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RAINFALL WATER MANAGEMENT IN THE ARAB REGION

State of the Art Report

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PREFACE

Water is becoming the "ISSUE" in this part of the world. The problem is becoming more significant due to the vastly expanding population and the increasing per capita demand to meet the great socio-economic developments of the last three decades. The natural renewable resource on the other hand , remained the same or rather decreased as a result of the widely reported decrease in annual rainfall and the more worrying factor of quality deterioration.

The situation is made even worse by the fact that most of the surface and groundwater resources in the region are, respectively, drawn from shared rivers and aquifers. This fact together with the natural water scarcity have led to the current speculations of severe regional conflicts and high prospects of confrontations. The consequences of water scarcity and conflicts could lead to serious crisis and possible confrontations, if they are not looked at and dealt with from a mandatory "Live and let other live" approach. Many options are open for this positive attitude where the key-words are; knowledge, communication and co-operation.

Three approaches are classically undertaken by professionals to survive the consequences of water scarcity, namely; to strictly (but rationally) manage the demand for that precious resource, to preserve and augment the supply, or more preferably to combine the previous two options in an integrated management plan aiming ultimately towards sustainable development. Demand management is currently a popular issue in which numerous technical and non-technical organizations are interested or actually involved. The preservation and augmentation of the supply, on the other hand, can be reached through improved management techniques for rainfall water, surface water and ground water as well as promoting non-conventional sources. There are, at present, reasonable regional efforts and focus on the surface and groundwater management issues, while the questions of alternative non-conventional resources are competently being dealt with in few financially able Arab countries. This leaves rainfall water management issue as a good choice for regional emphasis and concentration with the objective of enhancing the quantity of resulting renewable surface and groundwater resources.

Recent studies suggest that over 2300 billion m^3 of water is on average annually received as rainfall within the boundaries of the Arab countries. Only about 200 billion m^3 of that amount is actually received in the from of renewable surface and groundwater resources. This quantity is, together with the additional 144 billion m^3 of surface flow received from catchments outside the Arab region, is too small to meet the future needs of the increasing population of this region. Hence greater efforts should be sought through maximizing the benefits form these huge resources. There are, of course, fragmented but appreciable efforts in various countries of the region, directed towards making better use of their scanty rainfall. For example, artificial recharge methods are being widely used in many countries while various harvesting techniques and traditional methods have been tried by others. However, these efforts need development and sharing of experiences among the countries of the region. Hence, the purpose of this project is meant to survey the available techniques in the region and abroad, improve them and disseminate the results to the whole region. More specifically the immediate objectives of the project, as envisaged during the planning stage, has been outlined as follows:

- Creation of a regional working group in rainfall water management
- Publication of a regional state- of-the-art report, identifying priorities and outlining realistic follow-up lines of action.
- Prepare necessary documents for an extrabudgetary proposal in a selected area of the project field, preferably in collaboration with other interested organizations.
- Enlarge and utilize the members of the group as technical focal points in their countries.

These objectives and their follow-ups can not be achieved through ROSTAS finite human and financial resources. Hence, active participation from relevant technical agencies and institutes shall be investigated and pursued. UNESCO/ROSTAS encourages and supports. this style of work which had led, in the past, to successful achievements with many organizations such as the numerous activities implemented jointly with ACSAD. This initiative is in line with the current UNESCO's IHP-IV and forthcoming IHP-

V programs. The main implementation tools of this project were a four-man working group and an expert meeting that was held in the period 15-17 November 1994 in Cairo. The working group has prepared a combined report that was discussed during the expert meeting which produced a coherent state-of-art document and a list of high priority topics and themes that can be followed up in the immediate and medium term plans of the concerned agencies. This publication is a reviewed version of the above document with special references made to the material published in the following documents:

- "A survey of Rainwater Harvesting in Palestine", by Palestine Consultancy Group (provided by Brian Grover).
- "The Hafir" , by Shawgii I. Assad (Sudan)
- "Raw Water Harvesting in Egypt", by Abdelwahab M. Amer
- "IDRC Regional Experiences in Rainfall Harvesting", by Eglal Rached

Great appreciation and thanks are due to the authors of these documents and to the four-man working group who provided the technical material and its convenor who patiently and professionally edited the manuscript. The expert meeting in Cairo has added a lot to the material and format of the document and hence great appreciation must be extended to all of the experts who attended the meeting. Before sending the document for printing it was carefully reviewed by prof. A/Wahab Amer of Cairo University and his assistant Mr. Ayman Mohamed Al-Degwey, for final editing and correction of technical and typographical mistakes. Their well appreciated contribution has added very much to the correctness of the text.

