available, at least for the early years of trials, though these are detailed only for the project’s own trial plots. For years when complete records are available, yields from the contour ridge system have been approximately 300% of those from a hand dug control plot which received no runoff from outside. Yield advantages to water harvesting are said to have been consistent and visible.

Implementation and extension

The project has tested and demonstrated systems of water harvesting with the objective of encouraging adoption by local farmers. The trial role, however, is being handed over to the nearby Perkerra Agricultural Research Station. Apart from a brief period early in the life of the project, when a small amount of food–for–work was used as an incentive, it has been the policy to give no material assistance, other than seeds and pesticides, to farmers as an incentive to adopt the system. Implementation, other than on the project’s trial/demonstration plots, has been the voluntary responsibility of the farmer.

The labour used in construction of a contour ridge system was calculated to be approximately 32 man–days per hectare, with an extra 60 man–days to construct a cutoff drain where this was required. This compares with a figure of 50 man–days to dig a field in the conventional fashion (without a cut–off drain). Man–days refer to a four hour working day.

75 farmers out of 500 (15%) had adopted some form of WH by the end of 1986, and the majority was using contour ridges, though not always according to design specifications. It was reported that there had been an increase in uptake during 1987, though at the time of visit, the results of the survey were not available.

Field staff receive regular training in the technical aspects of water harvesting, as well as written guidelines on construction. This is required in order to supplement inadequate training in semi–arid systems, generally, received in most institutes.

The extension system utilised in this part of Baringo has been based on "off–farm" demonstration plots, strategically placed for visibility. Most of these plots have a dual trial/demonstration role. On–farm demonstrations have become increasingly important for the demonstration of water harvesting and other techniques. Field days are held in these and the off–farm demonstrations at strategic times of the year. The Ministry of Agriculture field staff are posted to villages and required to formulate their own work plans.

Monitoring, evaluation and reporting

As the project has established and maintained control over demonstration/trial plots, it has been able to monitor various input and production parameters, though in recent years has found it increasingly difficult to do so. Examples of the data are those quoted above. Monitoring of on–farm data has been less detailed, though a survey of adoption was initiated in 1986. Monitoring of baseline data, such as rainfall intensity, runoff and erosion (from runoff plots) and infiltration have all been carried out, as well as some basic sociological studies in the form of questionnaires. A full report of WH activities was included in the project's Interim Report of January 1984 and project progress reports are prepared quarterly.
DISCUSSION

Techniques and engineering

Technically speaking the contour ridge system is an economical and effective system of WH in the Njemps Flats area of Baringo District. It is able to make use of the efficient runoff characteristics of a short slope catchment and because no external catchment is utilised, there is little danger of damage to the ridges. The system is best suited to an area where hand cultivation is the norm and soil is easily worked – both of which apply in this case.

Production system

While the yield advantages to contour ridges compared with the control plots in the trials are impressive, two points need to be considered in relation to this. First the crops recommended and most frequently grown in the trials, sorghum and cowpeas, while being agronomically suitable, are rarely the choice of the local people. Secondly, the control plots, as acknowledged by the project, are not entirely representative of the fields that are locally cultivated. A number of these farmers’ fields are sited so as to benefit from runoff from outside. Nevertheless the contour ridge system in combination with appropriate crops, has demonstrated the possibility of reducing the risk of crop failure due to drought by the concentration of local runoff.

Implementation and extension

Implementation in this context refers to the project’s own trials/demonstrations, which for the most part are well managed, but more particularly to the on-farm trials and the farmers who have adopted the system themselves. It is noticeable that a number of farmers in the latter categories have not followed the technical specifications as closely as could be wished. The most common deviations from the standard design are to site ridges more closely together and sometimes, even, to plant the catchment area.

This is a low cost system. In contrast to most WH systems, the formation of contour ridges is simultaneously land preparation and no further digging needs to be done. Costs can be even less than those incurred in normal cultivation, though where a cut-off drain is required this will increase the cost significantly. The adoption rate is not, however, impressive – despite the apparent replicability of the technology. While project staff claim that even such low figures demonstrate a success in this very difficult area, there may be several factors which have slowed the process. These include the lack of attractiveness of a hand-dug system with modest dimensions, the rather novel planting pattern and the fact that this system is not applicable, technically, in all situations.

The project has had to develop its own training system for staff, the majority of whom have had no prior experience of water harvesting and little experience of, or training in, the relevant aspects of semi-arid agriculture. The institutionalisation of WH in college syllabi would give much more credibility to the concept and the lead to a stronger motivation and a more effective extension system. The approach adopted by the project with respect to WH, that is simultaneous trials and extension based on interim packages, may also have made the extension effort more difficult.
Monitoring, evaluation and reporting

This is one of the few examples of where objective data are available on a range of parameters in a WH project. Useful information is available about yields, runoff, rainfall and adoption. There is a need however for a closer analysis of what is happening on farmers' fields with relation to WH and its adoption.

BACKGROUND DATA

Project/Authority

Baringo Pilot Semi-Arid Area Project
P.O. Marigat
Via Nakuru

BPSAAP is one of Kenya's semi-arid area integrated rural development projects. The project is supported by a IDA credit and is implemented by GOK. The project began field work in 1980 and has as its objective the development of a field tested basis for the development of semi-arid Baringo. Water harvesting is one of several project initiatives.

Important reports include:

BSAAP Interim Report (Ministry of Agriculture, 1984)


Socio-economic factors/natural resources

see: Case study 5

Related WH systems

BPSAAP has also tested an "external catchment" system for small scale crop production, but this has proved less satisfactory than contour ridges because of bund breakages and uneven plant growth.

Hand dug contour ridges have been tested in Kitul District, but with less success, due to poorer soil fertility and less severe dry spells during the growing season. The contour ridge system can be mechanised and has been used in this way by other projects in Baringo for tree planting (see case study 5).

Date of visit: September 1987
Mali

General background

Area: 1.24 million km²
Population: 9.36 million (est. 1990)
Population Growth Rate: 2.8%
Climate: 62% arid or semi-arid
Staple grain: sorghum, millet and fonio

The average population density is 7.6 persons/km². This figure inadequately reflects the pressure on agricultural land as large parts of the country are inhospitable. According to one source the average rural population density per km² of arable land was about 350 in 1976 (Jeune Afrique, Atlas du Mali: 29).

Water harvesting

Place in Government: The place of WH in the national administration is not yet well defined.

Although Mali is one of the three countries in West Africa covered by the Sub-Saharan Water Harvesting Study, no WH case-studies have been included in this report. The major reason is that all WH activities in Mali have been initiated recently, and no major WH projects exist at present. The major “Projet Lutte Anti-Erosive” of the CMDT based in Koutiala is an erosion control project and not a WH project.

A spate of new small projects with WH components have recently been initiated or will soon be initiated. The techniques used include:

- permeable rock dams for gully rehabilitation and water spreading in the Douentza region, around Bla (Koutiala region) and in Diéma (Kayes region);
- stone contour bunds in Tominlan (region of San) and on the Plateau Dogon;
- “demi-lunes” (half moons) in Barouéli (Segou region) on the Plateau Dogon and in the Mopti region;
- pitting systems in Koro region.

Traditional SWC techniques are widely applied on the Plateau Dogon as well as in other regions. They have not been studied systematically and their present status is not known. Traditional water harvesting techniques (pitting systems) can be found in the region of Djenné – Sofara (about 400 mm. rainfall) where they are successfully used to cultivate loamy and gravelly soils. Again, no systematic study has been made of these techniques.
NIGER

**General background**

**Area:** 12,870 million Ha  
**Population:** 7.1 million (est. 1990)  
**Population Growth Rate:** 3.3%  
**Climate:** 100% arid/semi-arid  
**Staple grain:** millet and sorghum

The average population density in Niger is 5 persons/km², but the population distribution is very uneven. Most people live in the valley of the Niger river and along the southern fringe of the country, which receives the highest rainfall.

**Water harvesting**

**Place in Government:** Direction de l'Aménagement et de l'Equipement Rural  
Ministère de l'Agriculture

Since the beginning of the 1960s, almost all projects in the field of SWC/WH have been concentrated in the Tahoua Department and notably in the Ader Doutchi Maggia, a region with plateaus dissected by fertile valleys. Traditional SWC techniques (stone lines, stone bunds and stone terraces) are a relatively prominent feature in this region, but they have never been used as a starting point for new programs. Our knowledge of these techniques is still very limited.

The first "demi-lunes" (half moons), microcatchments for crops were introduced in the valley of Ourihamiza in 1974, but only after 1985 have they been constructed on a slightly larger scale.

A variety of WH have been introduced in the Keita region since 1984/85. They are: trenches used for tree planting; bunds with wingwalls and a catchment cultivated area ratio of 2:1 and bunds with spillways allowing the absorption of runoff from external catchments. All these techniques are used to reclaim land. All work is done on a food-for-work basis.

WH techniques have recently also been introduced in other regions, notably in the Tanout region (Zinder department). In this region a project has tested tied furrows and curved mini trenches using tractor drawn equipment. The technical performance, the yields obtained and the low cost per hectare have drawn the attention of several donor agencies.

Finally, WH techniques are now also being introduced in the Northern Niamey Department.
Case study 7

"DEMI-LUNES" FOR CROP PRODUCTION
OURIHAMIZA

INTRODUCTION

The Ourihamiza Project uses a system of "demi-lunes" (semi-circular hoops) for crop production within the Sahelo-Saharan zone in Niger. The first demi-lunes were constructed in 1974 at the initiative of the Catholic Mission of Tahoua. They have recently become accepted by the Regional Development Council of the Tahoua Department, which recommended a target in 1987 of 1000 hectares for each of its districts. "Demi-lunes" are constructed by hand labour under a food-for-work regime, and the emphasis is on rehabilitation of degraded land in an area where the inhabitants are impoverished agropastoralists. This is a rather unique method of water harvesting for crop production. Though it is relatively cheap and simple, there is, as yet, no spontaneous adoption by the local people.

WATER HARVESTING SYSTEMS

Techniques and engineering

The system used is termed "demi-lunes" (semi-circular hoops) and as runoff from outside the plot is either insignificant or excluded, this constitutes a short slope or microcatchment technique. The "demi-lunes" are semi-circular and have radii of 2 metres. Bund height is approximately 25 cm, after the earth has settled, and base width is about 50 cm. Earth for the bund is dug from the area within the hoop, which is thus levelled. The design density is 313 demi-lunes per hectare giving a catchment : cropped area ratio of 4:1 (approximately 25 m² of catchment for each demi-lune). However in some plots farmers have increased the size of the "demi-lunes" and thus reduced the ratio.

Although the "demi-lunes" are arranged on lines approximating to the contour, lines (and rows) of "demi-lunes" are laid out in a grid pattern after surveying of the first line. Some sites are protected from external runoff by diversion ditches. "Demi-lunes" are constructed in relatively large blocks; one site for example covers 30 ha. Original design incorporated "demi-lunes" within trapezoidal "banquettes" (bunds), though "banquettes" are now omitted due to cost.

