Water Harvesting

Indigenous Knowledge for the Future of the Drier Environments

Theib Oweis
Dieter Prinz
Ahmed Hachum

International Center for Agricultural Research in the Dry Areas (ICARDA)

Water Harvesting

Indigenous Knowledge for the Future of the Drier Environments

Theib Oweis
Dieter Prinz
Ahmed Hachum

International Center for Agricultural Research in the Dry Areas (ICARDA)

The authors: Theib Y. Oweis is Senior Irrigation and Water Management Scientist at the International Center for Agricultural Research in the Dry Areas (ICARDA), Dieter Prinz is Professor of Agricultural Engineering at the University of Karlsruhe, Germany, and Ahmed Y. Hachum is Professor of Irrigation and Drainage Engineering at the University of Mosul, Iraq.

Recommended Citation: Oweis, T., D. Prinz and A. Hachum. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo, Syria. 40 pages.

Key words: water harvesting, drier environments, water scarcity, micro-catchment, macro-catchment, desertification, afforestation, runoff farming.

Front Cover

Top

The traditional *Jessour* water-harvesting system built to support palm trees, olives and figs in the dry areas of southern Tunisia.

Bottom

An indigenous water-harvesting system, which still provides drinking water for people and livestock in the WANA region.

Back Cover

Top

In Western Sudan, under conditions of extreme water scarcity, water harvesting is the main source of water for human and live stock consumption.

Middle

Eyebrow system on fig trees concentrate runoff water and help to overcome the long, dry summer in North West Egypt.

Bottom

A small runoff-basin system supporting shrubs, at a demonstration site for micro-catchment water harvesting at the ICARDA research station, Tel Hadya, Syria.

All photos by T. Oweis except where indicated otherwise.

ICARDA
P.O. Box 5466, Aleppo, Syria.
Tel.: (963-21) 2213433, 2225112, 2225012.
Fax: (963-21) 2213490/2225105/2219380.
E-Mail: ICARDA@CGIAR.ORG
Web site: http://www.icarda.cgiar.org

Foreword

The steppe, known as *al-badia* in Arabic, covers vast areas of land in West Asia and North Africa (WANA), and is characterized by harsh climatic conditions. People who live in the steppe are economically disadvantaged, being totally dependent on the availability of grazing for their livestock—their main source of income. Drought and overgrazing are seriously eroding the capacity of the steppe to support the livestock feeding. As a result, migration from the steppe to urban areas is increasing, but this entails social and environmental problems. At the same time, production of livestock and therefore of meat and dairy products is declining, which has implications for their price in the market and for human nutrition.

In view of these realities, the importance of supporting research and development in the drier environments cannot be underestimated. The cost of doing nothing, and so letting this cycle of degradation and migration continue, cannot be predicted using conventional economics, but is undoubtedly very high. If people's living standards are to be raised, and the migratory trends reduced, it is essential to improve the management of natural resources in the dry areas.

The most important natural resource in the drier environments is rainfall. Despite its scarcity, rainfall is generally poorly managed, and much of it is lost through runoff and evaporation. Capturing the rainwater and making an efficient use of it is crucial for any integrated research and development project. Water harvesting can play an important role in meeting the objectives of such projects.

Water harvesting is not a new concept; indeed, we have inherited a wealth of indigenous knowledge about this ancient practice. ICARDA (International Center for Agricultural Research in the Dry Areas) recognizes the importance of this knowledge and has developed a project to blend the indigenous with modern knowledge for the benefit of the WANA region. The project is exploring the potential of different techniques, and adapting them to local conditions. Known as "On-farm Water Husbandry in West Asia and North Africa," this project covers 11 WANA countries.

This publication distils the knowledge and experience of water harvesting gained by ICARDA, national research groups, and advanced institutions over the years and presents them in a non-technical language. Although it emphasizes the techniques most suitable for the steppe areas of WANA, the principles outlined are applicable in dry areas worldwide.

We hope this publication will prove useful to decision makers in national governments, national researchers, donor agencies, and to other stakeholders in agricultural research and development.

Prof. Adel El-Beltagy
Director General, ICARDA

Contents

Introduction

The Challenge of Dry Areas

Rainfall in the drier environments is generally insufficient to meet basic needs for crop production. As it is poorly distributed over the growing season and often comes in intense bursts, it usually cannot support economically viable farming. In the Mediterranean areas, for example, annual rainfall is generally less than 250-300 mm and comes mainly in sporadic, unpredictable storms. Even this water is mostly lost in evaporation and runoff, leaving frequent dry periods during the growing season.

Runoff can occur even in relatively flat areas, where unfavorable soil surface conditions prevent infiltration. Here, most of the rain collects as puddles, before flowing into streams and then into swamps or "salt sinks," where it loses quality and evaporates; only a small portion joins the groundwater. On its way it may cause substantial gully erosion.

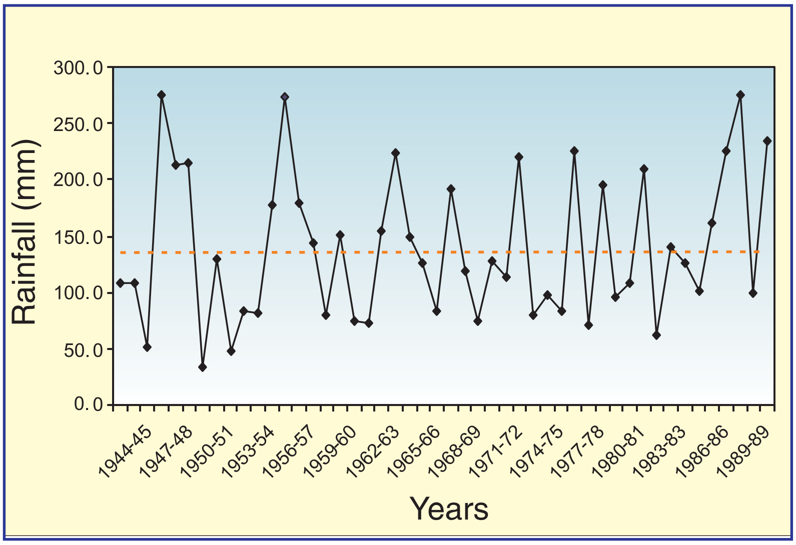
Loss of what little rainfall there is causes severe moisture stress in growing crops, reducing yield drastically if, indeed, any yield is produced at all. The problem is exacerbated by other unfavorable natural conditions, such as extreme temperatures during cropping periods and shallow soils of poor quality.

Rainfall is mostly lost in evaporation immediately after it falls. Photo from the Syrian badia *near Palmyra.*

Runoff water in the badia *causes substantial erosion before being lost in "salt sinks."*

Typical degraded lands in the Jordanian badia*; note the poor vegetative cover.*

Although social and cultural factors may be implicated, the loss of water without benefit for agricultural or domestic use, and the mismanagement of land, are significant factors in the process of desertification and the increasing poverty of the dry areas. For agriculture to have a chance of success, rainwater must be husbanded and land must be properly managed. Water harvesting is the key to making better use of rainwater for agricultural purposes: it increases the amount of water available per unit of cropping area, reduces the impact of drought, and uses runoff beneficially.



Typical annual rainfall with great variability and low amounts in the drier environments of WANA. Data for Matrouh, northern Egypt.

Purpose and Scope of this Document

As water shortage in the dry areas is a recurrent crisis, people have a great need for information on how to capture and use every available drop of water efficiently. Water harvesting is an effective and economical means of achieving this objective and information on its various systems and techniques is in great demand.

Although many publications focus on water harvesting, most of them are technical papers in scientific journals with limited value to the average water-harvesting practitioner. Furthermore, each document covers only selected aspects of water harvesting for a specific region or environment. Other documents on water harvesting are published as country reports with very limited circulation and are usually site-specific, mainly for sub-Saharan Africa.

Unlike technical papers in scientific journals, this publication covers the essential aspects of water harvesting, concisely and simply, in a manner that responds to the needs of ICARDA's national research and development partners. The knowledge and techniques most suitable and adaptable to the WANA region are presented. Also summarized here, are some of the findings of the adaptive research conducted by ICARDA and its national partners, and indicates future research needs. The approach adopted in classifying, presenting and relating water-harvesting systems to field conditions is unique in the literature, and is believed to be appropriate to the nature and needs of practitioners in the region.

The main purpose of this publication is to increase awareness, among those working directly with farmers, of the potential of water harvesting, and its technical and socioeconomic aspects. It should also prove helpful to policy-makers in charge of developing water resources, as well as to all those with an interest in dryland agriculture. In many places previously published material is used. A list of major sources of information and references for further reading is provided.

Principles and Benefits of Water Harvesting

What is Water Harvesting?

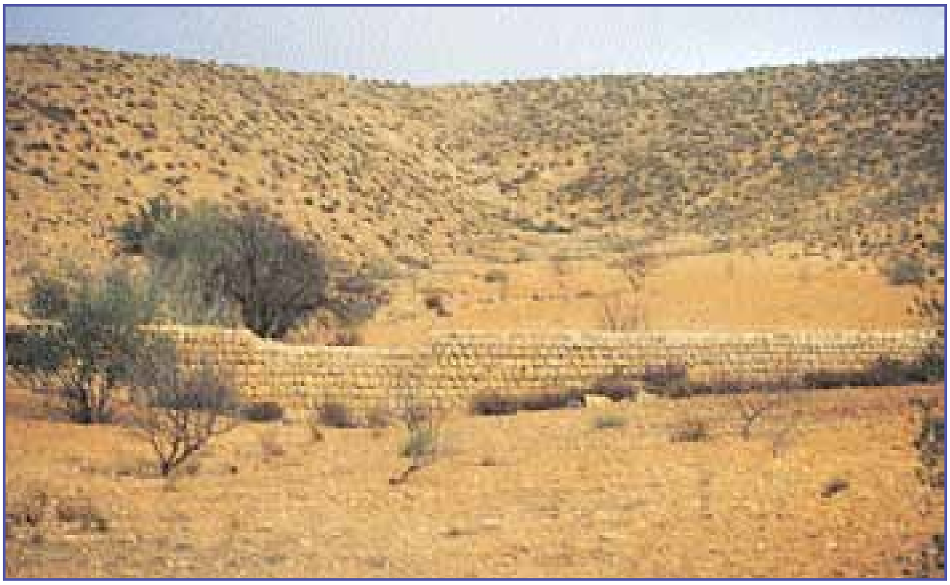
Water harvesting is based on the principle of depriving part of the land of its share of rain, which is usually small and non-productive, and adding it to the share of another part. This brings the amount of water available to the latter area closer to crop water requirements and thereby permits economic agricultural production.

For example, an area of four hectares in an arid zone receiving 150 mm of annual rain cannot normally produce an economic crop. If two hectares forming one half of the area add their share of 150 mm of rain to the other half, then the latter will have a total of 300 mm. This amount may be enough to support drought-resistant crops. Furthermore, if three hectares of the land contribute their quantity of rain to the remaining one hectare, this quarter would have a total of 600 mm, i.e. its own 150 mm share of rain and the shares of the other three hectares (450 mm). If well distributed, this may be enough to support quite a wide range of crops. Of course, in reality, only a portion of this water may be diverted easily and at low cost. Such concentration of rainwater is called water harvesting, which may be defined as "the process of concentrating precipitation through runoff and storage, for beneficial use."

Rainwater naturally harvested in depressions in Marsa Matrouh in northern Egypt, where it supports figs and olives.

Water harvesting may occur naturally or by intervention. Natural water harvesting can be observed after heavy storms, when water flows to depressions, providing areas for farmers to cultivate.

Water harvesting by intervention involves inducing runoff and either collecting or directing it, or both, to a target area for use. Besides being applied to agriculture, water harvesting may be developed to provide drinking water for humans and animals as well as for domestic and environmental purposes.



The indigenous jessour *system of Tunisia, using stone walls, has supplied fig and olive trees with sufficient water in a very dry environment for hundreds of years.*

An Ancient Practice

As long as people have inhabited the drylands and have cultivated crops, they have harvested water. Ephemeral streams (*wadis*) and water collected in *wadi* beds and cisterns, supported people's livelihoods in the arid and semi-arid areas many thousands of years ago, and allowed the growth and development of cities. Millions of hectares of land in the dry parts of the world must once have been cultivated using water harvesting, but, for a variety of reasons, this practice has steadily declined.