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1. INTRODUCTION

The Arab region of some 14 million Km^2 extends between latitudes 4^oS and $37^o22'N$. It occupies an important part of southwest Asia and North Africa. The part which lies in low and middle latitudes have limited areal extent whereas the greater part of the region extends across a dry climatic belt which lies between 15^o and 30^o N, and encompasses the Sahara and Rub El Khali which rank among the driest areas in the world. These dry arid lands occupy the northern part of the Arab-African Platform and are underlain by large sedimentary basins which contain huge reserves of non-renewable groundwater resources.

Out of the 22 Arab countries only 9 lack perennial rivers. Socio-economic development in most of these countries have imposed considerable stress on conventional water resources, particularly groundwater which is of wide occurrence and could be developed at relatively low cost. This result in depletion of storage in aquifers which is considered a strategic reserve for present and future generations. Groundwater depletion is usually associated with deterioration of groundwater quality as a result of salt-water intrusion and/or upconing.

In arid Arab countries and in semi arid parts of most Arab states, wadi flow constitutes an important source which could be developed by means of water harvesting techniques or could be recharged to strained aquifer systems which confront problems of depletion and degradation of water quality.

Networks of wadi systems occur in almost all Arab countries. Information on water resources and hydrology of wadis are scarce because in the past little attention was given to this resource. However, since water shortage is becoming a major development constraint seriously impeding the economic growth of many countries, most Arab countries are giving increased attention and higher priorities to the development of water resources of ephemeral wadis. Water scarcity has led to the development of ingenious methods which are well adapted to the climatic and hydrologic conditions of semi-arid zones. Traditional techniques have been improved and new techniques have been introduced.

Throughout history, civilizations have flourished in Europe and the Middle East in areas where water resources were sufficient to sustain life.

Some of these civilizations used water efficiently through conservation practices. Because of supply limitations they learned how to effectively collect, store and utilize rainfall and runoff through water harvesting. Water harvesting is a technique which can be used to augment the quality and quantity of existing water resources, or provide water where other sources are either not available or are too costly to develop. Archaeological evidence indicates that rainfall and runoff water was harvested through terrace agricultural systems, and separate irrigation and water storage structures were used more than 6500 years ago.

Terracing, also known as staircase farming, is one of the oldest water diversion and soil conservation systems in the world. In the Middle East, it is said to have been first developed by the Phoenicians along the western coast of the Mediterranean and practiced in northern Africa and the Arabian peninsula. The ancient traditional system of terracing was found to be a solution for growing crops on steep slopes and preventing erosion, as well as allowing efficient use of water. Water for irrigating the terraces was stored in underground storage tanks, leather bags and even hollowed out trees.

Evidence of ancient water harvesting systems appears throughout the peninsula (Myers, 1974). The first water harvesting system was built around 4500 B.C. in Iraq. It is known that terracing systems were used to supply water for pilgrims and caravans traveling from the Arabian Gulf to Mecca. Evidence of these systems can still be seen today along some desert roads.

Hydraulic structures such as dams and diversions were first used about 5000 years ago by civilizations in the Middle East, India, and China. The Assyrians, Babylonians and Persians built dams to store water which augmented their natural water supply. The Egyptians built large masonry water diversion structures on the Nile near Kosleish in 2900 B.C. In Syria, six meter high rockfill dams, built in 1300 B.C. on the Orontos river are still being used today.