Production system

"Demi-lunes" are used for crop production in Ourihamiza. Pearl millet is the most common crop, but sorghum is also grown. All operations are carried out by hand. The crop is planted only within the demi-lunes, the catchments between being kept weed free. Yield estimates for millet are given as 600 – 800 kg/ha for a good year and 250 kg/ha for a poor year.
Case Study 7
"Demi-Lunes" for crops
Ourihamiza, Niger

artist's impression.

cut-off drain
contour
slope 0.5-1%
200 cm
25 cm
200 cm
a
a'

a
Implementation and extension

"Demi-lunes" were originally constructed under a cash-for-work programme (125 CFA per "demi-lune"; 1 US$ = about 300 CFA). The average rate of implementation was 8 "demi-lunes" per man/day. Later the project changed to food-for-work and the rate of implementation dropped to 4 "demi-lunes" per man/day. The total area covered by this system is estimated at about 400 ha in 1985, but the number of hectares treated has increased considerably since then. The Inadoucoum sub-project, which was constructed later, alone accounts for 190 ha. Started in 1974, construction of "demi-lunes" has become accepted as a recommendation by the Regional Development Council (replacing an in situ moisture conservation system of mechanised bunds where the crop was planted throughout the plot) in 1987, and a target of 7,000 ha per annum has been set.

Monitoring, evaluation and reporting

At this stage of the project, little has so far been done to monitor systematically parameters such as yields, labour inputs or rainfall. The initiation of a simple monitoring system is now an acknowledged priority. Since 1986 the "Ecole Polytechnique Fédérale de Zurich" has been undertaking studies on infiltration and soil humidity, and the University of Niamey is undertaking a village land use management study.

DISCUSSION

Techniques and engineering/production system

The use of "demi-lunes" for crop production is unusual, and in this respect the Ourihamiza Project is rather unique in Sub-Saharan Africa. Most WH systems for crops in SSA use long slope catchments, external to the cultivated area. At Ourihamiza it is acknowledged that as block sizes are rather large, so the effect of an external catchment becomes relatively unimportant and thus the need for inclusion of diversion ditches into the design. Farmers who increase the size of the "demi-lunes" relative to the catchment may not have understood the principle of the system, however there could indeed be room for a reduction in the catchment: cultivated area ratio, which at 4 : 1 is rather large for a microcatchment cropping system.

"Demi-lunes" cannot be mechanised, nor can they be considered as a system when animals are used for land preparation. However they are well suited to manual construction. The project has had problems with breakage of structures, and this is associated with poor design of diversion ditches and the rigid plot layout, rather than the design of the "demi-lunes" themselves. Diversion ditches need to be improved, and in the case of large blocks, back-up ditches should be put in within the plot. Contours should be surveyed every few lines of demi-lunes, rather than the first line only.

Implementation and extension

"Demi-lunes" apparently have not yet been spontaneously adopted by the people. No research has been done yet on reasons for non-adoption. The following hypothesis could be advanced:
a. the labour requirements for construction and maintenance could be perceived as too high;

b. the cultivation of crusted loamy soils ("fako" in hausa) deviates considerably from their present food production strategy (cultivation of dunes).

Indications are that young men who do not have access to dune soils, which can easily be cultivated, are most interested in getting a field with "demi-lunes" and they seem to maintain them better than others do.

Monitoring, evaluation and reporting

The costs of one hectare of demi-lunes have been estimated at 45,000 CFA (about US$ 150). These costs include the value of food-for-work rations, but not the costs for depreciation of tools used (Desbos, et al., 1987). Unfortunately yields have so far not been measured. Nor has any research been done on reasons for (non-)adoption.

BACKGROUND DATA

Project/Authority

Projet Ourihamiza
Tahoua, NIGER.

Projet Ourihamiza is a Swiss funded project implemented by the Rural Engineering Division (Génie Rural) of the Ministry of Agriculture and Environment and Swissaid.

Important reports include:


Bender, H. and E. Drack. Demi-lunes de Ourihamiza (to be published in 1990)

Sociological factors

The population of the Ourihamiza valley consists mainly of Tuareg and some Hausa. The Tuareg used to be semi-nomads till they lost their livestock in the major drought of 1968-1973. Since then, they have become sedentary agropastoralists.

Natural resources

Climate

The Ourihamiza Valley lies in the Sahelo-Saharan zone (rainfall below the "Northern Limit of Cultivation"). Estimates for recent average annual rainfall give figures slightly below 200 mm. Rainfall is unimodal, the wet season lasting from June to September, with peak rainfall in August.
Soils

The soils on the upper, middle and lower slopes are typically eroded (by water and wind), and infertile. WH is used on barren, crusted sandy loam soils ("fako" in Haussa), which used not be cultivated. These "fako"s typically have low slopes (1 to 2 %). There is little loose stone.

Vegetation

Ground cover is poor. The plateaus are virtually barren. Calotropis procera constitutes the most important source of fuel. The vegetation is mainly concentrated in the narrow valley bottoms, where Acacia nilotica and Balanites aegyptiaca are locally common.

Related water harvesting systems

Another WH technique, water spreading from a sand river, is also managed under the project. 400 hectares are flooded by means of a series of five gabion weirs across the bed. The gabion weirs are intended to raise the bed by 4–5 metres to an original level. While the system is working at present, the lowest weir, some 22 metres wide is being cut around and undermined, needing radical repairs. The long term stability of these structures is questionable.

A soil and water conservation programme initiated in 1988 in the Illela district of the Tahoua Department has adopted the design of Ourihamiza for its demi-lunes. At the same time this project intends to test a smaller number of demi-lunes per hectare (206 instead of 313). The catchment: cultivated area ratio is increased in order to increase the water supply to the plants in years of low rainfall. This project is also testing planting pits ("zay").

Date of visit: November 1987
Case study 8

WATER HARVESTING TECHNIQUES
THE KEITA VALLEY

INTRODUCTION

A series of WH techniques are being implemented by the Keita Valley project in the Tahoua Department of Niger. Systems have been devised for crops, fodder and afforestation. Structures are made either by hand, using food-for-work, or by a combination of machine and hand. The project's stated objectives are to assist the local people to attain food self-sufficiency while conserving soil and water. The project is active in an area where serious land degradation has occurred and average annual rainfall has diminished by over 25% in the last 30 years, to an annual average of 374 mm. Approximately 4,000 hectares had been treated by the end of 1987.

The Keita Valley project is an extremely interesting WH case study in Sub-Saharan Africa. The project is fully implementational, operating with impressive efficiency and most of the techniques used appear to be effective. WH is used as a tool in rehabilitating degraded land, and areas treated are spoken of as being "recuperated". However, the treatments implemented are expensive and it is questionable whether maintenance will be carried out voluntarily, or whether such techniques are replicable without intensive project-based support.

WATER HARVESTING SYSTEMS

Techniques and engineering

Three of the project's most important techniques are covered here. Two are not given specific names as techniques, by the project, other than anti-erosion bunds ("diguettes anti-erosives") nor is the term WH (or its translation) specifically used by the project.

The first technique is that used under the "système sylvo-agricole" on the plateaux. This technique utilises short slope catchments which supply runoff to plots bunded on three sides. The second is the technique used on the lower areas with gentle slopes, the "glacis", which also makes use of earthen bunds, but in this case utilises external, long slope catchments. These two techniques have evolved from the system of simple contour bunds originally employed. The third is a short slope technique for tree planting on rocky hillsides, termed "tranchées" (trenches).

Bunds on the plateaux

Under the "système sylvo-agricole" (agroforestry system) on the plateaux, bunds are made on three sides of a plot, by machine, to a height of 50 cm and then carpeted, by hand, with stone on the top and backslope. These bunds are termed "diguettes anti-erosives". Each unit has a bottom/contour bund (usually a straight line) of approximately 75-100 metres, and wingwalls which reach about 15 metres upslope. The area impounded by the bund is planted, a system of ridges parallel to the bottom bund distributing the runoff collected within.
Case Study 8
"Systeme Sylvo-Agricole"
Keita Valley, Niger

artist's impression

catchment

- cultivated area -

slope

- a -

30 m

15 m

100 m

5 m

- a' -

2.5 m

trees at 5 m spacing

- stone pitching -

- 60 cm -
On typical slopes of less than 0.5%, units are sited 45 metres apart upslope, thus allowing for an unplanted catchment strip of 30 metres length between cultivated plots, giving a catchment: cultivated area ratio 2:1. There is a small gap of 3 or 4 metres between individual structures in the same rank.

Bunds on the glacis

On slopes between 1 and 3%, a similar configuration of bunds is constructed, at slightly closer spacing, though in this case the objective is to accommodate and spread runoff from a large, and external catchment. Thus the main difference is that the whole area is planted, as it receives an external supply of runoff, and also soils are both deeper and more fertile than on the plateaux. Spillways between the wingwalls of the structures are protected with stone lines. Bunds are covered all over with stone for reinforcement. This system is sometimes referred to as "le système perméable" (the permeable system).

Trenches ("tranchées")

Trenches are used for tree planting on hillsides, often where there is considerable stone. Each trench is designed to hold one cubic metre of water, dimensions being 3 metres long, 60 cm wide and 60 cm deep. Design rainfall is 50 mm. Trenches are slightly curved, tips pointing upslope. To reduce the potential danger of water logging, a 20 cm high step is left in the centre of the pit on which the seedling is planted. Trenches are theoretically spaced in lines, one metre between trenches within a line, and lines three metres apart. Thus each trench is served by a catchment area of 12.6 square metres, and about 700 are constructed per hectare. Actual field configuration is dependent on topography.

Production systems

Bunds on the plateaux

Under the agroforestry system on the plateaux, crops are planted in the impounded area, and trees are planted on the bunds. The land is ploughed for the first two seasons by tractor, then by animal draft. Millet is the most common crop, and is planted in furrows. The tree species preferred for the bunds are Acacia seyal, A. nilotica and Prosopis juliflora. No specific yield or growth rate data is available.

Bunds on the glacis

The whole treated area is planted on the glacis, no uncultivated catchment being left, and the common crops are sorghum and millet. The land is ploughed by tractor for the initial seasons. Trees are planted in front of the bunds, and in this situation the species chosen are Acacia seyal, Prosopis juliflora and Parkinsonia aculeata. No specific yield or growth data is available.

Trenches

Trenches are for afforestation. Seedlings are planted on a small step within the trenches, usually in the month of August when runoff from the early rains has already been stored. The species planted are mainly Acacia nilotica, A. radiana, A. seyal and Prosopis juliflora. No precise figures on establishment, which is said to be very good, or growth
rates are yet available.