The importance of West Asia and North Africa in the development of ancient water-harvesting techniques is unquestioned. In southern Jordan early water-harvesting structures are believed to have been constructed over 9,000 years ago. Evidence shows that simple water-harvesting techniques were used in southern Mesopotamia as early as 4,500 BC.

Runoff agriculture in the Negev desert can be traced back as far as the 10th century BC. In Yemen a system dating back to at least 1,000 BC diverted runoff water to irrigate 20,000 ha, producing crops that may have fed as many as 300,000 people. In southern Tihama, Yemen, runoff agriculture is traditionally used for sorghum production. In Baluchistan, Pakistan, the *khuskaba* and the *sailaba* systems, described here later, were applied in ancient times, and are still in use today.

Even in pre-Roman times, water-harvesting techniques were applied extensively in North Africa. Archeologists have revealed that the wealth of the "granary of the Roman Empire" was largely based on runoff agriculture. In Morocco's Anti-Atlas region a great variety of harvesting techniques still exists. In Tunisia water-harvesting systems known as the *meskat*, the *jessour* and the *mgoud*, using slopes and walls, have a long tradition and are still practiced. In Egypt, the northwest coast and the northern Sinai areas have a long tradition in using cisterns and *wadi-bed* runoff cultivation.

How Can Water Harvesting Help?

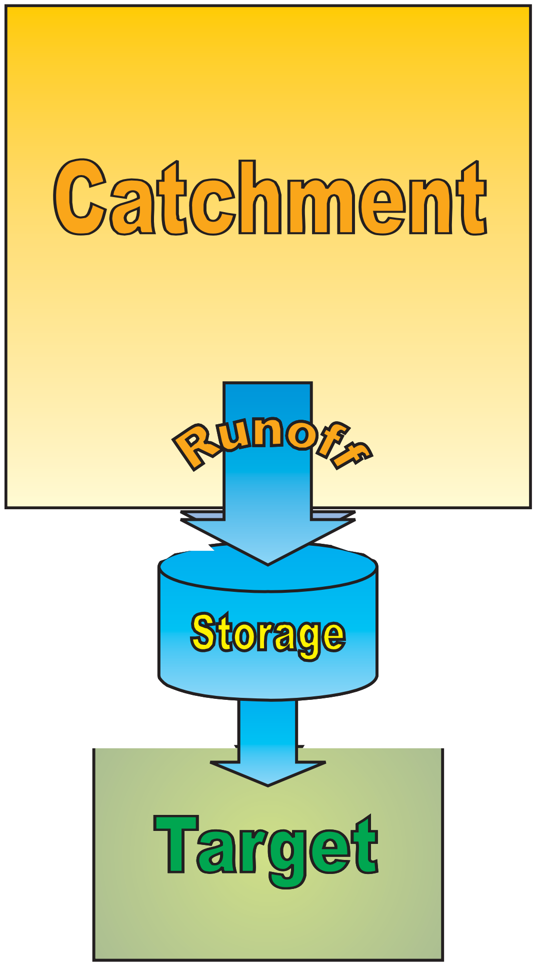
Water harvesting is particularly advantageous in the following circumstances:

- In dry environments, where low and poorly distributed rainfall normally makes agricultural production impossible. Provided other production factors such as soils and crops are favorable, water harvesting can make farming possible despite the absence of other water resources.
- In rainfed areas, where crops can be produced but with low yields and a high risk of failure. Here water-harvesting systems can provide enough water to supplement rainfall and thereby increase and stabilize production.

Water-harvesting reservoirs dug in the rocky mountains of Al Baida, near Petra in southern Jordan, supported civilizations several thousands of years ago.

- In areas where water supply for domestic and animal production is not sufficient. These needs can be satisfied with water harvesting.
- In arid land suffering from desertification, where the potential for production is diminishing, due to lack of proper management. Providing water to these lands through water harvesting can improve the vegetative cover and can help to halt environmental degradation.

The specific benefits listed above lead in turn to many other non-tangible and indirect socioeconomic gains. These include the stabilization of rural communities; reduced migration of rural people to cities; use and improvement of local skills; and improvement in the standard of living of the millions of poor people living in drought-stricken areas.



Components of Water-Harvesting Systems

The main components of water harvesting systems are:

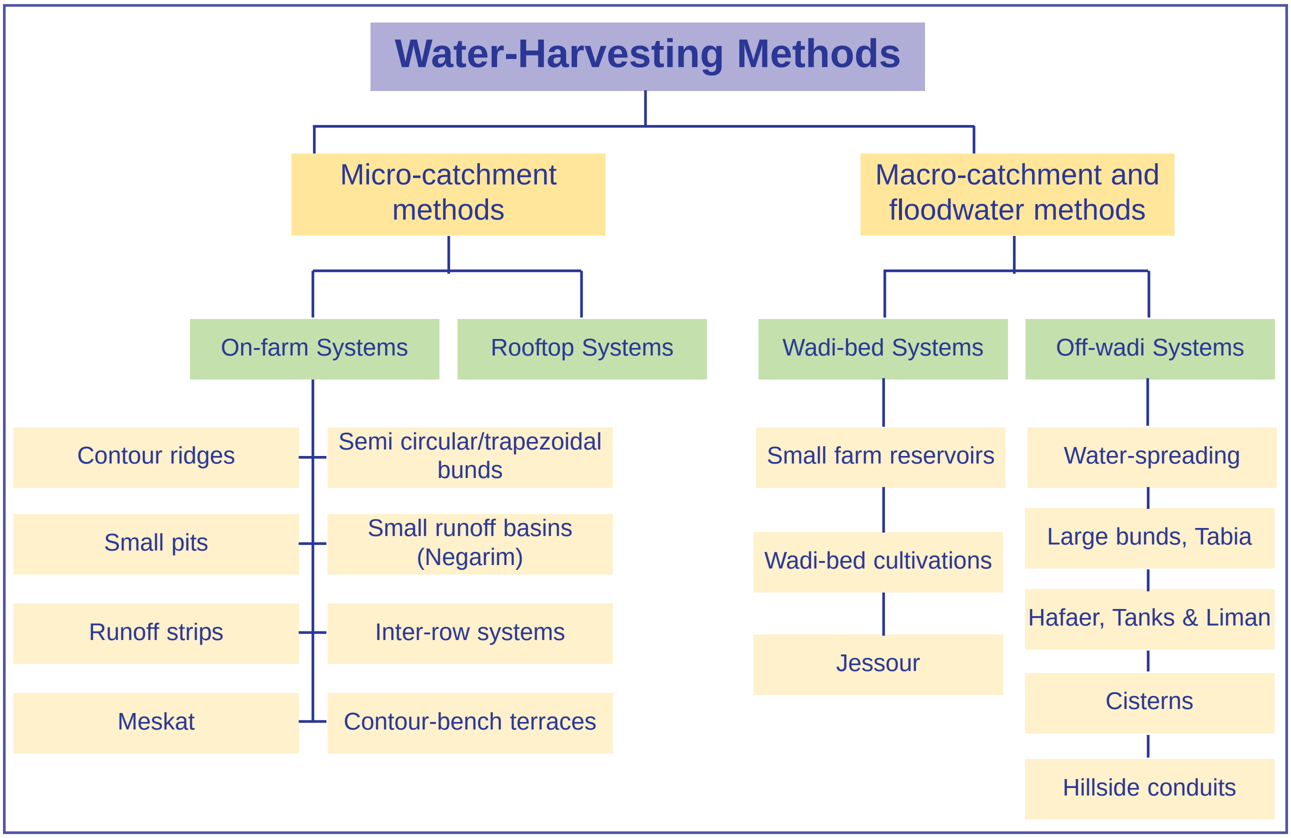
Catchment area: the part of the land that contributes some or all its share of rainwater to a target area outside its boundaries. The catchment area can be as small as a few square meters or as large as several square kilometers. It can be agricultural, rocky or marginal land, or even a rooftop or a paved road.

Storage facility: the place where runoff water is held from the time it is collected until it is used. Storage can be in surface reservoirs, subsurface reservoirs such as cisterns, in the soil profile as soil moisture, and in groundwater aquifers.

Target area: where the harvested water is used. In agricultural production, the target is the plant or the animal, while in domestic use, it is the human being or the enterprise and its needs.

Overview of Water-Harvesting Systems

As water harvesting is an ancient tradition and has been used for millennia in most drylands of the world, many different techniques have been developed. Most of these are for irrigation purposes, while others are to conserve water for human and animal consumption. The same techniques sometimes have different names in different regions and others have similar names but, in practice, are completely different. Water-harvesting methods are classified in several ways, mostly based on the type of use or storage, but the most commonly used classification is based on the catchment size.



Classification of water-harvesting systems

Micro-catchment Systems

Micro-catchment systems are those in which surface runoff is collected from a small catchment area with mainly sheet flow over a short distance. Runoff water is usually applied to an adjacent agricultural area, where it is either stored in the root zone and used directly by plants, or stored in a small reservoir for later use. The target area may be planted with trees, bushes, or with annual crops. The size of the catchment ranges from a few square meters to around 1000 m^2. Land catchment surfaces may be natural, with their vegetation intact, or cleared and treated in some way to induce runoff, especially when soils are light. Non-land catchment surfaces include the rooftops of buildings, courtyards and similar impermeable structures.

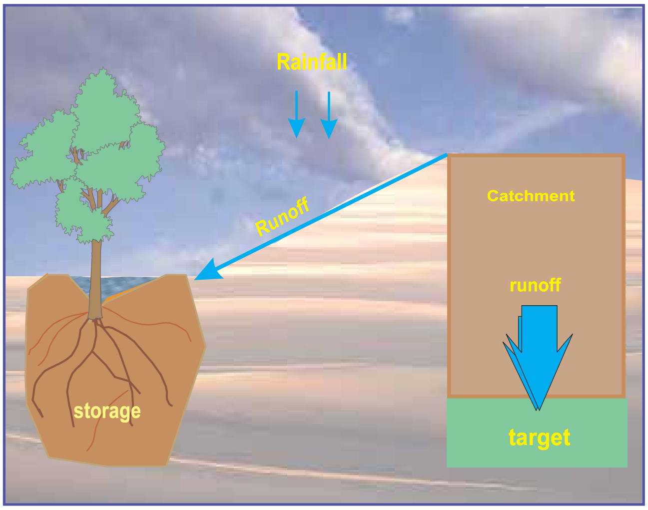


Diagram of micro-catchment water-harvesting systems

On-Farm Systems

On-Farm micro-catchment systems are simple in design and may be constructed at low cost, making them easily replicable and adaptable. They have higher runoff efficiency than macro-catchment systems and do not usually need a water conveyance system. They allow soil erosion to be controlled and sediments to be directed to settle in the cultivated area. Suitable land-based micro-catchment techniques exist for any slope or crop. However, these systems generally require continuous maintenance with a relatively high labor input.

Unlike macro-catchment systems, the farmer has control within his farm over both the catchment and the target areas. All the components of the system are constructed inside the farm boundaries. This is an advantage from the point of view of maintenance and management, but because of the loss of productive land it is only in the drier environments, where cropping is most risky, that farmers are willing to allocate part of their farm to a catchment.

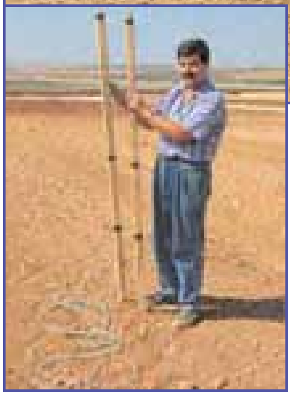
The most important land-based micro-catchment or on-farm water-harvesting systems in the dry areas of WANA are described below.

1. Contour ridges

These are bunds or ridges constructed along the contour line, usually spaced between 5 and 20 m apart. The first 1–2 m above the ridge is for cultivation, whereas the rest is the catchment. The height of each ridge varies according to the slope's gradient and the expected depth of the runoff water retained behind it. Bunds may be reinforced by stones if necessary. Ridging is a simple technique that can be carried out by farmers. Ridges can be formed manually, with an animal-driven implement, or by tractors with suitable implements. They may be constructed on a wide range of slopes, from 1% to 50%.