Dams and diversions were also used by ancient Arabian Civilizations to assure continuous water supplies and maintain sufficient resources for irrigation. Construction of early dams in this region was associated with the ancient society at Marib, home of the Himyarite tribals in Yemen, circa the first millennium B.C. and first century A.D. This civilization was the center of innovative irrigation, water conservation and hydraulic engineering works. The great dam at Marib helped to supply

ROSTAS project entitled "Rainfall Water Management" aims at surveying and improving rainfall water management methods and distributing the result in the Arab region. Such an endeavor would contribute to the sustainable water resources development in the Arab region. A working group set up by ROSTAS is entrusted with the responsibility of preparing a state-of-the art report and outlining realistic guides for future action.

The present report deals essentially with water harvesting and artificial recharge techniques. It touches on related areas such as precipitation enhancement and water conservation in soils. Rainfall characteristics, reduction of evaporation and agrometeorological applications in the Arab countries have been dealt with by Dr. Adam. Runoff characteristics, rainfall-runoff relations and runoff management have been tackled by Mr. Kallel. Spate irrigation and recharge dams and other water harvesting systems used in the Arabian Peninsula were highlighted by Dr. Abdulrazzak.
These contributions, together with an overview of the subject in the Arab region as persued by Dr. Khouri, have been combined and streamlined to form the final version of the regional state-of-the art report.

2. CLIMATE

The Arab region is dominated by an arid climate. It varies in its greater part from semi-arid to hyper arid.

The hyper-arid Sahara and deserts zone extends almost uninterrupted, from the Atlantic ocean in Mauritania and Morocco to the Gulf and the Arabian Sea in Yemen, Saudi Arabia, Oman and other Gulf countries. The semi-arid zone comprises the steppes that extend along the Mediterranean coast, and the thorn scrub and dry savanna south of the Sahara.

The region is affected by three main dominating pressure systems (Kawasma, 1983, ACSAD-UNESCO-IIHEE, 1988).

a. The Siberian anticyclone (in Winter)
b. The monsoon Asiatic low (in summer)
c. The Azores high pressure (in North Africa).

From the Azores high pressure cell which is located over the Maghreb, cyclones blow in an anticlockwise direction and move from the abundant irrigation water until its failure in 575 A.D. A number of civilizations flourished in the peninsula, especially in the southwestern region which was more populated. Considering number of generations of its population used innovative engineering and irrigation techniques to store and use the limited water resources, of this area, in a highly efficient manner.

The ruins of many old dams can still be seen in the peninsula, especially in the southwestern regions of Saudia Arabia and Yemen. Diversion dams were used to channel surface runoff into cisterns to be used for pilgrims travellting on Darb Zubaydah trail, 1600 Km long from Baghdad to Mecca, which was used heavily in the eighteenth century (MAW, 1984). Ancient dams and diversions were also built near Najran, close to the Yemen border, and near Taif and Khaybar in the western part of Saudi Arabia. Dams were also built in the southern parts of Oman along the old trading routes. Few dams have been well preserved, however most of the dams are deteriorated, filled with sediment or completely destroyed. These ancient dams range from 5 to 35 meters in height and from 100 to 200 meters in length. They were built of both cut and uncut stone, unmortared rubble and large boulders of various shapes and sizes. The material was chinked with small stones in successive horizontal rows using stepped construction. Sometimes two retaining walls were built with pebbles and boulders in lime mortar and the space between them was filled with loose stones. Lime mortar was sometimes used in the masonry work of larger dams.

During the past 6500 years, many water harvesting systems have been constructed in different parts of the world, especially in arid regions. Some have been employed successfully to achieve their objectives while others were abandoned due to poor design, lack of maintenance and changes in social and economic conditions. Recently, however, there has been renewed interest in traditional water harvesting techniques. Scientists have been called on to ensure the success of old water harvesting techniques through the use of new revolutionary technology and innovations. Thanks to their efforts, some of the old water harvesting techniques have been revived and have proven to be efficient methods of water utilization. Some of these methods are currently in use in the countries of the Arabian Peninsula. Further enhancement of their efficiency, however, can be achieved through proper maintenance and operation, thereby increasing their importance and value as water harvesting systems.

Atlantic ocean to the Mediterranean where they become humid and continue further to the east, carrying winter rains over the southern and eastern coasts of the Mediterranean.