Implementation and extension

Bunds

Bunds are constructed by machines and then protected with stones which are put in place by hand. The workforce is supplied with rations of food-for-work, each daily ration having a market value of approximately one dollar US.

On the plateaux, a typical bund is constructed, after survey, by a sequence of machine operations: first the earth is ripped by a bulldozer; this is followed by a double chiselling by a tined tractor, and subsequently by a specially designed bunding tool mounted on a tractor. The three sides of each plot are bunded in a single operation, thus the angles are rounded. The final operation is a double compaction of each side of the bund by a tractor-mounted roller.

The project is able to treat up to 20 hectares each day in this fashion (catchment areas included), equivalent to 5,000 metres of bunds. Estimated costs for establishment of the bunds on the plateaux (and including land preparation and fertilisers) are CFA 178,000 per hectare (CFA 310 = US$ 1.00).

Trenches

Construction of trenches is now entirely by hand, though at one stage they were dug by a tractor-mounted digger. Hand tools, including shovels, pick axes and hammers are used to dig the holes. According to an FAO report (1988) total costs per hectare for construction of trenches for tree planting is 544,880 CFA per hectare, or US$ 1758 (1 US$ = 310 CFA).

Physical achievements at the end of 1987 are given as follows:

Plateaux: 720 hectares treated (bunds, with catchments: plus 120 ha for a slightly modified sylvo-pastoral system)

Glacis: 3,000 hectares treated (with bunds - i.e. "le système perméable")

Trenches: 150,000 units, equivalent to over 200 ha.

There has not yet been any voluntary adoption of the techniques by the population, nor would this be expected given size and cost of the structures. At present, structures are either made by the project's mechanisation unit, or people participate on a food-for-work basis. No figures are available to quantify the adoption of improved husbandry techniques.

Monitoring, evaluation and reporting

The Keita Valley project has not yet established a full monitoring system, though some aspects, such as recording of climatic data, and measuring work rates have been started. Precise data on crop yields, and tree growth (and comparative data from "controls") are not available. Evaluation has, so far, been largely limited to accomplishments of targets of land
successfully recuperated. However the project does incorporate flexibility in approach, and has been prepared to modify techniques and approaches on the basis of experience.

A high quality illustrated brochure giving background details to the project is available for visitors. This is a useful and informative document. A recent paper written by the project's technical advisor gives a fuller account of the specific approaches adopted by the project in terms of actions against desertification.

DISCUSSION

Techniques and engineering/production system

Of the techniques considered in this profile, both the bunding system seems technically appropriate, though the cost of structures on the infertile plateaux is high, when viewed in the light of potential productivity of a millet crop. While acknowledging the efficiency of the mechanisation, where adequate stone exists, it may be cheaper and simpler to create stone bunds rather than stone-pitched earth structures. The incorporation of agroforestry trees into the system is a positive attempt at sustaining productivity and diversification.

The trenches will have more appeal for the soil conservationist than the economist; they have considerably more design storage capacity than will normally be required. It would be useful to compare alternative structures which have a lower volumetric capacity. Survival rates may be high, but this is achieved at considerable cost. The emphasis on traditional tree species however is creditable.

Implementation and extension

Project documents note that local people are involved in planning decisions, and the project has shown that it is prepared to modify techniques and approaches in the light of experience. The project has taken initiatives to establish active village organisations concerned with conservation.

Yet a basic question is that concerning maintenance and replicability. Clearly expensive structures made by machine are unlikely to be voluntarily constructed by hand in the same area, hence wide-scale replicability of techniques is tied to the availability of machinery, or in the case of trenches, a source of food-for-work. It is by no means certain that maintenance would be carried out either without incentives, as participation to date has been linked to the provision of food.

Monitoring, evaluation and reporting

The need to introduce a monitoring system is urgent, so that the effect of structures, in terms of crop/tree performance, can be evaluated, and the costs compared with benefits. Such information would add to the value and increase the importance of a document like the project brochure which, while giving a clearly laid out background to the project, would benefit from a little more information on productivity and constraints to implementation.
BACKGROUND DATA

Project/Authority

Programme de Developpement Rural Intégré dans l'Ader Doutchi Maggia: Vallée de Keita: Projet GCP/NER/028/ITA
B.P. 11246, Niamey, Niger

The Keita project is financed by the Italian Government and implemented by FAO. The contribution of the Italian Government is US$ 29 million, and the World Food Programme is further providing 3.3 million daily rations. The Niger government contributes in payment of staff salaries.

The project has an expected life of seven years, and implementation began in May 1984. The project's objectives are to assist the local people to attain food self-sufficiency, to raise standard of living, to conserve soil and water and to strengthen local institutions.

The project has a stated objective of working from the starting point of the expressed requirements and wishes of the local population, and the work programme is designed to be flexible enough to accommodate the evolution of these felt needs.

Important reports include:

The official project brochure

"Notes Sur le Cas de Keita" (mimeo), Carucci, R. 1987

Socio-economic factors

In the District of Keita, which includes the Keita Valley, there is a population of 150,000 split between 205 villages. The rural population is 99% of the total, and the majority of the able bodied men practice seasonal migration to find work to supplement incomes.

Natural resources

Climate

The Keita Valley lies on the boundary between the Sahelian Zone (average annual rainfall between the Northern Limit of Cultivation and 350 mm), and the Sahelo-Sudanian Zone (average annual rainfall 350-600 mm). Records from the project area show that the average annual rainfall between 1956 and 1966 was 517 mm, but this had diminished to an average of 374 mm between 1967 and 1987. The rainy season lasts from June to September. Rainfall intensities are reported to reach more than 50-60 mm/hour.

Monthly mean maximum daily temperatures are at their highest in April (33.8 C) and May (33.2 C). Annual potential evapotranspiration is 2,450 mm, of which 673 mm correspond to the period between June and September.

During the dry season, and particularly between December and February, the "Harmattan" wind blows in a South/South-West direction. This wind causes considerable erosion.
Soils

On the plateaux, the soils are very shallow, low in organic matter, very acidic (pH = 4.2 - 4.5) and infertile. On the gentle slopes below the plateaux (the "glacis") there are signs of both sheet and rill erosion. At one time these soils were regularly cultivated, but they have now largely been abandoned. They are deep, low in organic matter, very hard when dry, neutral to slightly alkaline, low in infiltration, and sometimes quite well supplied with phosphorus.

Vegetation

Although ground-cover grasses, herbs, and bushes are conspicuous by their absence in the more degraded areas, there remains a reasonable good number of mature trees except on the plateaux and steeper slopes.

Related water harvesting systems

The Keita Valley project is also involved in water spreading/gully stabilisation activities in the area, utilising gabion weirs.

Date of visit: November 1987
Case study 9

MECHANISED TIED FURROWS
DAMERGOU

INTRODUCTION

The Integrated Programme for Rehabilitation of the Damergou region, based at Tanout, has developed a tractor-drawn implement which creates tied contour furrows quickly and efficiently. The implement, termed "le train", is reversible and can cover up to 10 hectares per day. The objective is to bring into cultivation, degraded land, which is difficult to rehabilitate using locally available resources in an area which has received considerably less rainfall in the last decade than its long term annual average of about 350 mm. Work began in 1988 when a pilot area was cultivated, and an encouraging crop produced.

WATER HARVESTING SYSTEM

Techniques and engineering

The reversible plough produces tied furrows/ridges which are generally in straight lines, as close to the contour as possible. The furrow, upslope of the ridges, collects the runoff produced by the uncultivated inter-ridge catchment. The ridges are rather large, at 30 cm. (+-) in height and are spaced at 2.0 to 2.5 metres apart. Earth ties are created automatically in the furrows by the machine at an interval of 4–5 metres apart. Spacing can be varied according to local requirements. The reversible plough which is pulled by a tractor of over 100 h.p. subsols as it ploughs breaking up the compacted land, thus permitting increased infiltration.

Production system

The tied furrow system is used for crop production. In the Damergou area, which is close to the northern unit of cultivation, millet is the usual cereal crop, though sorghum is also grown. Cowpeas are the most common legume. Recommendations for configuration and spacing of planting had not yet been finalised at the time of the visit. However, while the project prefers planting on/beside the ridge only, some local cultivators planted in the catchment also in this first season of trials. The harvest had not yet been carried out at the time of the visit, but plant growth was impressive.

Implementation and extension

The project constructs the system for use by the local villagers. This is an implementational project, and the system is not intended to be one which the people can copy using their own resources. Nevertheless villagers are given responsibility for all cropping activities. The land treated, which traditionally is communally used, is allocated to villagers at up to 0.25 ha per family.

The plough can treat up to 10 hectares of land per day, at the rate of one hectare per hour. Overall costs of initial land treatment are estimated to be less than US$ 100 per hectare, but it is not yet clear after how many seasons the ridging operation would need.
Case Study 9
Mechanised Tied Furrows
Tanout, Niger

Curved mini-trenches for trees
artist's impressions

earth ridge

30-40 cm
furrow
uncultivated catchment

75 cm 75 cm

2.0 - 2.5 cm
to be repeated. The cost price of the plough itself is given as US$ 12,000.

Monitoring, evaluation and reporting

At the time of the visit, operations had only been underway for a short time, and no formal monitoring system had yet been established. Nevertheless, the capacity of the machines, was being recorded. Subsequent to the visit, brochures were produced outlining the efficacy of the technology.

DISCUSSION

Techniques and engineering

The mechanised contour furrows of Damergou are of considerable interest, not only because this is one of the few examples of a contour furrow/ridge system being used for crop production, but also because the implement itself has been specifically designed to produce ridges quickly and efficiently while simultaneously subsoling. This microcatchment system makes use of the efficient runoff generated by the very short catchment lengths, while simultaneously giving excellent soil conservation. Other examples of similar systems for crops (see case studies #6 from Kenya and #13 from Zimbabwe) are from relatively wetter areas, so the experience from the Sahel will be a most interesting comparison.

Production system

It is important that the land users are trained to plant crops only in the vicinity of the ridge/furrow. Otherwise, if crops are planted in the catchment area also, the WH effect of the system is lost.

Implementation and extension

One of the most interesting aspects of this system is the project's philosophy: the scale of environmental degradation is such that it exceeds the capacity of the local people to reverse the trend by using their own resources. Therefore the project believes that support based on mechanisation is required. This refutes the alternative school of thought according which mobilising the population is the only means of sustainable and widespread land management, at least for this zone of severe degradation and low population density. However, in clear contrast to several other mechanised projects, the costs are relatively cheap, and the ridging itself is a one-pass operation allowing very rapid implementation, at least on flat loamy sands.

Monitoring, evaluation and reporting

Both an evaluation of the effective costs and the acceptability of this system are urgently required, due to its potential importance in similar areas.
BACKGROUND DATA

Project/Authority

Programme Intégré de Réhabilitation du Damergou,
B.P. 42, Tanout,
Département de Zinder
Niger.