The key to the success of these systems is to locate the ridge as precisely as possible along the contour. Otherwise water will flow along the ridge, accumulate at the lowest point, eventually break through and destroy the whole downslope system. Surveying instruments, or an A-Frame and hand tools, can be used for contouring, but these methods are too sophisticated and time-consuming for most small-scale farm-

Contour ridges constructed at the ICARDA research farm at Tel Hadya, northern Syria.

The tube level is used to locate the contour precisely before ridge construction. Low in cost and easy to use by farmers.

ers. The simplest method is a transparent, flexible tube 10–20 m long, fixed on two scaled poles. The tube is filled with water so that the two water levels are clear on the scale. Two people can trace the contour by adjusting the position of one of the poles so that their water levels are the same.

Contour ridges supporting young shrubs with sufficient amount of water in the dry environment of the badia *of Jordan.*

If precise contouring is not feasible, small cross-bunds (ties) may be added at suitable spacing along the ridge to stop the flow of water along the ridge. Contour ridges are one of the most important techniques for supporting the regeneration and new plantations of forages, grasses and hardy trees on gentle to steep slopes in the steppe. In the semi-arid tropics, they are used for arable crops such as sorghum, millet, cowpeas and beans.

A special form of contour ridge may be constructed for use with stone bunds on gentle slopes. Stone bunds are permeable structures working only to slow down sheet flow and promote infiltration. Earth can be excavated and added to the upstream side of the bund to turn it into an impermeable contour ridge. In the semi-arid tropics, this system is sometimes combined with other techniques, such as the *zay* system or the tied-ridge system. These stone bund systems can be used only if suitable large stones are available in the vicinity.

2. Semi-circular and trapezoidal bunds

These are usually earthen bunds in the shape of a semi-circle, a crescent, or a trapezoid facing directly upslope. They are created at a spacing that allows sufficient catchment to provide the required runoff water, which accumulates in front of the bund, where plants are grown. Usually they are placed in staggered rows.

The diameter or the distance between the two ends of each bund varies between 1 and 8 m and the bunds are 30–50 cm high. Cutting the soil to form the bund

Layout of semi-circular bunds in staggered rows in the field. Photo from the Syrian badia.

Semi-circular bunds planted with Atriplex halimus, *collected additional water after a moderate storm, in northern Syria.*

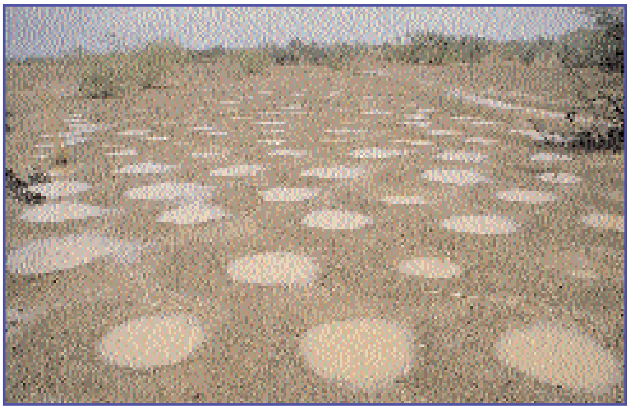
immediately upstream creates a slight depression. Runoff is intercepted here and stored in the plant root zone. If soil is cut upstream the slope is increased and this raises the runoff coefficient; in this way the technique can be used on level land, but it can also be used on slopes up to 15%. These bunds are used mainly for the rehabilitation of rangeland or for fodder production, but may also be used for growing trees, shrubs and in some cases field crops (e.g. sorghum) and vegetables (e.g. watermelons).

An eyebrow terrace is a form of semi-circular bund supported by stones on the downstream side. The greater the slope, the more the bunds have to be strengthened with stones. The establishment and maintenance of this system is labor-intensive.

3. Small pits

Pitting is a very old technique used mainly in Western and Eastern Africa, but adopted in some WANA areas. It is excellent for rehabilitating degraded agricultural lands. The pits are 0.3–2 m in diameter. The most famous pitting system is the *zay* system used in Burkina Faso. This consists of digging holes to a depth of 5–15 cm. Manure and different kinds of grass are mixed with some of the soil and put into the *zay*. The rest of the soil is used to form a small dike

An eyebrow terrace supporting fig trees with additional runoff water near Salloum in northwestern Egypt.



The zay *system concentrates substantial runoff water in the pit, where the crop is grown. (Photo by Prinz).*

Left: *The* Kimseed *pitting machine adapted by ICARDA for use in West Asian environments*

Below: *Pits created by a pitting machine ensure a suitable environment for reseeding steppe areas.*

down the slope of the pit. Pits are applied in combination with bunds to conserve runoff, which is slowed down by the bunds. This system allows much degraded agricultural land to be put back into use.

Pitting systems are used mainly for the cultivation of annual crops, especially cereals such as millet, maize and sorghum. However, if the pits are dug on flat instead of sloping ground, they may be regarded more as an *in situ* moisture-conservation technique than as a water harvesting one. The labor requirement for digging a *zay* system is high and may constitute a considerable investment in the first and even in subsequent years since, after each tillage, the pits have to be restored. A special disk-plow may be adapted to create small pits for range rehabilitation.

4. Small runoff basins

Sometimes called *negarim*, small runoff basins consist of small diamond- or rectangular-shaped structures surrounded by low earth bunds. They are oriented to have the maximum land slope parallel to the long diagonal of the diamond, so that runoff flows to the lowest corner, where the plant is placed. The *negarim* is best used on even ground. The usual dimensions are 5–10 m in width and 10–25 m in length. Small runoff basins can be constructed on almost any gradient, including plains with 1–2 % slopes; but on slopes above 5 %, soil erosion may occur and the bund height should be increased. They are most suitable for growing tree crops such as pistachio, apricot, olive, almond, and pomegranate, but may be used for other crops. When they are used

The negarim *allows runoff water to concentrate at the lowest corner of the basin where the plant needs it.*

for trees, the soil should be deep enough to hold sufficient water for the whole dry season.

If the catchment is well maintained, 30–80 % of the rain can be harvested and used by the crop. Soil conservation is a positive side-effect of *negarims*. Once the *negarim* system is constructed, it lasts for years with little maintenance. Plowing to control weeds may not be practical within the small space of each basin, so weeding may have to be done by hand or with chemicals. If the *negarim* is built on heavy or crusting soils, a high runoff coefficient may be achieved. However, since the system supports high-value crops, it can be economical to take measures to induce additional runoff.

Negarim *plots are best for trees, particularly when runoff inducement measures are economical, such as this system, for almonds in the Jordanian* badia.

5. Runoff strips

The technique of runoff strips is suitable for gentle slopes. The strips are used to support field crops in the drier environments (such as barley in the *badia*), where production is risky yields are low. The farm is divided into strips along the contour. An upstream strip is used as a catchment, while a downstream strip supports crops. The downstream strip should not be too wide (1–3 m), while the catchment width is determined in accordance with the amount of runoff water required. Runoff strip-cropping can be fully mechanized and needs only a relatively low input of labor. The same cropped strips are cultivated every year. Clearing and compaction may be needed to improve runoff.

Agricultural inputs such as fertilizers and pesticides are applied to the cultivated area, as well as water. Under good management, continuous cultivation of the cropped strip can build up soil fertility and improve soil structure, making the land more productive. This technique is highly recommended for barley cultivation and other field crops in large steppe areas of WANA, where it can reduce risk and substantially improve production. The catchment area can be used for grazing after the crop has been harvested.

One problem the farmer may face, however, is that the distribution of water across the strip may not be uniform. This happens especially on gentle slopes when the cropped strip is too wide, as with the *khushkaba* system in Pakistan, or if a

Runoff strips under preparation at the ICARDA research station, Tel Hadya, Syria.

Right: *A runoff strip planted with field crops receiving additional runoff water after a rainstorm in northern Syria. Water distribution uniformly needs enhancement.* ***Below:*** *Corrugations created by a special implement developed at ICARDA to overcome uneven water distribution across the cropped strip.*

small ridge is formed during cultivation along the upstream edge of the cropped strip. To overcome this problem, it is recommended that the cropped strip should not exceed 2 m in width, and that water distribution should be helped by good preparation of the strip surface.

To increase the uniformity of water distribution across the cropped strip, ICARDA has developed a simple implement towed behind the sowing machine to form small corrugations. These corrugations enhance the flow of surface runoff inside the cropped area.

6. Inter-row systems

Inter-row systems, also called "roaded catchments," may be the best technique to apply on flat lands. Triangular cross sectional bunds or levees are constructed along the main slope of the land as shown in photo 26. When high-value crops such as fruit trees and vegetables are involved, the bunds may be compacted or possibly covered with plastic sheets or treated with water repellent materials to induce more runoff. The bunds, with a height ranging from 40 to 100 cm, are built at distances of 2–10 m.

Runoff strips are best for field crops such as cereals and legumes, in areas where rainfall is low and slopes are gentle.

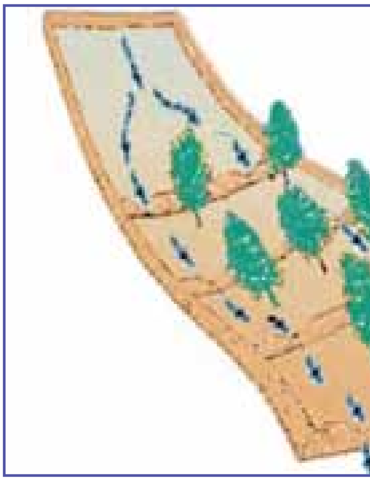
Inter-row system concentrating runoff water in a reservoir in Australia. Photo from booklet on water harvesting by the State Department of Western Australia.

Runoff flowing down the slope is collected between the ridges and either directed to a reservoir at the end of a feed canal or to a crop cultivated between the ridges. The catchment area has to be weeded and compacted on a regular basis to maintain high runoff output.

7. *Meskat*

Meskat is a term used in Tunisia for an indigenous water-harvesting system supporting mainly olives and figs. This system consists of a catchment, or *meskat*, occupying the slope adjacent to a flat cultivated area called *manqa*. Sometimes, the catchment areas are surrounded by a bund and may be provided with spillways to let runoff flow between plots without causing erosion.

Khushkaba is a similar technique used for growing field crops in Balochistan, Pakistan. Large plots of 1000–5000 m² are divided into two parts; the higher one serves as a catchment, supplying runoff water, and the lower one as a cropping area. A drawback of this system is the lack of uniformity in water distribution across the cropping area. If the width of the cropping area is reduced to improve uniformity, the system comes to resemble the runoff strip system described earlier. The *khushkaba* system is used mainly for improving wheat and barley production in very dry environments (< 250 mm rainfall).



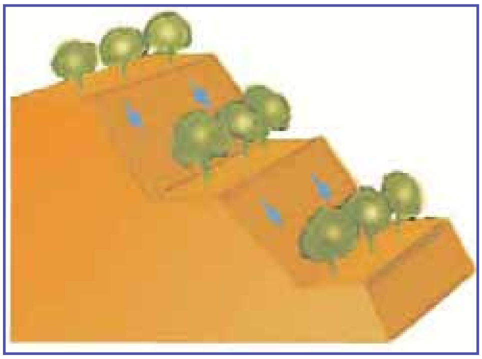
A Tunisian meskat *system.*

A meskat *system supporting olive plantation with harvested water in middle Tunisia, with rainfall less than 250 mm.*

8. Contour-bench terraces

Contour-bench terraces are constructed on very steep slopes to combine soil and water conservation with water-harvesting techniques. Cropping terraces are usually built level and supported by stone walls to slow down the flow of water and control erosion. They are supplied with additional runoff water from steeper, non-cropped areas between the terraces. The terraces are usually provided with drains to release excess water safely. They are frequently

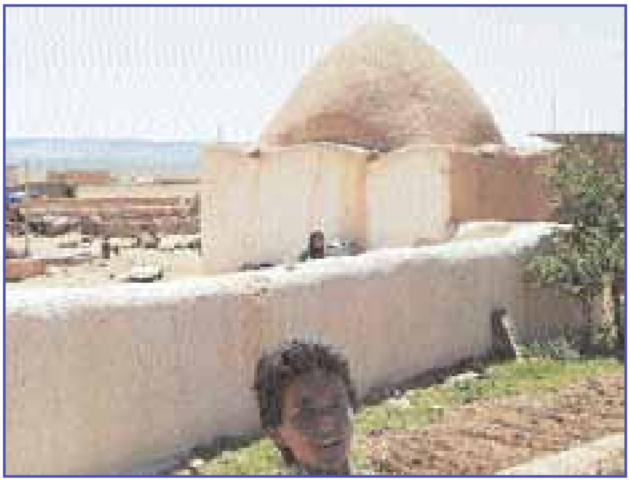
Ancient contour-bench terraces supporting coffee and qat trees in the mountains of Yemen.



used to grow trees and bushes, but rarely used for field crops in the WANA region. The historic bench terraces in Yemen are a good example of this system. Since they are constructed on steep mountainsides, most of the work is done by manual labor. The drawback of this system is that construction and maintenance costs are high.