PIRD began activities with tied furrows and curved mini-trenches (for trees) in 1988.

Important references include:


Socio-economic factors

In the area of intervention, the population consisting of Hausa amongst others, have traditionally cultivated sandy soils while also maintaining large herds of livestock. Historically there has been trade in foodstuffs (millet etc.) grown in this region. However recent droughts (especially in 1973 and 1984) led to widespread crop failure and accelerating environmental degradation. Population densities in this part of Niger are very low: Zinder Department has a density of 7 people/km² on average.

Natural resources

Climate

The climate of the Damergou region has been described as "south desert sahelo-sudanian". The annual average temperature is given as 25.5 °C and the recent annual average rainfall has ranged between 250 and 300 mm.

Soils

The soils treated by the tied furrow system are impoverished, denuded, capped soils, locally known as "Fako". These soils cannot be cultivated with traditional methods.

Vegetation

Vegetation is sparse: *Calotropis procera* is a characteristic shrub, indicating overgrazing. *Acacia* spp. and *Boscia* spp. are conspicuous amongst the few trees.

Related water harvesting system

An implement similar to the reversible plough for ridging has been designed for "interrupted ploughing" to make a series of curved mini-trenches ("cuvettes" in French) for tree planting (direct seeding). Up to 10,000 of the mini-trenches of 0.64 cm³ capacity each, can be made in a day. This machine however is not reversible and this number is reduced if
all the pits are aligned facing upslope. Up to 15–20 hectares can be treated in a day. This work rate compares with manual construction rates of about 6 pits of 0.23 cum. each per person/day.

This kind of technical innovation is relevant and most interesting, and it is not surprising that several projects in Niger have already shown a serious interest in procuring this equipment. However, some caution is needed as the technical success needs to be matched by participation of the local population.

However, some caution is needed as the technical success of this type of mechanisation could well become self-defeating. This statement requires some more explanation: unless the local population (agropastoralists and pastoralists) will be involved in the planning and management of these rehabilitation efforts, and unless it is clear to them from the beginning how the costs and benefits of such tree plantations will be shared, their voluntary cooperation could well be minimal or non-existent. In the absence of adequate fencing and guarding, the damage to tree plantations by their herds is likely to be substantial.

The challenge in this situation is to create viable local organisations for the management of such tree plantations, but this cannot be realised overnight. The rights and obligations of each party should be established by the project and the local resource users, and laid down in a contract. Sanctions should be defined, and technical training should be provided to the local resource users. Furthermore some kind of balance should exist between the size of the area rehabilitated in this way and the needs (fuel and fodder) and management capacity of the local groups.

Date visited: November 1988.
Somalia

General background

Area: 62.7 million ha
Population: 5.4 m
Population Growth Rate: 2.8%
Climate: semi-arid/arid
Staple grains: sorghum and maize

Somalia has a low population density: pastoralism is a common way of life and Somalia has, relatively, very high livestock numbers including a camel herd twice as large as any other country in SSA. Much of Somalia is covered by bushy rangelands which are extensively grazed/browsed. There is productive irrigation from the Shabelle river and bananas – for export – are a characteristic crop. However the majority of cropped land is rainfed and sorghum is the most common grain. Periodic food shortages associated with droughts can occur and in any case the level of food imports is consistently high.

Water Harvesting in Somalia

Place in Government: Ministry of Agriculture, and National Range Agency

The Central Rangelands of Somalia contains extensive areas of traditional small scale WH, particularly in Hiraan Region. These systems make use of overland flow, or small “toogs” (intermittent streams), to supplement rainfall for crop growth. The cultivators who use WH are in fact agropastoralists. These relatively unknown systems are efficient and cheap to construct, and thus of great potential interest. The Central Rangelands Development Project has begun trials using modifications of these traditional systems.

A number of water spreading schemes are also evident in the area where large “toogs” (wadis) have been diverted and spread. Some are traditional, others have been helped by NRA and various projects.

In the North West Region, a series of bunding projects have been constructing large bunds, with machinery, for over thirty years. While the main effect of these bunds is on soil conservation, in some cases they harvest water also.
Case study 10

TRADITIONAL SMALL SCALE WATER HARVESTING
HIRAAN REGION

INTRODUCTION

Traditional small scale WH systems for crop production are common over an extensive part of Hiraan Region in the Central Rangelands of Somalia. It has been estimated that up to half of the families within the region practice some WH. Structures are normally made by hand and the cultivation of the common crops of sorghum and cowpeas is generally by hand also. The majority of those involved are agropastoralists who supplement their income from livestock by cultivation and simultaneously benefit their animals with the by-products as fodder. The systems used are simple and cost little to construct. Though some improvements can be proposed, there is much to be learned from these little known techniques. The Central Rangelands Development Project has begun to test modifications to the traditional systems with respect to structural aspects and agroforestry.

WATER HARVESTING SYSTEMS

Techniques and engineering

The local people differentiate between two types of small scale WH system. These are "caag" (pronounced "ag") and "gawan". The caag system is found where considerable overland flow, or flow from a small "toog" (gully) can be captured behind bunds, whereas the gawan system acts mainly as an in situ moisture conservation system on the plateaux, though it is modified sometimes to accommodate runoff from outside.

Caag

In "Caag" sites, the WH aspect is well defined. This system is used normally where slopes are above 0.5% and there is significant runoff to be harvested. These are long slope, external catchment systems. Water may be diverted into the plot, commonly from small "toogs" or even road drains. "Contour" bunds are formed within the fields, to a typical height of 50 cm and base width of 150 cm. These bunds commonly extend across the entire plot (often one hectare or more in size), excess runoff typically being spilled around one upturned arm of the bund. The other arm extends higher upslope. Overflow then may be collected in front of a second, lower bund. There are rarely more than two such bunds in a field. An alternative overflow system occasionally seen is the incorporation of a plastic pipe (of approx. 10 cm diameter) within the bund.

The layout of the bund is achieved by a combination of eye and experience, but a contour alignment is clearly the objective. A precise maximum depth of flooding is not specifically designed for; rather it is said that if excess flooding occurs and water stands for more than five days the bund may be deliberately breached. In practice flooding depths can reach 30 cm.
Case Study 10
Traditional Small Scale WH "Caag" System
Central Rangelands, Somalia

artist's impression

slope

overflow

earth bund

bund may be breached later

example of "Gawan" system

slope

overflow

alternative "Gawan" system
Gawan

The techniques used on "gawan" site are borderline between WH and in situ moisture conservation. These are typically almost flat site which sometimes receive runoff from outside. The system itself compromises bunds of about 30 cm height, which divide plots of land into a grid, with individual basins in the order of 500 m² and upwards in size. Sometimes the basins are "blind", that is they have no inlet or outlet. However in the situation where runoff is expected from outside the plot, water is spread and controlled by the provision of gaps or breaches in the bunds, which act as spillways. Sometimes runoff is allowed to back-up and spill around a sidewall of the basin, in a similar fashion to the "caag" system. The configuration of two fields is never identical.

Production systems

Sorghum is the usual crop of choice. Sorghum provides grain and also stover which is a valued by-product for livestock feed. Cowpeas are also common. Sesame is sometimes grown, and it is said that if sorghum becomes waterlogged, then sesame is planted later into the residual moisture. Cultivation is usually by hand and farmers sometimes "punch plant" (punching pits with a pole) without digging first. Richer farmers hire tractors for bunding and ploughing.

Dry planting is practised by some people, though others wait until after the rains have begun. Two crops are taken during each year, if both the "Gu" and "Der" rains succeed. Yields for WH fields are not specifically available, though general average yields for this area are given as 415 kg/ha for sorghum and between 330 and 530 kg/ha for cowpeas. Although there is no tradition of tree planting, certain species are not cut if they occur in an area to be cleared for cropping. Conspicuous examples of this are Balanites aegyptiaca and Terminalia spinosa.

Implementation and extension

The WH systems referred to are entirely traditional. They are implemented by the farmers themselves at their own expense. No details are available about costs or labour input, but these are estimated to be modest, judging by the costs incurred by the Central Rangelands Development Project (CRDP) on trial plots using similar techniques (see Background Data). Bunds are normally constructed with a "kawawa", or two-man shovel, after the soil is first loosened with hoes. The "kawawa" consists of a rectangular metal blade approximately 50 cm long and 20 cm in height. The blade is attached to a wooden handle which is held by one operator while ropes attached to eyes in the blade are pulled by the second. The alternative method is by hired tractors, and, in this case, bunds are formed by successive runs with a disc plough. In one area, near Halgan, bunds have been formed by a bulldozer, on loan from road construction work. These bunds are considerably larger than normal.

Information is not available on the number of agropastoralists who use WH systems, though it is a widespread technique in the clay areas of Hiraan region. In Bula-Burti District, for example, an area where WH is common, it is thought that there may be 2,500 families using this system. One estimate by CRDP staff is that up to half the 35,000 families of the region practise WH, of one sort or another. There is no specific provision for training and extension in the field of WH in this predominantly rangeland area, although CRDP hopes to establish a suitable agropastoral extension package based on the results of trials.
Monitoring, evaluation and reporting

Other than general studies on agropastoralism in the Central Rangelands by CRDP, there are no specific WH data reported.

DISCUSSION

Techniques and engineering

As there is considerable variation in the field, it is not possible to discuss "precise" techniques, and thus discussion has to be general. Naturally some examples are better made and more efficient than others. The "gawan" system holds rainfall effectively in situ and where runoff is harvested it works best where an overflow is provided for, around side bunds. The less sophisticated models with mere gaps in bunds are less efficient at impounding runoff. Smaller basins could be an improvement and this indeed is one of the modifications being tested under CRDP.

The "caag" system is a simple and effective method of impounding and spreading flows of runoff from small channels. Indeed it is basically the type of system which is being introduced under a number of projects in SSA, usually at much greater expense and with little extra efficiency. Nevertheless it is evident that there are some problems – with waterlogging in some situations and also with bund breakages. The caag system could thus be improved in a number of ways, principally by the introduction of simple surveying instruments to establish the contour and to determine vertical intervals for spacing of bunds and positioning of spillways.

Production system

The two most popular crops, sorghum and cowpeas, cannot easily be bettered for rainfed farming in this zone. However there may be potential for the introduction of alternative varieties. Other promising crops being tested under CRDP include bulrush (pearl) millet and green grams (mung bean). CRDP are developing an agropastoral system for cropping in the Central Rangelands and extension packages are available for sandy zones. It is anticipated that similar cropping practices would be viable under water harvesting. The basis of the system is the incorporation of woody shrubs and trees to help maintain fertility as well as to provide economic products such as timber, fuelwood and browse. A further benefit would be the stabilisation of the bunds by the establishment of vegetation.

Implementation and extension

Small scale WH techniques are implemented voluntarily by the local agropastoralists because, they say, harvested runoff improves crop performance and, without it, crop failure may occur. There is evidence that these techniques have evolved over several generations. In certain areas of Hiraan Region, such as Bula Burti and Haigal, few farms can be observed without "gawan" or "caag" systems. These are low cost systems. The figures from CRDP suggest that the use of the "kawawa" for making bunds is quick and efficient and the alternative tractor hire is also relatively cheap in this area. Costs for construction of systems, at well below US$ 100 per hectare, are within the reach of the majority. That CRDP have established an agropastoral section and are working toward recommendations for extension in the field of water harvesting is commendable. Without revolutionising the
techniques or cropping pattern, there are several useful modifications which could improve the systems and make them more productive and sustainable. These will form the basis of an extension programme.

**Monitoring, extension and reporting**

There is a vital need to record more information about these systems, not only as a basis upon which to plan improvements, but also so that projects working in the field of WH is SSA can learn from these traditions.

**BACKGROUND DATA**

**Project/Authority**

Central Rangelands Development Project
P.O. Box 1525
Mogadishu

The Central Rangelands Development Project, supported by five donors in addition to the Government of Somalia, is primarily responsible for the administration and development of rangeland and livestock in Hiraan Region. An agropastoral section is responsible, amongst other things, for setting up water harvesting trials. The Ministry of Agriculture and the extension service AFMET are mainly concerned with irrigated agriculture.

**Important reports include:**


**Socio-economic factors**

The traditional economic mainstay of the Central Rangelands is nomadic pastoralism. Although livestock remain the most important means of production, there is an increased sedentarisation amongst the herders and an associated increase in agropastoralism. Between 1975 and 1984, the proportion of settled rural population rose from 22% to 34%, and the nomadic population decreased from 62% to 47%. It is estimated that up to 30% of food requirements are met, in a normal year, from cropping activities; up to a third of families are agropastoralists. In some more favourable areas, the great majority of families grow some crops. In Hiraan Region, it is estimated that 6.5% of the land area is either cropped or fallowed.

**Natural resources**

**Climate**

The average annual rainfall for the region is reported to be in the order of 150–300 mm though data are scarce. The long term average for Belet Weyne town, which is close to some important WH areas, is 248 mm with a range of between 44 mm and 553 mm. There are two rainy seasons, the "Gu" (April – June) and the "Der" (October –December) of which the former is the more reliable. Evapotranspiration figures are not available.
Soils

Although most of the Central Rangelands is sandy, those areas where WH is common are the clay zones, where adequate runoff occurs, not far from the Shabelle river. These are referred to as the "Shabelle valley alluviums and colluvial fans". Fertility is higher than in the sandy zone, but there is evidence that land is traditionally rested after a number of years to restore the nutrient status.

Vegetation

The whole area is characterised by very productive and often dense bush, with the incidence of trees varying locally. *Acacia* ssp., *Commiphora* ssp., *Bosclia* ssp. and *Ziziphus* ssp. are all common. This is the homeland of the "Yeheb" bush – *Cordeauxia edulis*. The grass/herb layer is poorly developed beneath the bush canopy. Although most of the bush has been classified as being in good or fair condition, the upper limits of carrying capacity are rapidly being reached. Degradation is clearly a serious problem around permanent water points, and also where cultivated land has been abandoned, though this is more of a threat in the sandy areas where wind erosion is severe.

Related water harvesting systems

Within the same district, large scale water spreading schemes are also found, whereby "toogs" of 50 metres width or more are diverted into flood plains and cultivation carried out. A number of such schemes were started as local initiatives. While these can be very productive, they are only appropriate for specific sites and commonly suffer from breaches of the diversion bund itself.

CRDP began trials with small scale WH in 1987, and has established two trial sites near Bula Burti. The techniques under trial are variations on the traditional ones, and incorporate agroforestry production systems. An important innovation is the utilisation of the bunds themselves for production of woody species. The total cost of construction of the bunds in the system most similar to the traditional one would be considerably below US$ 100 per hectare. However initial loosening of the earth through ploughing is not included in this cost. Bunds are constructed using the traditional "kawawa".

Case study 11

BUNDING:
NORTH-WEST REGION

INTRODUCTION

Contour bunding has been the basis for soil conservation/water harvesting in the Hargelsa area of north-west Somalia since it was first introduced in the 1950s. The current multi-donor project, the North-West Region Agricultural Development Project (NWADEP) has entered its second phase of implementation and has a target of 12,500 hectares of bunding within a five year period. Bunds are made by bulldozer and the major crop is sorghum which is valued for its stover as well as its grain. While physical progress is impressive and bunding is apparently popular with farmers, the standards of crop production and maintenance are poor. The system is generally effective in terms of soil conservation, however it is costly and the effect of bunding on crop production is unclear, though this is in the process of being formally quantified.

WATER HARVESTING SYSTEMS

Techniques and engineering

Bunding acts as a WH system only where a substantial external catchment serves the farmer’s plot. Otherwise the main effect is as an in-situ moisture conservation system. Design is not modified according to the size of the external catchment. Earthen bunds are created by wheeled or tracked bulldozer to a height of 1.0 - 1.2 metres and a base width of 3 metres. Bunds are constructed by pushing earth from below. The bunds follow the contour and are up to 60 metres in length. The distance between bunds is set at a 30 metres horizontal interval, or a 60 centimetre interval, whichever brings them closer. Since most slopes are 2% or less, 30 metres is the usual distance apart. Bunding is not normally recommended on slopes less than 1%.

Since 1987, a new design has included wingwalls. Previously bunds were "banana-shaped". The wingwalls leave the contour bunds at an angle of approximately 45 degrees and reach to a vertical distance of about 20-30 cm upslope. The tips of the wingwalls, around which excess flow is drained, are aligned on the contour. Bunds are usually constructed in a series downslope and to prevent the erosion which has been caused in some situations by overflow meeting in a common erosive flow, cut-back ditches have been proposed to redistribute runoff into the bund below.

An experimental design is being tested under the project and this is a variation on the bunding system, termed an "enhanced runoff system". Use is made of interbund catchments to supply the cultivated area with extra runoff. This system is similar to the "Zing", a conservation bench terrace, developed in America. The bund, with wingwalls, is constructed from earth pushed downslope and a level cultivated area is simultaneously formed. The catchment: cultivated area ratio has been calculated to be between 3:1 and 4:1 in order to ensure an adequate sorghum crop in a poor year. Thus for a cropped strip of ten metres wide, the uncultivated, but cleared and smoothed catchment area is 30 - 40 metres. Bunds are laid out in an offset or "integrated" pattern and the intention is to continue the pattern,
### Case Study 11
Bunding
North-West Region, Somalia

<table>
<thead>
<tr>
<th>Existing System</th>
<th>&quot;Enhanced Catchment&quot; System</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 60m</td>
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<tr>
<td>slope 1-2%</td>
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<tr>
<td>VI = 20-30cm</td>
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<td>HI earth bunds</td>
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<tr>
<td>normally 30cm</td>
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<td>1-1.2m high</td>
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<td>30m</td>
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<tr>
<td>30m</td>
<td>cleared and smoothened</td>
</tr>
<tr>
<td>10m</td>
<td>catchment</td>
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</tbody>
</table>

artist's impression
with farmer's agreement, across field boundaries.

Production system

The predominant crop is sorghum, though some maize and pulses are also grown. Sorghum is grown under a very low input system, with the average farmer investing about 35 man days, excluding ploughing, per hectare. No inputs are purchased. The poor standard of husbandry may even have deteriorated in recent years. For example early (dry season) ploughing is being increasingly neglected and instead farmers are economising by broadcasting seed and ploughing it in. Cattle kraals piled high with unutilised manure are a common site. Estimates of average grain yield have been quoted as 820-1750 kg/ha for bunded land of different categories and 840-1220 kg/ha for equivalent land unbunded. However a yield survey commissioned in 1987 (a drought year) found average sorghum yields (190 kg/ha) similar for both bunded and unbunded areas, in a single sub-catchment. No specific reasons were proposed for these rather unexpected and disappointing results.

The relative importance of sorghum stover should be noted; the stover is often valued as highly for livestock feed as is the grain for human consumption, and a "failed" crop may still produce a significant amount of fodder. A second sorghum crop may even be planted, purely for fodder, if rains continue.

Implementation and extension

NWADP has six "bunding units" composed of four bulldozers each, plus tractors. Land is bunded for farmers by these units, and 30-50 metres of bunds can be achieved per machine hour. The estimated cost per metre of bunding is SO.SH 32, which is equivalent to approximately SO.SH 10,000 per hectare (1 US$ = 8 SO.SH at time of these calculations). Farmers are required, theoretically, to pay 50% of this total cost. However, in practice, once the initial deposit of SO.SH 4 has been paid, the repayment of the remainder of the loan is not enforced. Implementation is clearly linked to provision of subsidised machinery and thus the concept of "adoption" can only be applied to the readiness of farmers to pay the required deposit. There is considerable demand for bunding. Maintenance however is rarely carried out by farmers.

The responsibility for extension work in the area was taken over by the project in 1986 with the establishment of the Dryland Farming Extension and Training Research Unit. Under the project, extension is being strengthened by addition of personnel and transport to an original unit. The greater attention to extension husbandry and is based on simple agronomic recommendations and the promotion of animal cultivation.

Monitoring, evaluation and reporting

A small monitoring and extension unit under the project has carried out periodic crop cuts, but due to the lack of reliability of the information and the urgent need for accurate, objective assessment of comparative yields, consultants were given the mandate to carry out a crop survey for the "Dér" season of 1987. A follow-up survey, covering a larger area was proposed for the following rains. Part of the consultants' duty was to train and improve the capacity of the project's M&E unit.
DISCUSSION

Techniques and engineering

There has been much within-project discussion about the specifications of the bunds. These discussions have included the possibility of adjusting the horizontal interval (to allow wider spacing on lower slopes) and the potential benefits from offsetting structures to improve the absorption of excess runoff. The size of the bunds is in excess of that which is required purely for effective WH or soil conservation. However the project's justification is that large bunds require less maintenance. This is generally true for a number of years, but when and if repairs are necessary the farmers rarely carry them out. The fact that bulldozers are used means that it is as easy and nearly as quick to build large bunds as smaller ones.

The experimental design under test is a modification of the standard bunding and aims to improve yields by incorporating a microcatchment strip and thus providing for some WH in all situations. Standard bunding only acts as a WH system when a farm is situated below a natural catchment. The experimental "enhanced runoff" system however will not give comparable yields in good rainfall years because of the relatively small proportion of land actually planted, though this does have the advantage of reducing input costs considerably. There is a potential danger of reducing fertility by using topsoil from the cultivated area to make bunds. Nevertheless this system's benefits are apparently proving popular and its potential should be fully explored.