Rooftop Systems

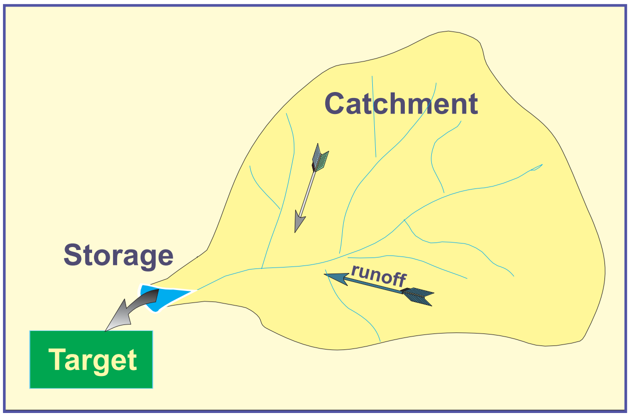
Rooftop systems collect and store rainwater from the roofs of houses or large buildings, greenhouses, courtyards, and similar impermeable surfaces, including roads. Most of the rain can be collected and stored. How the harvested water will be used depends on the type of surface used and it's cleanliness as well as users' needs. Modern roofing materials and gutters, for example, allow the collection of clean water suitable for drinking and other domestic uses, especially in rural areas without tap water. However, farmers usually avoid storing the runoff from the first rain as this may not be clean enough to drink. If water is collected from a surface that may have soil or plant debris on it, the runoff has to be passed through a settling basin before storage. Such systems provide a low-cost water supply for humans and animals in remote areas. Although mainly used for domestic purposes, this technique also has agricultural uses. Water not suitable for drinking may be used to support home gardens. Rainwater harvested from a greenhouse roof may be used in the green house for irrigation.



Rooftop water-harvesting system providing drinking and supplemental irrigation water in remote areas.

Macro-catchments and Floodwater Systems

Macro-catchment and floodwater-harvesting systems are characterized by having runoff water collected from a relatively large catchment. Often the catchment is a natural rangeland, the steppe, or a mountainous area. Catchments for these systems are mostly located outside farm boundaries, where individual farmers have little or no control over them.



A typical macro-catchment water-harvesting system.

Macro-catchment systems are sometimes referred to as "water harvesting from long slopes" or as "harvesting from an external catchment." The predominance of turbulent runoff and channel flow of the catchment water contrasts with the sheet or rill flow typical of micro-catchments.

Generally, runoff capture is much lower than for micro-catchments, ranging from a low percentage to 50% of annual rainfall. Water is often stored in surface or subsurface reservoirs, but may also be stored in the soil profile for direct use by crops. Sometimes water is stored in aquifers as a recharge system. The cropping area is either terraced on gentle slopes or located on flat terrain.

Water rights, affecting the distribution of water between the catchment and the cultivated areas and to the various users in the upstream and downstream areas of the watershed, are among the most important problems associated with these systems. The best solution to these problems is to plan interventions using an integrated watershed development approach in which all stakeholders are involved.

Large macro-catchment systems in steppe areas are often called "floodwater-harvesting systems." According to the location of the target area, two types of macro-catchment and floodwater system exist: *wadi*-bed systems and off-*wadi* systems.

Wadi-bed Systems

In this system, the *wadi* bed is used to store the water, either on the surface by blocking the water flow, or in the soil profile by slowing down the flow and allowing it to infiltrate the soil. The following *wadi*-bed systems have been found to be the most suitable for the steppe areas of WANA:

1. Small farm reservoirs

Farmers who have a *wadi* passing through their land can, if a suitable location exists, build a small dam to store some or all of the runoff water flowing down the *wadi.*

The water can then be used to irrigate crops or for domestic and animal consumption. These reservoirs are usually

Small farm water-harvesting reservoir for supplemental irrigation of field crops at ICARDA research station in northern Syria.

small but may range in capacity from 1000 to 500,000 m^3. Assistance may be needed from an engineer to plan, design and build the dam.

Small earth dam, broken due to lack of a sufficient spillway. Photo from booklet on water harvesting by the State Department in Western Australia.

The most important feature is to have a spillway with sufficient capacity to allow for the excessive peak flows that may pass through the *wadi*. Many of the small farm reservoirs constructed in the West Asian *badia,* have been washed away through lack of, or insufficient, spillway.

Small farm reservoirs are very effective in the *badia* environment. They can supply water to all crops, increasing and stabilizing production. Moreover, the benefits to the environment are substantial. To maximize water-use efficiency and reservoir capacity and minimize losses in evaporation and seepage, it is advisable that the collected water is pumped as soon as possible and stored in the crops' root zone (except for the water needed for drinking and for consumption by animals). This implies that, for greater efficiency, water should be used for the supplemental irrigation of winter crops, during the winter rainfall period, rather than left for the full irrigation of summer crops.

2. *Wadi*-bed cultivation

This technique is very common in *wadi* beds with gentle slopes. As a result of the slow water velocity, eroded sediments usually settle in the *wadi* bed and create good agricultural land. This may occur naturally or can be achieved by the construction of a small dam or dike across the *wadi* to reduce the flow speed and allow soil sediments to settle. *Wadi* cross-walls, usually

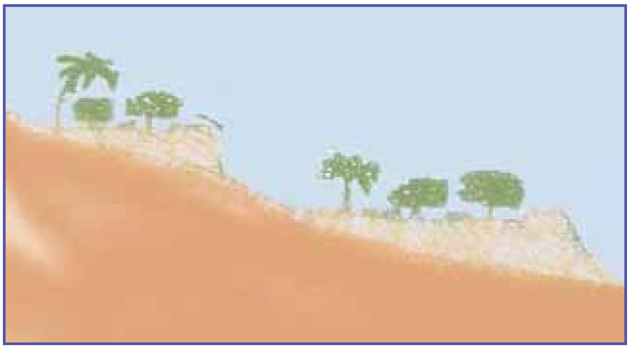
Stonewalls, if properly constructed across the wadi *bed, can help to store and distribute runoff water evenly and to build up soil behind them.*

Wadi*-bed stonewalls supporting fig plantations in Matrouh, north-western Egypt.*

no higher than 1 m, are preferably made of permeable stone and may be reinforced with gabions. The top of the wall should be all at the same level, so as to create uniform land behind it, allow excess water to overflow along its entire length. Distances between walls along the *wadi* bed are determined according to the slope of the *wadi* bed and the height of the wall. This technique is very common for fruit trees such as fig, olive, date palm and other high-value crops, since the soil in the *wadi* bed is usually fertile and the availability of water can be relied on with reasonable certainty. The walls increase the range of crops that can be grown in these marginal areas.

The main problems associated with this type of water harvesting are the costs and the maintenance of the walls. Another problem that has arisen recently in some WANA areas, where catchments are being developed for housing, is that less runoff water reaches the *wadi* beds, with the result that downstream crops become increasingly water-stressed. In such circumstances, an integrated watershed development approach is needed to decide on a fair allocation of the water supply.

The ancient jessours *of Tunisia have supported olive and fig trees for centuries.*



The jessour, *built along steep* wadi *beds.*

3. Jessour

Jessour is an Arabic term describing the widespread indigenous wall structures built across relatively steep *wadis* in southern Tunisia. The walls are usually high because the slope is steep. They are made of earth, stones or both, but always have a spillway, usually of stone. Over the years, as water is stopped behind these walls, sediments settle and accumulate, creating new land for planting, mainly with figs and olives but also with other crops.

This system is similar to *wadi*-bed cultivation except that it is used on steep *wadi* beds and always includes a spillway to release the excessive water. Usually there is a series of *jessours* along a *wadi* originating from a mountainous catchment. These systems require maintenance to keep them in good shape. Since the importance of these systems for food production has declined recently, vigilance and maintenance have also reduced, and many systems are breaking down.

Group of ancient jessours *in a* wadi *system in southern Tunisia.*

Off-*wadi* Systems

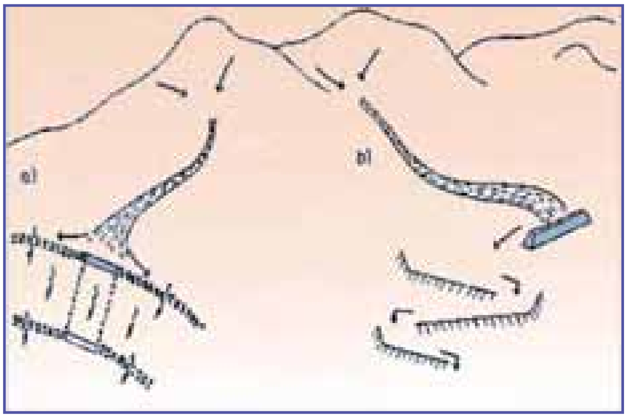
The rainwater harvested in off-*wadi* systems is applied outside the *wadi* bed. Structures may be used to force the *wadi* water to leave its natural course and flow to nearby areas suitable for agriculture. Similar structures may also be used to collect rainwater from catchments outside the *wadi* bed. The following are the most important off-*wadi* techniques:

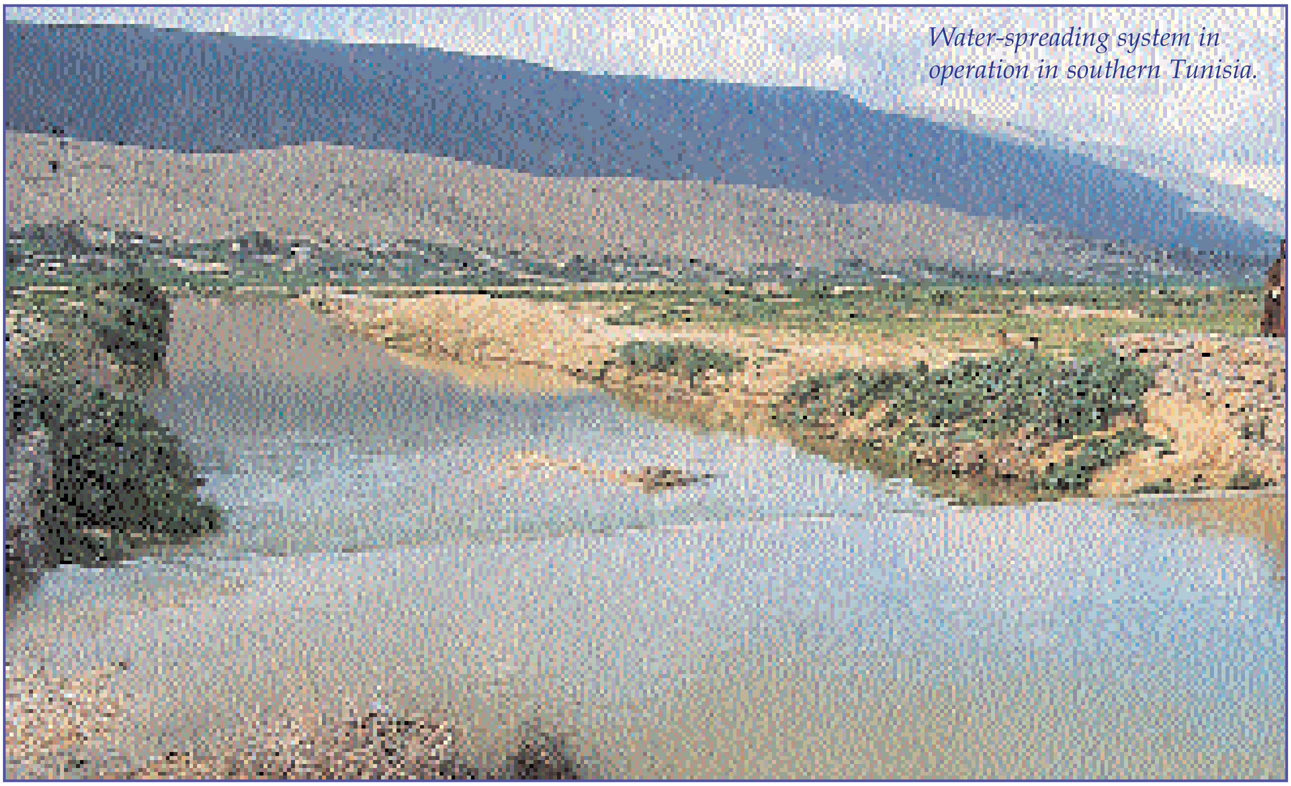
1. Water-spreading systems

In this technique, also called "floodwater diversion," part of the *wadi* flow is forced to leave its natural course and is then conveyed to nearby areas and applied to growing crops. Water is stored only in the root zone of the crops, i.e. it supplements rainfall. Diversion is usually accomplished by means of a structure that raises the water table in the *wadi* bed, allowing the flow to spread by gravity, on one or both sides of the *wadi*. The flow is directed by a levee, which should run a little off the contour, away from the *wadi* path.