Production system

The very poor standard of husbandry stands in stark contrast to the efficient mechanisation of bund construction. Husbandry of crops, amongst which sorghum is the most important, needs to be improved in nearly every aspect if the expense of bunding is to be justified. The lack of utilisation of the bund itself, which is basically a mound of potentially productive topsoil, occupying up to 10% of the land area, is also a surprising waste of productive capacity.

Implementation and extension

Bunding is carried out at an impressive rate, though supervision could be improved with respect to such aspects as contour alignment and meeting the required specifications of the wingwalls. Mechanised bunding was institutionalised under a previous project in the 1960s and the current project has followed suit. Tractors however have been replaced with bulldozers. As a mechanised, heavily subsidised enterprise, bunding is clearly considered to be a service to farmers. It is unlikely that such a system could be self sustaining without outside assistance of similar nature. Of particular concern is the lack of maintenance of the bunds by the farmers. The project has even proposed a sociological study to look into this problem, but maintenance by hand, or with animal traction, is most likely unattractive after construction by heavy machinery.

With the establishment of the new extension and training unit under project management, there are now signs that this element will begin to receive the attention it deserves. There can be no doubt that the previous weakness of this component has contributed to the low level of husbandry seen on bunded fields.
Monitoring, evaluation and reporting

It was not until 1987 that a systematic survey was carried out to compare yields on bunded and unbunded land. Prior to this date, a series of estimates and assumptions have been the basis for evaluation. The process of measuring comparative crop yields is underway, but other measurements, such as the reduction in bund height over time, siltation and runoff are also needed to evaluate the effectiveness of bunding.

BACKGROUND DATA

Project/Authority

North-West Agricultural Development Project (NWADEP)
P.O. Box 435, Hargelsa, Somalia

NWADEP is a multi-donor project supported by the World Bank, IFAD and the EEC, and implemented by the Government of Somalia with assistance from consultants. Phase 2 is scheduled to last from July 1985 to June 1990 and during this period 12,500 hectares of land is the target for bunding. Total phase 2 costs are US$ 30.9 million. The project was ahead of schedule at the time of visit (October 1987). Up to 60-70% of the cultivated land in the project area will be bunded when phase 2 is completed. Phase one of NWADEP bunded 16,000 hectares.

Important reports (in addition to internal products) include:


Socio-economic factors

Stock rearing is traditionally the principle economic activity of the region, and livestock are exported at very favourable prices to the Gulf States. In one sub-catchment recently surveyed, at Galooley, 90% of livestock owners had cattle with an average herd size of 9 animals. The majority of the population is now settled, and crop cultivation has been practised extensively, alongside livestock rearing, for around fifty years. Sorghum is the most important crop. The average agropastoralist with about two hectares of annual crops and 4-5 hectares of fallow scrub grazing is only 30% self-sufficient in grazing and fodder, and thus follows the importance attached to fodder from sorghum stover.

One further factor of significance is land tenure. It has been suggested that one of the reasons for the popularity of bunding is because of perceived insecurity of tenure and the stronger claim to the land inferred by having it bunded. An evaluation of the prior bunding project, under USAID, suggests that bunding had little effect on women's roles which follow the traditional pattern of differentiation of work.
Natural resources

Climate

The climatological network is sparse and records are incomplete. There are two rainfall seasons, the "Gu" in March–May, and the "Der" in August and September. The "Gu" is the main growing season for crops. The annual average rainfall for Hargeisa (project headquarters) is 424 mm with a 75% reliability of 348 mm. Boorama has an annual mean of 518 mm with a 75% reliability of 412 mm. Potential evapotranspiration is calculated to be 2,037 mm per annum at Hargeisa. The crop water requirements of sorghum are estimated at 650 mm, implying a regular moisture deficit for the crop.

Monthly temperatures reach a maximum in June (mean max 30–31°C) and a minimum in January (mean max 24°C).

Soils

The plateau area west of Hargeisa is predominantly underlain by Nubian sandstones. Alluvial materials predominate in the lowland areas. On the high plateau soils are mainly deep and heavy. The surface is sandy but has a tendency to crust and thus generate runoff. There are, however, no data on runoff. In certain areas, soils have a tendency to piping, and ponding of water, by bunding or otherwise, can make this problem worse.

Vegetation

The plateau, which forms much of the project area, ranges in altitude between 1400 and 1600 m.a.s.l., and is described as an Acacia etbaica bioclimatic zone. Much of the area is semi-open woodland with the tree layer dominated by Acacia etbaica with a ground cover ranging from 10 - 50%. Overgrazing is demonstrable by the increasing importance of unpalatable aloes.

Related water harvesting systems

A traditional WH system, used before the advent of bunding (and sometimes still seen) is known as "takaari" and is a type of ridge and furrow system, fed by runoff channelled in from outside the plot. Farmers evidently understand the practice of WH. Even today some farmers attempt to harvest extra water, through channels, into their bunding systems.

Date visited: October 1987.
SUDAN

General background

Area: 238 million ha
Population: 21.9 m (1985)
Population Growth Rate: 2.9%
Climate: Semi-arid/desert in north and humid in south
Staple grain: Sorghum

Sudan is a vast country, much of which is arid, semi-desert or desert. The agricultural sector provides the livelihood for around 80% of the population. The area between the two Niles, the White Nile originating in Uganda and the Blue Nile in Ethiopia, has undergone intensive development for irrigated crop production in the past few decades. Population and economic development are concentrated along the Nile. Mechanised crop farming, mainly of sorghum, is important on the eastern clay plains. Livestock are important throughout.

Water harvesting in Sudan

Place in Government: Soil Conservation Department (SDC), and Range and Pasture Administration (RPA), both within the Ministry of Agriculture

Sudan has probably the most extensive and diverse heritage of traditional water harvesting and water spreading of any country in SSA. Systems range from the utilisation of wadi flow by bunding within flood plains, variations of which can be seen throughout the semi-desert areas, to traditional small scale "teras" construction in the eastern plains.

RPA supervises several large water spreading projects, principally for fodder production, in Darfur. RPA also have fodder trials in the Gash Delta (near Kassala) and a rehabilitation site in North Tokar where floodwaters are spread by bunding.

SCD has a number of small water spreading projects underway, notably in Kassala and the Red Sea Hills, where "wadi" flow is diverted or spread by earth bunding on sites of traditional cropping. A number of organisations, UN agencies, bilateral projects and NGOs are also involved in various water harvesting/water spreading activities.
Case study 12

TRADITIONAL TERAS CULTIVATION
THE EASTERN PLAINS

INTRODUCTION

"Teras" cultivation is a traditional form of WH used extensively in the clay plains of Eastern Sudan. The word "teras" itself refers to the earthen bund which surrounds three sides of each cultivated plot, and impounds runoff from the plains. While some traditional areas of "teras" cultivation have been replaced by irrigation schemes, others are becoming mechanized and apparently may even have expanded in area. The "teras" system is a technique which is well adapted to the clay plains in arid eastern Sudan, but which also, through its simplicity, could be potentially useful elsewhere. It is of particular interest because it is one of the few examples of traditional WH spread over a very extensive area. This profile concentrates on one focal point of "teras" cultivation: the area around Kassala.

WATER HARVESTING SYSTEM

Techniques and engineering

While there is a considerable range in the design of the structures under "teras" cultivation, plots around Kalahout, west of Kassala town, serve as an example. The visual impression of the landscape is of a checkerboard, with individual plots interspersed within an uncultivated plain. The plain acts as the catchment, and the catchment:cultivated area ratio is rarely below 2:1 and is sometimes considerably greater. The system is essentially an external catchment, long slope technique of water harvesting.

A typical plot may be in the region of 3 hectares in size: in this case the bottom bund (straight, but approximating to the contour) is 300 metres or more in length and the upslope "arms" or wingwalls, aligned at right angles to the bottom bund, are between 50 and 100 metres long. In addition to the side arms which define the extent of the plot, there are usually other parallel bunds every 50 metres or less within the plot. The earthen bunds are 35–40 cm in height, after settling, with a base width of 1.5 – 2 metres. Most bunds in the Kalahout area have been created with a disc plough, but the few bottom bunds which have been built up with a front loader are as high as 75 cm. There is no deliberate provision of a spillway for the evacuation of excess water. On these slopes of approximately 0.5% the bottom bund will normally breach (or be breached) before runoff can back up around the tips of the side bunds.

In a description of "teras" cultivation in Butana from the 1960s (Randall J.R., 1963), the catchment area is referred to as the "sadra" and the cultivated area as the "hugna". Within the main "hugna" there was sometimes a smaller bunded plot termed a "gataa", which would collect a lesser depth of runoff and could be planted earlier.
Case Study 12
Traditional "Teras" Cultivation
Eastern Plains, Sudan

Various Patterns of "Teras" Systems
(Butana - Eastern Sudan)
from Lebon 1967

artist's impression

"gataa"
"hugna"
"gataa" (subsidiary cultivated area)
"hugna" (main cultivated area)
Production system

The "teras" system is essentially for sorghum production. One of the most common varieties grown is "feterita", a white sorghum with a pigmented testa. Another common variety in the Kalahout area is "aklamol", a brown seeded, goose-necked variety. Planting is in holes at one metre by one metre spacing. Several plants are allowed to establish in each station. Where tractor ploughing is practised, as at Kalahout, the disc plough is used to form a type of ridging up-and-down slope within the plot. Sorghum is planted in the bottom of the furrows. The traditional method of land preparation/planting is merely to clear debris from the field and then to use a planting stick, a "seluka", to make the seed holes. Yields of sorghum are said to reach 750 kg/hectare in an average-to-good season, though are usually lower than this figure. It is quite common to see watermelons planted on the bottom bunds, where they can benefit from the relatively good supply of runoff.

Implementation and extension

The "teras" system is entirely traditional and all operations are either carried out by the cultivator manually, or by hired tractors which are becoming more common. The only example of direct assistance from an outside source in the Kassala area was the provision of a front loader for bunding by the Soil Conservation Department in 1987. There are no figures available for the costs involved in the establishment of a "teras" system. However the operations involved are straightforward and, when the bunding is carried out by a tractor, the extra cost above simple ploughing is likely to be marginal. Maintenance of the bunds is required seasonally, but this is a modest task unless breaches have occurred.

The system is very widespread in specific areas. Between Kassala Junction and the Atbara River, there are said to be "thousands" of such plots. The most significant area for "teras", country-wise, are the Butana plains, to the west of the Atbara River. There are no training or extension programmes specific to the "teras" system.

Monitoring, evaluation and reporting

No monitoring system covers "teras" cultivation other than general Government agricultural reporting.

DISCUSSION

Techniques and engineering

The basic engineering system is extremely simple: an earthen bund around three sides of the plot which impounds overland flow. Extra upslope bunds subdivide the plot and ensure a more even impounding of runoff. The system seems to be equally adapted to hand labour or mechanisation, though it is said that with mechanisation some of the sophistication of alignment and construction has been lost. The extensive plains, where slopes are 0.5% or less and vegetation sparse, provide ideal conditions for harvesting runoff in a controlled fashion. While some catchment: cultivated area ratios are very large, around Kalahout a ratio of 2:1 is not uncommon and although this may not satisfy crop water requirement on a theoretical basis, yields are said to be reasonable in all but the poorest years. The lack of spillways could be viewed as a deficiency. The introduction of stone, brushwood or simple plastic pipe spillways would reduce the maintenance demand of breached bunds.
Sorghum is the crop of choice, as in the majority of WH systems in SSA, because of its drought tolerance and ability to withstand temporary inundation. There is a range of sorghums grown in the area and a wealth of local knowledge about their individual attributes. Little however is documented about yields under WH systems. The use of watermelons on the bottom bunds is sensible opportunism, which could perhaps be extended to a range of other crops. It is unusual that the most common alignment of within-plot ridging is downslope. While this assists the concentration of runoff at the bottom of the plot, which may be desirable in a very poor season, it tends generally to produce a more uneven crop. Planting in the bottom of the furrow is indeed the best technique for this area of low rainfall and deep fertile soils.

Implementation and extension

While it can be stated that the technique is obviously widespread and relatively inexpensive, the main comment is that not enough is known about these parameters. It is important to investigate the extent of the "teras" system, and whether it is declining or increasing in importance, and also to quantify the costs involved in construction and maintenance. Training and extension will become of importance when more is known about the system and specific possible improvements are identified.

BACKGROUND DATA

Project/Authority

While rainfed crop production falls under the Ministry of Agriculture, systems involving water harvesting or water spreading are specifically the concern of the Ministry's Soil Conservation Department:

The Director
Soil Conservation, Land Use and Water Programming
P.O. Box 1942, Khartoum

Important references include:


Socio-economic factors

Several ethnic groups practice "teras" cultivation. Around Kassala the Hedendwa (basically cattle herders, many of whom have now settled) are the principal practitioners, though some Rashaida (tent-living semi-nomads) also grow crops under "teras" systems. In the Butana plains, major groups using these techniques are the Shukriya and the Lahawn, both mainly herders. Although there is a considerable number of pure pastoralists within Kassala Province, only 12% of the 1.5 million population are considered true nomads. Population density over Eastern Region is about 7 people/square km, though there is considerable local variation.
Within Kassala Province, crude estimates indicate that the average stock holding per rural family is in the order of 9 SSU. Smallestock predominate in numbers, but there are almost as many camels as cattle. There are no accurate estimates of the proportion of families involved in smallscale rainfed cultivation of the "teras" type.

A plausible explanation for the involvement of semi-nomadic peoples in such cultivation, is that the wet season grazing areas often present the potential of fertile soil at a time of year when there is available labour. Furthermore the by-product of stover (and weeds) is of considerable importance to the livestock herder, even when the main crop fails. Increased sedentarisation, leading to increased interest in cropping has come about due to several factors. These include reduced cattle herds after recent droughts, the blocking of herd migration routes due to extensive mechanised farming in some areas and a growing awareness of the importance of education and access to medical facilities.

Natural resources

Climate

Kassala is on the threshold of the semi-desert zone to the north, but it is just within the "arid" zone, under the climatic zonation system of the Soil Survey Department. The arid zone is characterized as having average annual rainfall of between 225 and 400 mm. In only one or two months of the year is rainfall expected to be more than 50% of potential evapotranspiration. The actual long term average annual rainfall for Kassala is 290 mm, though the average of the first eight years of the 1980s has been less than 250 mm. Mean maximum temperatures range from 34°C in January to 42°C in May. Mean Minimum range from 16°C to 25°C (in the same months).

Soils

The area used for "teras" cultivation are clay plains. Often these plains are alluvial in origin, for example the old Gash Delta near Kassala. Many of the clays show some degree of cracking and indeed there are some vertisols cultivated under this system. Most of the soils are said to be non-sodic and non-saline.

Vegetation

Typically the plains are open with few trees. The trees which do exist, locally, include Balanites aegyptiaca and Acacia sep. in some places, especially close to settlements and roads, Prosopis juliflora has become naturalised, quite densely in favourable parts. Calotropis procera and Capparis decidua are prominent shrubs/bushes in most areas. The grass layer consists mainly of annuals and cover — and correspondingly runoff — varies very considerably dependent on recent rainfall.

Related water harvesting systems

"Teras" systems are not exclusive to the Eastern Region of Sudan and variations can be found as far away as South Darfur, where such bunding is apparently sometimes associated with cultivation of the flood plains of "wadis". However, as the term "teras" refers to the bunds itself, not all "teras" systems are WH systems; some "teras" on hillsides are for soil conservation.
Within Eastern Region, water spreading from "khors" is commonly used for cultivation. Often spreading occurs naturally when the "khor" bed fans out into a "wadi" or onto a plain. Sometimes local cultivators have built traditional diversions, and even used brushwood barrier to collect wind-driven sand which thus develop into bunds which help spread runoff. Recently SCD as well as RDA have instigated water spreading programmes, under which diversion and spreading bunds are constructed.

ZIMBABWE

General background

Area: 38.6 m ha
Population: 8.4 m
Population Growth Rate: 3.2%
Climate: Majority of area below 650 mm rainfall/annum
Staple grain: Maize

Zimbabwean agriculture is highly dualistic: large scale commercial farmers occupy about 40% of the agricultural land, and apart from a small number of small scale commercial farmers, the vast majority of the population farm the "communal" lands, which are for the most part situated in the relatively low rainfall zones. Since 1979, there has been an increase in the share of total agricultural output from communal and other small farmers. Zimbabwe produces a very wide range of agricultural products for consumption and export, though the main crops of the communal farmers are maize and sorghum.

Water harvesting in Zimbabwe

Place in Government: Department of Research and Specialist Services (Research), and AGRITEX (Extension) both under Ministry of Lands, Agriculture and Rural Resettlement

While Zimbabwe has a long history of on-farm soil conservation measures, these have been principally designed for soil conservation, rather than moisture conservation, and have been concentrated in the wetter areas of the country.

As far as is known, there is little or no traditional small scale Wh for plant production. Recently the Department of Research and Specialist Services have begun experimentation with various techniques. At Matopos, the Research Station, oriented to "veld" (rangeland) management, has begun trials on WH (and other) treatments for rangeland rehabilitation, whereas at Chiredzi Research Station, small scale water concentration techniques based on ridging are being tested on-station and on-farm.
INTRODUCTION

Trials with the Chiredzi tied furrow system for rainfed cropping began in 1982. The general objective of developing "conservation and concentration" systems for the communal areas around Chiredzi is to improve the reliability of cropping while accepting that in this area there will always be some years with little or no production. The system has two components, namely the formation of broad based furrows which conserve and concentrate rainfall, and the simultaneous reduction of plant population. Yields using this system at the Chiredzi Research Station have given an average 14 - 20% increase over conventionally planted controls. Tied furrows appear to work impressively in a technical sense. While the system is not yet an official recommendation, on-farm trials have led to a popular demand by farmers to test the technique more extensively on their fields. The development of an extension package and appropriate tools will be necessary to ensure rapid adoption of the technique.

WATER HARVESTING SYSTEM

Techniques and engineering

The "tied furrow" system is basically a short slope (microcatchment) technique, though it is specifically referred to at the station as "conservation and concentration" of rainfall. It consists of a broad based ridge/furrow system, with a 1.5 metre spacing between ridges. The ridge/furrows are formed by a tractor-drawn ridger and are sited on a gradient of approximately 0.33%, which conforms to the alignment of existing conservation bunds. Although other spacings have been tested, 1.5 m combines good performance with convenience of mechanisation. The furrows are considered to be semi-permanent. The height differential between the bottom of the furrow and the apex of the ridge is 30 cm. Earthen ties 15 - 20 cm high are formed by hand within the furrows every 5 to 10 metres, depending on the slope. The system is designed to hold, in situ, a maximum rainfall event of 75 mm (discounting infiltration) before overtopping of the ties allows safe discharge along the gradient of the furrows.

The ridge acts as the catchment and the furrow as the concentration/planted area. The average slope of the side of the ridge is 40%, and this causes appreciable runoff into the furrow where the rainfall is stored after infiltration. The effective catchment to cultivated area ratio is difficult to define, but is at least 1:1, depending on the precise cropping pattern.

Production system

The second important element of the system is the reduction in plant population. Sowing is carried out in a line, on one side only of the furrow, about 20 cm away from the centre, i.e. close enough to make use of the concentrated water while avoiding the danger of waterlogging. The concentration of water improves seedling establishment as well as general performance. It is recommended that, where practicable, the side chosen is that which
Case Study 13
Tied Furrows for Crop Production
Chiredzi, Zimbabwe

Cross Section Tied Furrow System - showing effect of 27 mm rainfall event
faces away from the strong afternoon sun. The overall plant populations are considerably reduced from standard practice to about 33,000 or fewer plants per hectare for sorghum, and 15,000 or fewer for maize.

Sowing is done by hand into moist soil two to three days after a rainstorm. While sorghum, maize and cotton are the main crops, relay planting of additional crops is also recommended in the event of favourable rains. This technique goes some way towards addressing farmer feeling that the spacings are too wide. Crops such as groundnuts, cowpeas and pigeon peas have been tested in this respect. Relay crops are planted on the opposing side of the furrow. Fertilizers are applied on the red paragneiss soils and the alluvia also, though they are not required for the fertile vertisols. Sandy soils do not respond to the extra water without considerable improvements in fertility. Farmyard manure and phosphorus fertilizers are applied pre-planting beneath the furrows and nitrogenous fertilizer applied, if continuing rain warrants, as a top dressing.

Yield responses to the tied furrow system have been consistently positive since trials began, with the exception of maize failures (in all plots) in drought years, and no responses on unfertilized sandy soils. Over a four year period the average increase in yield for sorghum, maize and cotton, on a red paragneiss soil ranged from 14-25%. Two of the years experienced good rainfall, and the other two were drought years. During this period the average yield of sorghum grown on the flat was 1,415 kg/ha, and under furrows was 1,715 kg/ha.

Implementation and extension

The system is limited to the station’s own plots (on about 8 hectares) and on-farm trial plots (35 plots of about 0.2 ha each). On the farmers’ plots, initial construction of the furrows has been carried out by the station’s tractors. Various inputs have also been supplied, though the participant farmers have provided their own labour. Although the trial stage is as far as the system has progressed at present, there is considerable demand from farmers for the tractor drawn ridger to expand the area under tied furrows on their land.

Tied furrows are made by a tractor with a ridger, after initial ploughing where necessary. The actual ridging operation can be done twice as quickly as the ploughing. Ties are constructed by hand. Both planting and weeding have to be done by hand at present, as a suitable ox-draught tool has not yet been developed. Upkeep of the system in subsequent years is limited to a ripping (or similar operation) of only the planted zone, restructurig each season. In most situations therefore the system required less cultivation effort than the customary ploughing.