Water spreading requires relatively uniform land with a gentle slope. Agricultural land may be graded and divided into basins by levees to allow enough water to be stored for the season. Soils should be deep, with sufficient water-holding capacity.

As this system requires proper siting, design and construction of the structure and the conveying canal, the expertise of an engineer may be required. The structure should be strong enough to resist the flow and be at an elevation sufficient to divert the required portion of the flow. Different





Water-spreading system in operation in southern Tunisia.

materials have been used to build diversion structures, including stone and concrete. The most durable structures are made of stone-filled gabions.

One important point to consider is that the slope of the conveyance canal should allow a flow velocity sufficient to prevent the accumulation of sediments near the structure, otherwise these will block the flow and entail high maintenance costs.

2. Large bunds

Also called *tabia* in Tunisia, this system consists of large semi-circular, trapezoidal or open V-shape earthen bunds with a length (the distance between the tips of each bund) of about 10–100 m and a height of 1–2 m. Often, they are aligned in long, staggered rows facing up the slope. The space along the contour between adjacent bunds is usually about half the length of the bund. The tips of the bund should be protected against erosion, as water often overflows round them. Large bunds are usually constructed by machinery and only rarely by hand. They are used to support trees, shrubs, and annual crops in WANA, but also sorghum and pearl millet in sub-Saharan Africa.

Large semi-circular bunds can store large quantities of water, but can break under extreme rainstorms, so a control overflow has to be planned for. The most critical period is immediately after construction, before they are fully consolidated. Any breakage must be repaired immediately. As these systems are not traditional, adoption can pose problems.

Typical tabia *from the Matmata Mountains in southern Tunisia.*

3. Tanks and *hafair*

Tanks are usually earthen reservoirs dug in the ground in gently sloping areas that receive runoff water either by diversion from *wadis* or from a large catchment area. They are known as “Roman ponds” in parts of North Africa, where they are usually built with stone walls. The capacity of these ponds ranges from a few thousand cubic meters, in which case they are called *hafair*, to tens of thousands of cubic meters. Tanks are very common in India, where they support over 3 million ha of cultivated land. In the WANA region, especially Sudan, Jordan and Syria, the smaller tank is more common and is mainly used for water consumption by humans and animal.

Hafair *in western Sudan provide water for people and their livestock during the dry season.*

Several problems are associated with *hafairs*: stagnant water may be polluted, attract insects and become a source of disease. As they usually have no protection around them, there is a risk of drowning accidents, which may involve people or animals. Large losses through seepage and

Guidelines for Selecting Water-Harvesti

Technique	Crop	Soil		Land	Land
		Depth (1)	Texture	Slope (2)	Vegetation (
Micro-catchments					
On-farm systems					
Contour ridges	range	variable	variable	med.,steep	poor,med.
	field	med.,deep	"	medium	poor
	trees	deep	med.,heavy	low,med.	poor,med.
	vegetable	med.,deep	"	"	"
Semi-circular bunds	range	"	variable	"	poor
(trapezoidal	field	"	med.,heavy	"	"
triangular)	trees	deep	"	"	poor,med.
	vegetable	"	"	"	"
Small pits	field	"	"	"	poor
	range	shallow,med.	"	"	poor,med.
Small basins	range	med.,deep	"	"	poor
(Negarim)	trees	deep	"	low	poor,med.
Runoff strips	range	variable	"	low,med.	poor
	field	med.,deep	"	"	poor,med.
Inter- row system	trees	deep	"	Low	poor
(roaded catchment)	vegetable	medium	variable	"	"
	field	"	"	"	"
Meskat (Khushkaba)	trees	deep	med.,	low,med.	poor,med.
	field	medium	heavy	"	poor
			"		
Contour bench	trees	deep	"	Steep	"
terraces	field	medium	"	"	"
Rooftops	drinking	na	na	na	na
	vegetable	variable	variable	"	"
Macro-catchments					
Wadi-bed systems					
Small farm reservoirs	all crops	variable	"	low,med.	variable
Wadi-bed cultivation	trees/ vegetable	med.,deep	med., heavy	"	poor
Jessour	trees	"	"	med.,steep	variable
Off-wadi systems					
Water spreading	field/trees	"	"	low,med.	poor
Large bunds	trees	deep	"	"	poor,med.
	field	medium	"	"	poor
	range	shallow,med.	variable	"	med.,dense
Tanks and hafair	*all crops*	variable	med., heavy	low	variable
Cisterns	drinking/ trees/vegetable	deep	rock	all slopes	poor,med.
Hillside runoff systems	field/trees	med.,deep	med.,heavy	low,med.	poor,med.

(1) shallow < 50 cm, medium: 50-100 cm, deep> 100 cm; (2) low < 4%, medium: 4-12%, steep > 12%; (3) poor < 15%, medium: 15-30%, dense > 30%
(7) low < 5 man-day/ ha, medium: 5-20 man-day/ ha, high > 20 man-day/ ha; na : not applicable.

g Techniques in the Drier Environments

Cover	Socio-economics				Storage type
Stoniness (4)	Farm size (5)	Capital (6)	Labor (7)	Skill	
low-med.	variable	low	medium	local/	soil profile
low	small,med.	"	"	training	"
"	"	"	"	"	"
"	small	"	"	"	"
low,med.	variable	"	high	local/no	"
"	small,med.	"	"	training	"
low	"	"	"	"	"
"	small	"	"	"	"
"	variable	"	medium	"	"
low,med.	"	"	"	"	"
"	small	"	high	"	"
"	small,med.	"	"	"	"
"	"	"	low	"	"
"	"	"	"	"	"
low	large	high	medium	local/training	"
"	"	"	"	"	"
"	med.,large	"	"	"	"
"	variable	low	"	local/no	"
"	small,med.	"	low	training	"
				"	
"	"	high	medium	external skill	"
"	"	"	"	"	"
na	small	"	medium	local/training	surface/
"	"	"	"	"	subsurface
					"
variable	med.,large	high	high	external skill	surface/ subsurface
Low	small,med.	medium	med.,high	local	surface/soil profile
variable	small	"	high	local/training	"
low,med.	variable	"	medium	external skill	soil profile
"	med.,large	"	"	local/training	"
low	medium	"	"	"	"
variable	med.,large	"	"	"	"
"	"	med.,high	"	external skill	surface/subsurface
variable	small,med.	medium	high	local/training	subsurface
low	small,med.	"	high	local/training	soil profile

ow < 10%, medium: 10-25%, high> 25%; (5) small<5 ha, medium:5-25 ha, large> 25 ha; (6) low < $ 25/ ha, medium: $ 25-100/ ha, high > $ 100/ ha;

evaporation are further disadvantages. Several improvements, including fencing, lining and settling basins, have been proposed and, occasionally, introduced to overcome these limitations.

Ancient roman tanks are still functioning in many WANA areas.

4. Cisterns

Cisterns are indigenous, subsurface reservoirs with a capacity ranging from 10 to 500 m^3. They store water for human and animal consumption. In many areas, as in Jordan and Syria, they are dug in the rock, in which case they usually have a small capacity. In northwestern Egypt, farmers dig large cisterns (200–300 m^3) in the earth deposits underneath a layer of solid rock. The rock layer forms the ceiling of the cistern, whereas the walls are covered with impermeable plaster. Modern concrete cisterns are being constructed in places where there is no rocky layer.

Cisterns are vital to people in remote areas where no other source of water is available. This one in Egypt still supports people, livestock and gardens in rural areas.

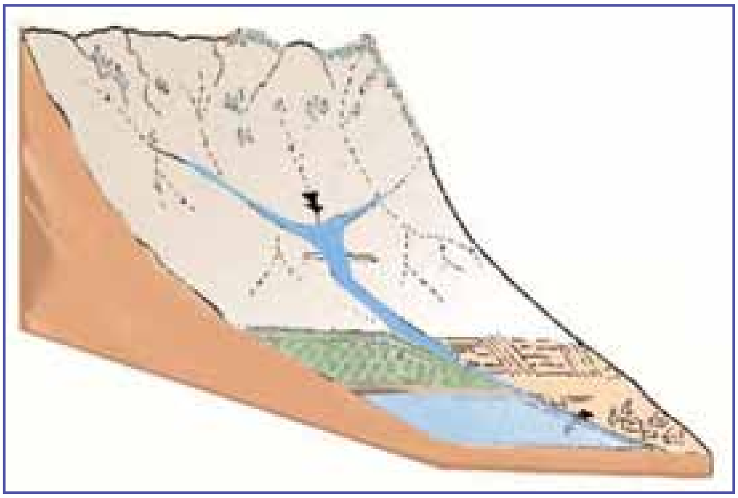
Runoff water is collected from an adjacent catchment or channeled from a remote one. The first rainwater runoff of the season is usually diverted away from the cistern to reduce the likelihood of pollution. Settling basins are sometimes constructed to reduce the amount of sediments, but farmers usually clean the cisterns once a year or every other year. Water is typically lifted by a bucket and a rope.

Cisterns are still the only source of drinking water for humans and animals in many dry areas of WANA, and their role in maintaining rural populations in these areas is vital. They are now often used to support home gardens, in addition to meeting domestic needs. Problems include the cost of construction, limited capacity, sediments, and sources of pollutants from the catchment.

5. Hillside-runoff systems

In Pakistan, this technique is also called *sylaba* or, as previously mentioned, *sailaba*. Runoff water is directed by small conduits to flat fields at the foot of the slope. Fields are leveled and surrounded by levees with a spillway to drain the excess water to another field downstream. When all fields in a series are filled, water is allowed to rejoin the *wadi*. When several feeder canals are planned, distribution basins are useful. This is an ideal system for using the runoff from bare or sparsely vegetated hilly or mountainous areas.

Hillside conduit schemes require proper design, a high labor input, and, probably, the assistance of an engineer. The conduits should have sufficient slope to prevent sedimentation, otherwise they have to be cleared after heavy rainstorms. Fields need to be leveled and spillways constructed at a proper elevation to ensure uniform distribution. This technique can be applied to almost any crop.



The hillside runoff system captures runoff water as it flows down the hill. (Photo by Prinz.)

Planning, Design and Implementation

Socioeconomic Aspects

Water-harvesting projects do not depend solely on good engineering and suitable agronomy for their success. Socioeconomic considerations are just as important. In the drier environments people have been living at subsistence level for centuries and have developed their own priorities for their way of life and survival. It is of the utmost importance, therefore, to take their values, perceptions, attitudes and preferences into consideration rather than try to impose solutions on them.

One effective way of introducing and developing water-harvesting projects is first to go to the prospective beneficiaries, talk to them, learn from them and show willingness and potential to serve them. If the scheme really meets their needs, then interventions can be planned with them, starting with their knowledge and building on it, using what they have. It is important to make them feel that the project is their own and that it will be of real use to them. Although planners may often ignore indirect benefits when conducting feasibility studies of water-harvesting projects, it is essential to understand the importance of these too. They include halting land degradation, combating desertification, supplying drinking water for animals, slowing migration to the cities, minimizing social problems, improving the standard of living of the farmers' families and enhancing the stability and security of village life. Farmers who implement water-harvesting projects in the drier environments will be contributing to these benefits for the population in general.

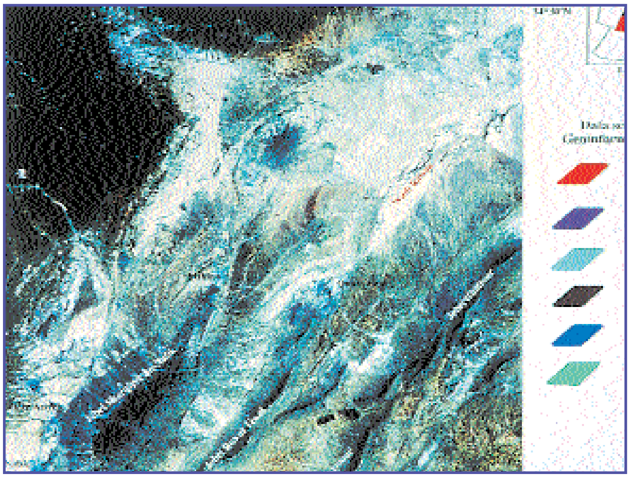
Yemeni farmer holding the controversial crop, qat, *grown in the famous water-harvesting terraces of the Yemen mountains. High returns insure maintenance of the system.*

Another important issue is land ownership. This can often be a problem, since much of the land requiring structural interventions may be communally used or owned by the state. In these circumstances, individual farmers have little incentive to initiate costly development.

Designing Water-Harvesting Systems

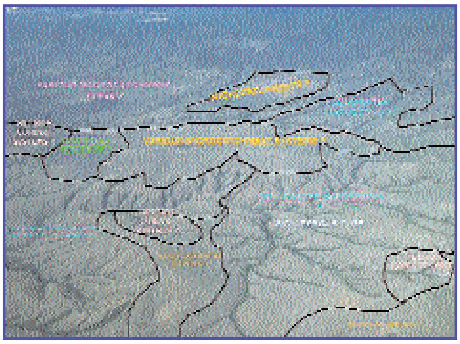
Selecting the Site and Technique

The suitability of an area for water-harvesting depends on its being able to meet the basic technical requirements of the system. In addition, whatever technique is selected must be compatible with local social conditions and farming practices. In planning the systems, appropriate data must be available on the climate, soil, crops, topography and the socioeconomics of the project area. Among the tools and methods of data acquisition for planning, designing and implementing water-harvesting systems are field visits, site inspection, topographic and thematic maps, aerial photos and satellite images (remote sensing) and Geographic Information System (GIS). As an aid to selecting the most suitable method, Table 1 provides general guidelines on the requirements of the most important water-harvesting techniques.



Remotely sensed data combined with ground data in a GIS environment can result in substantial saving of effort in investigating the suitability of sites for water harvesting. (Photo by Oberli.)

The site and methods are determined by taking into account the use to which the harvested water will be put. Proximity to buildings and purity of water will be issues to consider if the water is for domestic use or for livestock, while different demands must be met for water needed for agriculture or for multi-purpose use.



Classification of areas according to suitability for various water-harvesting methods. (Photo by Prinz.)

Although water-harvesting systems may be implemented on a wide range of slopes, topography is still a major factor in the selection of an appropriate technique. Generally, but not invariably, steeper slopes with shallower soils are used as catchments, and cropping is allocated to gentler slopes, where soil is deeper. This allows the less productive, shallow soil to contribute its share of rain to the deeper, more productive soil.

Soils with high infiltration rates, such as sandy soils, are not favorable as catchment areas for water harvesting without some measures to induce runoff. Generally, this is only feasible when using micro-catchments to harvest water for human and animal consumption or for the production of high value crops. Soil texture should be considered because it affects soil erosion in the catchment. Both soil texture and depth influence the total water-storage capacity of the soil profile, and this, in turn, controls the amount of water that can be made available for crops during the dry periods.

Water rights, land tenure and use are among the problems that sometimes hinder the selection of proper sites and techniques. In the past many water-harvesting projects have failed simply because these issues were not taken fully into account. Collective land ownership increases the number of options available, including the choice of a macro-catchment. Large-scale systems may be more economical because they require less work to install and less maintenance per unit area.

As a result of changes in social attitudes towards private ownership, economic incentives and personal aspirations, small-scale farmers are now more open to the idea of introducing a micro-catchment on their land. The farmer's ability to operate and maintain the system, however, remains a constraint to using more sophisticated systems. Construction requirements such as availability of materials and skilled labor must also be taken into account in the selection of systems.

Selecting the Crops

In general local crop or tree species are best adapted to the environment and should have priority over introduced species. Water harvesting may, however, allow farmers to grow species previously considered too risky. Improved varieties may be suitable, provided their introduction follows research and adaptation programs that prove their viability. The crops and trees selected should be capable of integration with the local farming system and able to withstand the 2–3 days of waterlogging that are typical in most water-harvesting systems after heavy storms. Maize, for example, is not suitable.

Almonds, olives, palms and figs are among the most suitable trees to be grown in the drier environments using water-harvesting systems.

As water-harvesting systems can only partially compensate for low and erratic rainfall, it is strongly recommended that drought-tolerant trees, shrubs and crops be selected. These can often survive even in extreme drought, when the system fails to provide sufficient moisture. In drier environments, fodder shrubs and trees are generally able to recover more quickly after heavy browsing. To ensure the most efficient use of water and to obtain a harvest rapidly, winter crops should be given priority over summer ones. When trees are selected, it is essential that deep soil with sufficient water-storage capacity is available in order to provide the necessary moisture over the entire dry period of the year. In areas where there is a possibility of water standing on the surface for long periods, crops tolerant to waterlogging must be selected.

Designing the System

The design of the water-harvesting system should ensure, with reasonable probability, that a specific amount of water is available for the designated use. It is important to emphasize that in the drier environments, it is not always necessary for the potential water demand to be fully met, as crops may be grown economically, and produce, without their water needs being completely satisfied. The design water amount, i.e. the amount of water the water-harvesting system is designed to provide, should allow maximum economic, social and environmental return.

Where there is no local information available, runoff coefficient plots are essential to determine design parameters for micro-catchment systems.

With micro-catchment systems the catchment area must be able to supply the design water amount to the target area. The size of the catchment can be decided according to rainfall characteristics, land slope, soil characteristics, land cover, crops, and economic considerations. Similar care is needed in the design and provision of the water-harvesting structures used for conveying and then storing or distributing the water. The design of the entire system must be flexible enough to allow for any necessary changes in the cropped area or crop type during implementation and future operation.

The main design steps for micro-catchment water-harvesting systems are:

1. Determine the design annual runoff coefficient of the selected site. This coefficient is the ratio of the amount of annual runoff to the amount of annual rainfall. Its value depends on rainfall amount and intensity, soil, topography, land surface, and catchment size. Coefficients derived by techniques valid for macro-catchments are not applicable to micro-catchments.

   There is a notable lack in the literature on reliable and practical methods or techniques for determining runoff from smaller catchments (those ranging in size from a few to several hundred square meters). One way to determine runoff is by experimentation using field plots or by using field rain simulators.

   Since the design annual runoff coefficient depends on rainfall characteristics, the value adopted must be at an acceptable level of probability. Treating the soil surface physically or chemically (or both) can significantly increase the runoff coefficient, but also increases costs. Such treatment for inducing runoff may be economically justified, depending on the purpose of the water-harvesting system.
2. Determine design crop water requirements (under water-harvesting conditions). These requirements are usually set at only a fraction of the stress-free water requirements usually associated with the use of inputs and proper system management. Normal methods of estimating crop evapotranspiration may be used with an estimated stress coefficient reflecting the level of stress the crop can be expected to tolerate during the dry period.

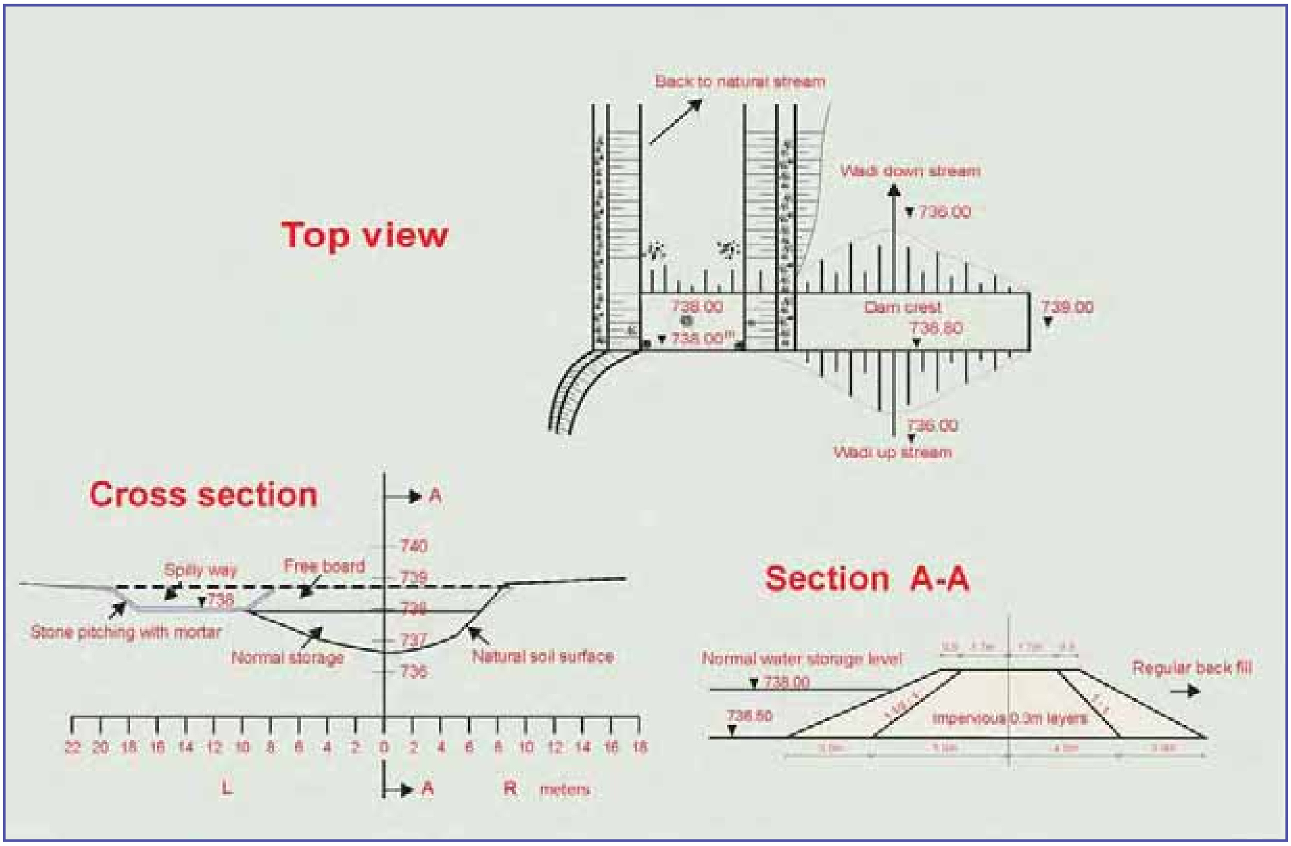
Low cost weirs may be installed on wadis *to measure runoff rate from macro-catchments. This one is in Mouaqar, Jordan.*

Table 1. Estimated runoff coefficients and cost of typical inducement techniques

Treatment	Runoff coefficient (%)	Estimated life (years)	Cost (US$/ 100 m²)
Catchment clearing	20-35	1-3	1-4
Surface smoothing	25-40	2-4	2-4
Soil compacting	40-60	2-3	6-10
Surface modification	70-90	3-5	10-20
Surface sealing	60-80	5-10	4-10
Impermeable cover	95-100	10-20	20-100

3. The design of the water-harvesting system should be based not on average values of rainfall in the area, but on lower values, so as to ensure greater dependability of the system. Water-harvesting systems for trees, shrubs and perennial crops should be based on rainfall data. Generally, the design should be able to provide water to the plant economically at least three years out of four; i.e. a dependability level of 75%.
4. Based on the outcome of Steps 1, 2 and 3, the ratio of the catchment area to the cropped area is determined. An allowance for non-uniformity of water distribution and deep percolation in the cropped area should be provided through a storage-efficiency factor. This is represented by the ratio of the volume of harvested water stored in the effective depth of the root zone to the total volume of water harvested.