As tied furrows are not yet a general recommendation, training is limited to contact with the farmers involved in the trials.

Monitoring, evaluation and reporting

Since the development of the tied furrow system is under the auspices of a Research Station, monitoring of performance parameters is particularly thorough. Plant yields are recorded from all plots involved in the trial, soil fertility is monitored, and soil moisture is measured with neutron probes. The station also records runoff from a simulated tied furrow, where a gutter is situated at the bottom of the furrow to collect runoff.
Apart from regular station reports, the tied furrow system has been the subject of various papers. A comprehensive description was presented at a workshop in 1987 (see section 4).

DISCUSSION

Techniques and engineering

Tied ridging is a well known system in Africa, but normally the ridges/furrows are narrow and act as in situ moisture conservation systems, rather than microcatchments. The Chiredzi tied furrows, being wider based, actually concentrate water around the plant roots from a defined catchment (the ridge) and the planting configuration is such that the crop lines are at a wider than normal spacing, and situated adjacent to the stored moisture. This is a variation of the contour ridge technique described in case study 46, differing in that the whole land surface is disturbed and is very similar to the "microwatersheds" used experimentally in the Negev desert of Israel. Technically the system is appropriate in terms of WH as well as soil conservation. The very short length and the high slope of catchment ensures runoff from even very small rainfall events. The alignment of the furrows on a slight gradient provides a relatively erosion-free emergency overflow facility.

Production system

The production system is based on the popular crops of the area, however the low plant populations may prove a stumbling block to easy adoption. Nevertheless, low plant populations themselves are an effective method of increasing production when the rains are poor and in combination with WH, the effect is magnified. However very low populations of maize in particular will inevitably reduce the top yields in the best years. In this context, the introduction of relay crops is a sensible way of making more efficient use of excess water in good seasons. The introduction of new crops for relay planting is a promising idea, especially so when the choice is a rapidly maturing legume.

Implementation and extension

Testing of the system over a five year period both on-station and on-farm has created the base for potential adoption as an extension recommendation; and the demand for the system by farmers testifies to its growing popularity, after several years of first hand experience. The costs of the system are reasonable - namely a 50% increase in land preparation in the first season, followed by considerably reduced costs each season thereafter, in all soils except vertisols. However these costs are dependent on the availability of hired tractors for original furrow construction and the provision of suitable oxen drawn tools for subsequent maintenance/land preparation, as well as the development of appropriate tools for weeding. It is these factors which probably present the most serious constraint to rapid adoption of the system.

Training of the farmers through on-farm trials/demonstrations is evidently beginning to show results. Four years of first hand experience have created confidence. The challenge will be the eventual translation of this training experience into an extension message.
Monitoring, evaluation and reporting

Although it might be expected from a research station, the standard of data collection, its presentation and discussion, is extremely comprehensive.

BACKGROUND DATA

Project/Authority

Chiredzi Research Station
Department of Research and Specialist Services
P.O. Box 97, Chiredzi, Zimbabwe

Chiredzi Research Station falls under the Ministry of Lands, Agriculture and Rural Resettlement’s Department of Research and Specialist Services and is the main Lowveld Research Station in Zimbabwe. Its research emphasis has changed in the 1980s from irrigated crop production towards the problems of rainfed crop production in natural Region V.

Important report include:

Recommendations for Cropping in the Semi-Arid Areas of Zimbabwe: a report of a workshop held at University of Zimbabwe in August 1987 (includes sections reporting Chiredzi experience).

Socio-economic factors

In the "communal areas" around Chiredzi, where livestock are often of prime importance, families cultivate a relatively large area (up to 15 ha is apparently common) and grow maize, sorghum and some cotton. Maize, though less well suited agronomically to the area than sorghum, is preferred as a food. Crop failures are interspersed with years of surplus. Reliability of production is more of a problem than long term average yields. Most of the cropped land has already been treated with graded soil conservation bunds. Most families own oxen with ploughs and those without can hire from those who have. A tractor hire service, with limited capacity does exist.

Natural resources

Climate

The area falls within Natural Region V where the official description states that: "rainfall in this region is too low and erratic for the reliable production of even drought resistant fodder and grain crops". The long term average annual rainfall is 525 mm at Chiredzi. The average over the growing season is 450 mm with a range of 250 to 1,200 mm. Rainfall events of up to 200 mm in less than 24 hours have been experienced. Open pan evaporation is approximately 2,000 mm in a year and 950 mm over the growing season. It has been calculated that over a 67 year period, the rainfall (amount and distribution) would have adequately met the crop water requirement of sorghum in only 15 seasons. Rainfall occurs during the summer which lasts from October until the end of March. During the summer mean maximum temperatures range between 31 and 34°C and mean minima between 16.5 and 20°C. The start of the rains, defined as the date when 100 mm has fallen, occurs on average
during the third week in November.

Soils

There are four common types of soil in the area: vertisols, red paragneiss, alluvium and sandy soils. Topography is generally flat or gently sloping. The vertisols are rich in nutrients, the sandy soils infertile and the other two types intermediate. Most of the testing of the tied furrow system and the most consistent results have been from plots on the red paragneiss soils.

Total average runoff is calculated to be approximately 33% of the rainfall on bare soil with a 2–3% slope, and similar amounts can occur on lower slopes during heavy storms.

Vegetation

The immediate vicinity is characterised by Baobab (Adansonia digitata) and Mopani (Colophospermum mopani) trees. Ground cover of grasses and forbs is generally good where the tree stands are sparse.

Date visited: October 1988
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ANNEXE 1 - GLOSSARY

adoption the voluntary uptake of a system by farmers/villagers

agropastoralism the combination of pastoralism with cropping

agropastoralist are those who practise agropastoralism

bund an earth or stone structure larger than a ridge

"caag" a traditional WH system in Somalia where earth bunds impound channel flow (see case study 10)

catchment (catchment area)
area of land surface producing runoff

catchment: cultivated area ratio (C:CA ratio)
size of the runoff generating catchment relative to the area cultivated

catchment length the distance from the top to the bottom of a catchment

contour a line joining points of the same elevation on the land’s surface

contour bund an earth or stone structure, larger than a ridge, following the contour

contour ridge a small earth structure, usually 10–20 cm in height, which follows the contour

cut-off drain (= diversion ditch)
a ditch made to protect cultivated land from external runoff. Normally graded at 0.25–0.5%

"demi-lune" French term, (literally "half moon") for semi-circular hoop

dry planting technique of planting crops before the rains

ephemeral flow flow which occurs for short duration, often in torrents, in normally dry watercourse

external catchment system (= long slope catchment technique)
WH technique making use of overland flow, or rill flow, from catchments outside the cropped area. Catchment lengths in the order of 30–200 metres. C:CA ratios typically 2:1 to 10:1. Spillways necessary to dispose of excess runoff.
"fanya-Jumu" an earth terrace bank formed by throwing soil upslope (from the Kiswahili "do up")

floodwater harvesting (= water spreading)

a WH system which uses channel flow (a "wadi" for example) as its source of runoff. C:CA ratios very large.

food-for-work food rations supplied in exchange for labour

freeboard the height of a bund above the maximum depth of ponded water

FYM farmyard manure

"gawan" a traditional WH/in situ moisture conservation system used in Somalia (see case study 10)

horizontal interval the distance between two structures

in situ moisture conservation

system conserving rainwater where it falls, permitting no runoff (thus differing from WH)

intercropping a combination of crops grown simultaneously in a mixture, often in alternating lines

"kawawa" two-man push-pull shovel used in Somalia for making earth bunds (see case study 10)

level flooded terraces

a system of water harvesting where successive levelled basins are formed in steps along a valley. Spillways are constructed within the bunds

long slope catchment technique see "external catchment system"

microcatchment (= short slope catchment technique)

WH techniques which make use of overland flow from catchments typically less than 20 or 30 metres in length. C:CA area ratios usually 1:1 to 3:1. Catchments normally interspersed amongst the crop/trees (hence sometimes referred to as "within-field catchment system")

"negarim micro-catchment"

specific microcatchment technique of catchment basins used for trees, normally in a continuous block with diamond-shaped pattern. Trees are planted in pits at the lowest corner. An Israeli term derived from the Hebrew "Neger", meaning runoff.
permeable rock dam

long, low, level rock structure across a valley bottom used for water spreading. A translation of the French term "digue filtrante" (see case study #2)

r/Eo ratio

the ratio (of aridity) between rainfall (r) and open water evaporation (Eo). Open water evaporation is approx. 80% of potential evapotranspiration

ratoon

second harvest taken from (typically) a sorghum crop after the plants have been cut back

relay crop

supplementary crop planted amongst another already established crop

replicability

the "transferability" of a technique from one situation to another

ridge

an earth structure smaller than a bund. Usually 10–20 cm high. Spaced closer together than bunds. May follow the contour, be slightly graded, or straight

runoff

surface flow of rainwater occurring when rainfall intensity exceeds the infiltration capacity of the soil

SSU

standard stock unit

"sekuka"

a pole used for punching planting holes in Sudan

semi-circular hoops

ridges of earth formed in a semi-circular shape (see case study 4)

short slope catchment technique see "microcatchment"

spate irrigation

floodwater harvesting where spate flow is diverted from a "wadi"

spillway

an outlet allowing overflow of excess runoff

SSWHS

the Sub-Saharan Water Harvesting Study

stover

leaves and stems of crops left as harvest by-product

"teras"

Arabic word for bund. Used in Sudan additionally to describe a traditional WH technique where plots are bunded on three sides (see case study 12)

ties (cross-ties)

arthern plugs made in furrows to prevent lateral flow of runoff

"toog" (or "tug")

Somali word for "wadi"

trapezoidal bund

a type of long slope catchment technique where runoff is impounded behind an earth bund with configuration of three sides of trapezoid when seen from above (see case study 3)
"V"-shaped microcatchment

Open-ended catchment basins for trees, constructed in a "V" shape

**vertical interval**

Spacing between two structures determined on the basis of a fixed difference in ground elevation

**"wadi"**

Arabic term for a watercourse with ephemeral flow which often spreads on to plains

**"wasug"**

A push-pull shovel used for earth bund construction in Sudan

**water harvesting**

The collection and concentration of surface runoff, before it reaches seasonal or perennial streams, for productive use. In the context of SSWHS, water harvesting is limited to plant production systems

**water spreading**

See floodwater harvesting

**wingwalls**

Side bunds extending upslope from a base, or bottom, bund – for example in a trapezoidal bund system

**within-field catchment system** See "microcatchment"

**"zai" or "zay"**

Hand-dug about 20 cm, deep and wide planting pits used in West Africa for concentration of runoff
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