   Typical values for this storage efficiency range from 50 to 75%. If the ratio of the catchment area to the cropped area is underestimated, the actual value of this factor may approach 100%. Conversely, if this ratio is overestimated, the actual storage efficiency may be very low, resulting in water being wasted and more land being unnecessarily put out of production as catchments.
5. If the size of the cropped and catchment areas is known, their shape and dimensions can be decided depending on the



Layout of a small earth dam and a spillway designed and built in the Muaqqar area of the Jordanian badia.

type of system, the kind of crop and the topography. The engineering works required can then be planned. These include system layout, details and quantities of the earth or stone works and of other water-control structures.

Macro-catchment and floodwater systems usually involve the design of a small dam, diversion structures, and the requisite water conveyance and distribution systems. These systems may also include facilities to store water for subsequent use. The size of a macro-catchment or floodwater catchment area is not under the designer's control. The designer merely determines the extent of the cropped area to be served by the expected runoff.

Runoff may be determined from runoff measurements, gauges at the *wadi*, and, more rarely, from flow cross-sectional area and velocity measurements. Alternatively, it may be estimated from simulation models. As such large-scale systems are beyond the ability of individual farmers, engineers are needed to do the design.

Implementation

Water-harvesting systems may be implemented by:

- **The farmer**

As mentioned earlier, micro-catchment systems are usually within individual farms. This is a simple and low-cost approach, although farmers may experience some difficulty with elements requiring precision, such as following the contour lines or determining maximum slope.

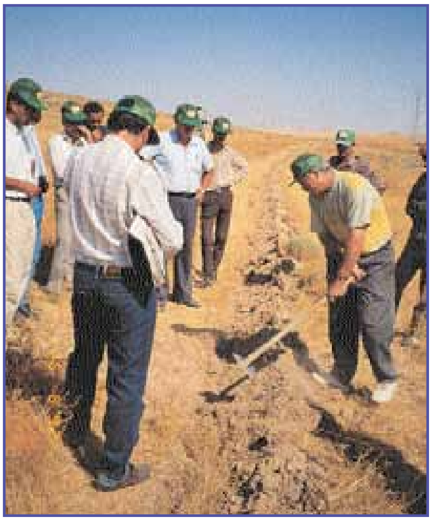
- **The community**

The community may be involved in micro- and macro-catchment or floodwater-harvesting systems, typically through a project planned locally with the help and guidance of the government.

- **Public agencies**

These are usually needed for large-scale macro-catchment and floodwater harvesting schemes. Government services or contractors are used in this approach. Usually machinery is used or paid local labor employed. Initial cost is relatively high. This is a top-down approach, however, and there is a risk that the scheme will not be accepted or maintained by farmers.

The first two approaches have proved more successful than the third, but do need government support with simple demonstrations, training and extension services. A round-table discussion involving all parties, with the aim of finding the best technical approaches for the locality, is helpful. The selected plan of action should be simple enough for the local people to implement themselves. The planner should be



Proper construction of water harvesting systems requires skilled labor. Enhancing the capacity of people involved is usually needed.

A water-harvesting system implemented by the farmer has a higher chance of success. Photo from Balochistan, Pakistan.

Planning water-harvesting systems at large scale requires appropriate information in map form.

ready to listen and learn from the farmers so as to respond effectively to their needs. Putting the farmer in a managerial role will also contribute to the success of the project.

Operation and Maintenance

Poor management and lack of maintenance are the main reasons for the failure of water-harvesting projects. Large-scale systems require the creation of a local association to manage the facility and liaise with the appropriate government agencies. Guidelines and procedures for the operation and maintenance of all components of the water-harvesting system are needed at the outset of the project.

New systems should be inspected often, especially during the first one or two rainy seasons after construction. Micro-catchment systems should be inspected after every runoff-producing rainstorm so that any minor break in bunds can be promptly repaired. Special attention should be paid to earthen dikes and bunds, water-storage facilities and their spillway and the diversion structures. Treated catchments, in addition to target structures, should be protected against damage by grazing animals. Silt and rubbish should be removed from the water conveyance and distribution systems and from storage facilities.

Farmers unfamiliar with irrigation may need advice about irrigation techniques and related activities. This should include methods for improving soil fertility and erosion control. Systems providing drinking water should be protected against pollution and should be cleaned regularly. Cleaning the catchment annually, maintaining silt traps and settling basins, and de-silting cisterns are further necessary measures.

Prerequisites for Success

- **People's participation**
  The people directly concerned should be included in all phases of the project: planning, development, implementation, operation and maintenance.

- **Acceptability to the beneficiaries**
  The project should be simple and appropriate to their existing farming operations.

- **Demonstrations and training**
  These are needed to support newly introduced systems or practices.

- **Attractive benefits**
  On account of the risk and uncertainties involved, the farmer may need to be convinced of the benefits of water harvesting. The most important form of benefit is increased income from the sale of additional produce. It is therefore essential to check that there is a market for this. Micro-credit schemes or other forms of subsidy may still be needed to finance the construction, operation and maintenance of systems before the benefits from additional crop production are felt. With appropriate policies and regulations, micro-credit may also be used to support the creation of local groups, and human-capacity building through demonstrations, training, extension services and dissemination of information.

  Subsidies may also be needed to compensate farmers for their contribution to improvements in the national environment and socioeconomics resulting from water harvesting projects.

- **Clear land tenure and property rights**
  These concerns have been overlooked in many projects in the past leading to conflicts over both land and water. These often severe constraints to development need to be addressed early in the planning process.

- **Downstream water rights ensured**
  Downstream water users and environmental water needs should be taken into consideration when adopting macro-catchment and floodwater-harvesting systems. It must never be forgotten that the development of water resources demands an integrated watershed management approach.

Farmers in Matrouh Natural Resource Management Project in north Egypt participate in the planning and implementation of water-harvesting works at their farms.

ICARDA's Research Activities

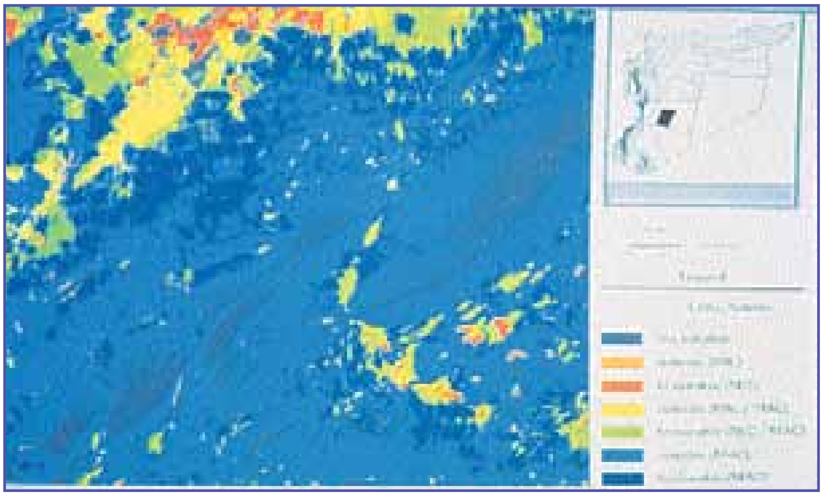
The ecoregional project "On-farm Water Husbandry in WANA" was launched by ICARDA in 1996 to promote the integration of water harvesting in the farming systems of the drier environments. Since then, national teams in eight countries of WANA have been implementing the project in partnership with ICARDA. The countries involved are: Egypt, Libya, Tunisia, Morocco, Syria, Jordan, Iraq and Pakistan. Then, in 1999, Algeria, Yemen and Iran joined the project.

Research themes have been identified in which the complementary strengths of all partners are combined in strategic and applied research throughout the region. The project research themes are:

1. **Water in present land-use systems:** indigenous knowledge, and end-user perceptions and participation. This theme involves documentation and analysis of indigenous water management and recognition of what can be learnt from it.
2. **Water resources and capture potential:** This theme involves analyzing rainfall-runoff relations and developing methodologies for investigating water-harvesting potential under different conditions.
3. **Options for water use:** Water-harvesting methods and techniques suitable for the prevailing land, crops and socioeconomic conditions are studied and adapted and ways of integrating these techniques into farming systems are researched.
4. **Dissemination, development and impact:** This theme involves building people's capacity through training and demonstration. It also includes studies and evaluation of how the social, economic and policy issues governing the adoption of improved water-harvesting systems will affect the farmers, their livelihoods and the environment.

The following are examples of the project's major findings:

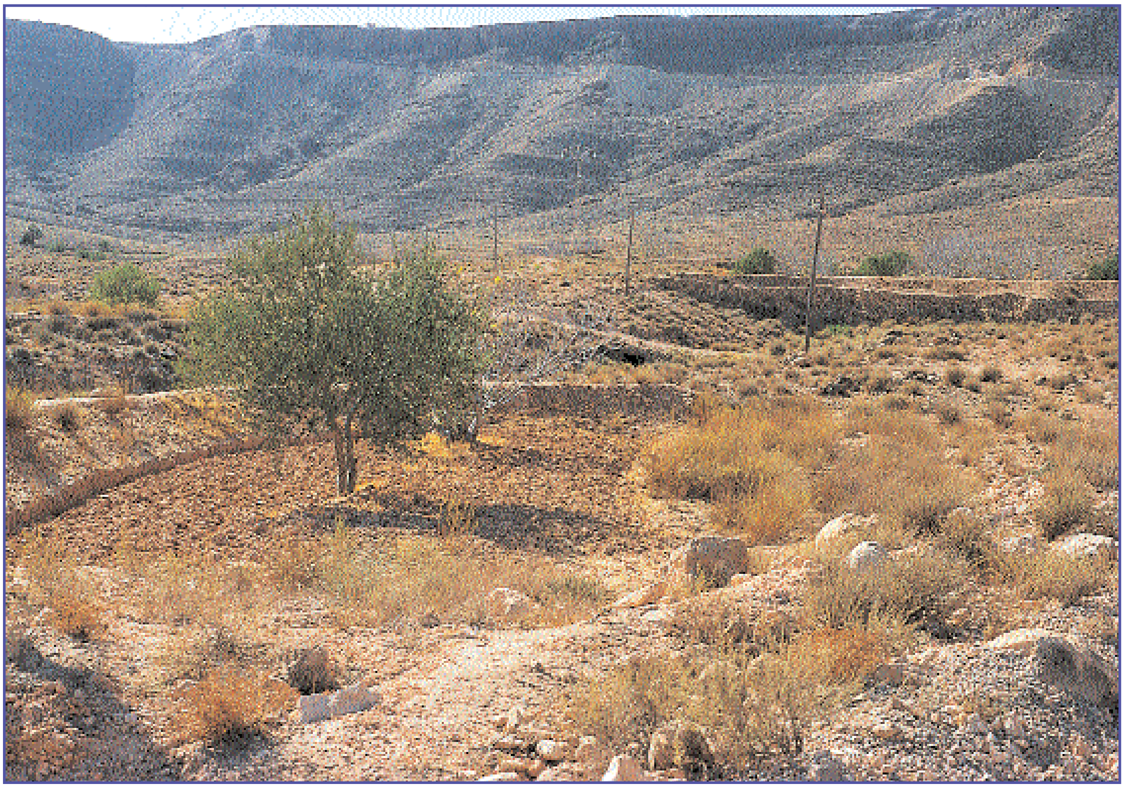
Planning Water Harvesting using Remote Sensing and GIS



Water-harvesting-suitability map for central Syria, produced at ICARDA through research using remotely sensed data, ground data and GIS techniques.

Conventional investigations for planning water harvesting are intensive. If water-harvesting is needed on a large scale, such investigations becomes tedious and very costly. ICARDA has used remote sensing and GIS to develop a methodology for classifying large areas according to their suitability for water harvesting using different techniques and systems. Data from a full LANDSAT scene for central Syria were first used to provide valuable information on vegetative cover, surface conditions, and drainage systems.

Additional information including soil types, topography, rainfall and expert criteria on water-harvesting techniques were then entered in a GIS environment and analyzed together with satellite data to produce the final classification. This methodology gave very promising results at low cost. Work is continuing to include provision for hydrology so as to estimate the amount of runoff to target areas and for soil depth relevant to aid crop selection in specific areas.



The efficiency of indigenous water harvesting systems is being researched at ICARDA with results that should prove applicable in many areas of WANA.

Indigenous Water-Harvesting Systems

Indigenous water-harvesting systems in Egypt, Iraq, Jordan, Libya, Morocco, Pakistan, Syria, and Tunisia were documented and analyzed, and lessons on their relevance to future development were identified. A national team supported by ICARDA scientists produced the document in each country.

Problems with these systems include the cost of construction and maintenance, limited capacity, sediments, and sources of pollutants from the catchment. ICARDA is conducting research in many areas to find solutions to these problems. Of particular importance is research being conducted in northwestern Egypt to improve water collection, storage and use in cistern systems.

Micro-catchment Success Stories

Research results in Syria, Jordan, Morocco and Egypt have shown great success in using micro-catchments. In the Syrian *badia* (annual rainfall 100-200 mm), a special implement mounted on a tractor was used to construct semi-circular bunds mechanically. The mechanized tool can be used to implement this technique on a large scale.

In an ICARDA-supported research project in the Syrian *badia*, the implement was able to provide over 20 ha with many bunds per day, creating over 5,000 bunds of varying size and spacing. It is ideal when labor is not available or when it is costly. Operating cost is around US $100/ha, including planting. Shrubs planted in the semicircular bunds showed a survival rate of over 90%, compared to 10% without water harvesting.

In Jordan and Egypt, small basins and semicircular bunds provided almond and olive trees with sufficient water to grow normally in areas with 120–150 mm annual rainfall. In Morocco, a system combining trees and shrubs with the use of contour ridges proved very successful in areas with rainfall of 100–200 mm.

Water Harvesting for Supplemental Irrigation

Applying limited amounts of water during stress periods as a supplement to rain sub-

A mechanized implement for making micro-catchments saved labor costs and proved suitable for improving production and reducing degradation in the Syrian badia.

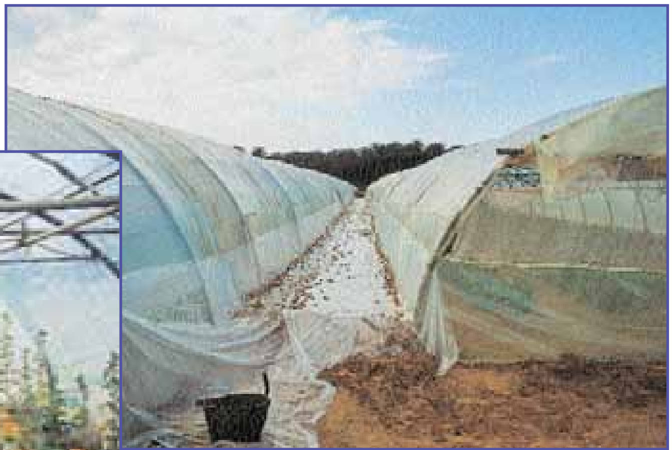
The sustainability of mountain reservoirs and the efficiency of using harvested water in supplemental irrigation are being researched in Tunisia.

stantially increases and stabilizes production. In areas where full-scale irrigation is not available, water harvesting can provide the essential moisture. In Tunisia small water-harvesting reservoirs have been built in the mountainous areas and are being assessed using GIS for their use in supplemental irrigation.

The research work showed great potential in improving water-use efficiency in the production of winter and summer crops such as wheat and vegetables. Similar research conducted by the Pakistani team in Balochistan province developed some promising options for use of ground water in conjunction with water harvesting in supplemental irrigation.

Water Harvesting from Greenhouse Roofs

A system for harvesting rainwater falling on the roofs of plastic greenhouses was introduced and monitored by the Egyptian team of the on-farm, water-husbandry project near Alexandria, where annual rainfall is less than 100 mm. The harvested water was conveyed to the vegetable crop in the greenhouse, where a technique known as "hydroponics" was used to provide water and nutrients at high use efficiency. The



Greenhouse roofs provide a sizeable share of crop water requirements in the Al Busaili area near Alexandria in northern Egypt.

greenhouse roof was able to provide 50% of the water requirements of the vegetable crop allowing about 15 tonnes of melons to be produced. In areas where water is very scarce, and farmers otherwise have to buy in costly water to produce good crops, this method can make all the difference.

Emulsified paraffin wax developed in Iraq being sprayed on a micro-catchment to induce runoff near Aleppo, Syria.

Runoff Inducement

Light soils with high infiltration rate do not produce much runoff. This is a major problem in many sandy areas of WANA where water harvesting is very much needed. Although the soil surface is sometimes modified to induce runoff, the search continues for practical, low-cost and environmentally friendly material that can be used for this purpose.

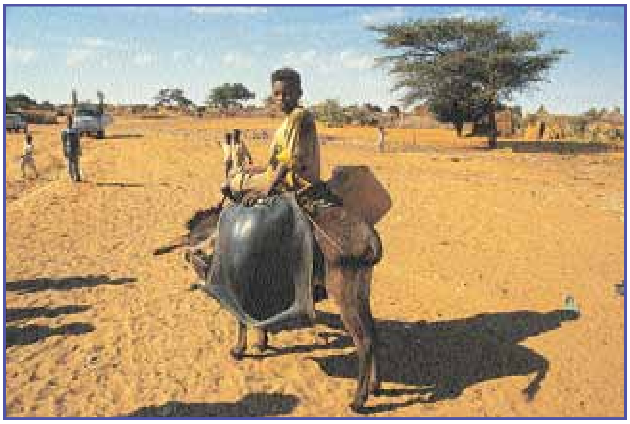
The project team in Iraq has patented a process to overcome the difficulties of using paraffin wax in inducing runoff. They have succeeded in emulsifying the wax by using low-cost additives and a machine they developed specially. The emulsified wax, which looks like milk could be applied easily to research plots by means of a small sprayer. The use of the wax p a tripled the amount of runoff from small plots.

Plastic sheets ensures very high runoff coefficient; it is however, costly and mostly used for harvesting water to cash crops.

Future Challenges

Considerable progress has been made in identifying the most important components of efficient schemes for harvesting and using water for crop production. Constraints to the implementation and adaptation of these schemes include: difficulties arising from farmers' unfamiliarity with the technology; conflicts and disputes over water rights, land ownership and use; and lack of adequate characterization of rainfall, evapotranspiration and soil properties. These areas need more research, based on sound hydrology and engineering. Recommendations and future challenges for research and development include:

- Interdisciplinary research aimed at constraints to the adoption and management of water harvesting at the farm level. This would require better characterization of climate, soils, adaptable crops and socioeconomic factors.
- Definitions of optimum catchment size relative to cropped area under various field conditions. Modeling and simulation, backed up by carefully designed field experiments, play a major role here.

Providing sufficient water for drinking and agricultural production in remote dry areas is one of the most serious challenges for water harvesting research and development, related directly to the poor.

- Detailed cost-benefit analysis in relation to additional crop yield and cost of the system. This should take into account other benefits such as controlling soil erosion and preventing migration.
- Further work on runoff-inducement techniques and their economical feasibility. Cost of materials is a major constraint. Research is therefore needed to identify low-cost, more durable materials that are easy to use.
- Identification of water-harvesting sites with high potential, taking into account all hydrological and environmental factors. WANA countries should prepare maps indicating the location of these sites some of which may be used for pilot projects.
- Study of the patterns of water consumption of recommended crops and trees under water-harvesting regimes. Crops under water harvesting undergo unavoidable periods of water shortage and stress, which inevitably reduce yields. This, of course, affects yield too. Information regarding crop yield under different levels of soil-water availability is notably lacking in the literature. This information is essential for designing sound systems and in modeling and simulation studies of water harvesting. Figures for stress-free crop consumption are usually not valid in the design of water-harvesting systems for the drier areas.
- Water harvesting is a complex interdisciplinary technology and its various techniques are mainly site-specific. To be technically and economically feasible, strong commitment and cooperation from the beneficiaries are required.
- Development of new techniques for minimizing evaporation and seepage losses from storage facilities.

Finally, it should be emphasized that the ultimate goal of on-farm water harvesting is a sustainable and environmentally friendly system of agricultural production. The aim is to complement rather than replace the existing water-use system. Improved systems must be socially acceptable as well as more productive.

It is highly recommended that water-harvesting interventions form part of a plan for integrated land and water resources development and that such a plan that takes into consideration all the necessary technical, agricultural, socioeconomic and institutional aspects and inputs.

Selected Bibliography

Boers, Th. M. and J. Ben-Asher. 1982. A review of rainwater harvesting. *Agricultural Water Management* 5: 145-158.

Critchley, W. and K. Siegert. 1991. Water Harvesting. FAO, Rome, Italy.

FAO (Food and Agricultural Organization of the UN), 1994. Water Harvesting for Improved Agricultural Production. Water Reports 3, Proceedings of the FAO Expert Consultation, Cairo, Egypt, November 1993, FAO, Rome, Italy.

Department of Agriculture, State Development, western Australia, 1992. Water Harvesting, Improving the reliability of farm dams in western Australian wheatbelt. A booklet. pp. 22.

Frasier, G.W. 1990. Runoff Farming: Irrigation Technology of the Future. Pages 404-409 *in* Visions of the Future. ASAE Publication 04-90. American Society of Agricultural Engineers. St. Joseph, Michigan.

Frasier, G.W. and L.E. Myer. 1983. Handbook of Water Harvesting. Agricultural Handbook No.600. United States Department of Agriculture, Agricultural Research Service, USA.

Hachum, A.Y. and J.F. Alfaro. 1980. A Physically-Based Model of Water Infiltration in Soil. Utah Agricultural Experiment Station Bulletin 505. Logan, Utah, USA.

Hudson, N.W. 1987. Soil and Water Conservation in Semi-Arid Areas. FAO Soils Bulletin 57. FAO, Rome, Italy.

Hutchinson, G.R., and M.A. Garduno (eds.). 1981. Rainfall Collection for Agriculture in Arid and Semiarid Regions. Proceedings of a Workshop, University of Arizona, USA. Commonwealth Agricultural Bureaux, UK.

Nasr, M. 1999. Assessing Desertification and Water Harvesting in the Middle East and North Africa. Policy Implication Discussion Paper No. 10. Center for Development Research (ZEF), Bonn, Germany.

Oweis, T.Y. and A.Y. Taimeh. 1996. Evaluation of a small basin water-harvesting system in the arid region of Jordan. *Water Resources Management* 10: 21–34.

Oweis, T.Y., A. Oberle and D. Prinz. 1998. Determination of potential sites and methods for water harvesting in central Syria. *Advances in GeoEcology* 31: 83–88.

Oweis, T, A. Hachum, and J. Kijne. 1999. Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency. System Wide Initiative on Water Management Paper No. 7. International Water. Management Institute, Colombo, Sri Lanka.

Prinz, D. 1994. Water harvesting - past and future. *In*: Pereira, L.S. (ed.). Sustainability of Irrigated Agriculture. Proceedings of the NATO Advanced Research Workshop. Vimeiro, March 1994. Balkema, Rotterdam.

Reij, C., P. Mulder and L. Begemann. 1988. Water Harvesting for Plant Production.World Bank Technical Paper No. 91, Washington D.C.

Sharma, K.D. 1986. Runoff behavior of water-harvesting microcatchment. *Agricultural Water Management* 11: 137–144.

Stewart, B.A. and J.T. Musick. 1982. Conjunctive use of rainfall and irrigation in semi-arid regions. *Advances in Agronomy* 1: 1– 24.

Tauer, W. and G. Humborg. 1992. Runoff Irrigation in the Sahel Zone. Verlag Josef Margraf Scientific Books, FR, Germany.

UNDP (United Nations Environment Program). 1983. Rain and Storm Water Harvesting in Rural Areas. Tycooly International Publishing Limited, Dublin.

Vorhauer, C.F. and J.M. Hamlett.1996. GIS: a tool for siting farm ponds. *Journal of Soil and Water Conservation* 5(5): 434–438.