This process is reversed during summer as the high pressure Azores mountains to the north block the rainstorms (ACSAD-UNESCO-IIHEE, 1988). However, the southern parts of the Arab region is dominated mainly by the western extension of the monsoon Asiatic low. This thermal depression extends its influence to the eastern Mediterranean, the Corn of Africa and the Nile valley (Kawasma, 1983).

The coastal mountain ranges play an important role in the distribution of precipitation in the Mediterranean, Red Sea and Gulf of Oman. An exception to this general rule is in the Sudan where the saturated air masses, coming from the Atlantic and Indian Oceans, cross the Congo in a northeastern direction and divert to the north, and continue their journey to reach a depth of 1300 km inside the Sudan near Atbara city.

The average temperature, in January is 5 ^{o}C or less in the mountainous regions of the Maghreb and Mashrek. It increases southwards to 15 ^{o}C and may pass 20 ^{o}C. During July the temperature on the coast reaches 20^{o} -30 ^{o}C. It increases inland and may reach 50^{o}C or more in the Sahara and desert regions.

Factors which influence evaporation are air temperature, wind velocity and air humidity. Evaporation is high in the Arab region due to high temperatures, low relative humidity and abundance of heat energy resulting from net solar radiation.

Evapotranspiration is the withdrawal of water from a land area by direct evaporation from water surfaces, soil, and by plant transpiration. It has the first call on precipitation. It reduces the amounts available for streamflow or groundwater recharge.

The drought variation coefficient, which is the ratio of the net radiation left on the surface to the product of the annual rainfall at the evaporation temperature, attains its highest value in the Arab World; it usually exceeds 3 in the Sahara and deserts of Saudi Arabia (ACSAD-UNESCO-IIHEE , 1988). This coefficient ranges from 0.35 to 1.5 in Europe.

Evaporation from free water surfaces along the southern and eastern coasts of the Mediterranean ranges from 150 to 1000 mm/yr (ACSAD-UNESCO-IIHEE, 1988). This value increases inland to about 2000 mm/yr, while in the desert areas of North Africa it reaches 3000 mm/yr. In the Arabia peninsula and Gulf region evaporation is about 2500 mm/yr. The value of 2000 mm/yr is considered to represent the average evapotranspiration in the Arab region. It ranges, however, from 800 mm/yr in the eastern coast of the Mediterranean to 2500 mm/yr in Arabia. Data on evaporation from Tunisia exceplifies the variation of evaporation in coastal (Susah, 1330 mm/yr) and inland (Qayrawan, 1800 mm/yr) areas. Jordan evaporation records, on the other hand, provide an example of variation of potential evapotranspiration from mountainous regions eastwards to the arid flat land and westwards towards the rift valley (Dead Sea , below sea level).

3. RAINFALL CHARACTERISTICS

Rainfall Distribution

The total volume of precipitation in the Arab region is estimated in the order of 2238 BCM. The greater portion, namely, some 1488 BCM falls on an area not exceeding 19% (2.66 million Km^2) of the total area of the Arab world, and about 406 BCM falls on about 15 % of the total area. The remaining part (344 BCM) falls on the arid and hyper arid deserts totaling 9.24 million square kilometers, which constitute about two thirds of the total area of the Arab world .

The Arab region can be divided into three sub-regions depending on the rainfall regime. These are: the northern or Mediterranean Sub-region, the Arabian Peninsula and southern subregion or Arabic part of the Sahelian region.

The Mediterranean sub-region is characterized by winter rainfall. Rainfall generally decreases from north in the coastal zone to south in the interior desertlands. In the eastern Mediterranean precipitation decreases, generally, from west to east. Rainfall is high over the coastal mountains of Syria and Lebanon. It decreases from 1500 mm/yr on the high Lebanon mountain belt west of the rift system to about 800 mm/yr on the Anti-Lebanon mountain ranges east of rift zone. Rainfall decreases also southwards to about 400-500 mm/yr in Jordan.

In the Maghreb, a similar precipitation regime exists in the Atlas Mountain ranges over the coastal Rif-Teli Atlas. Precipitation reaches 1800 mm/yr in Morocco and 1500 mm/yr in Algeria and Tunisia. It decreases southwards over the high plateau and Sahara Atlas to about 500 mm/yr and on the slopes adjacent to the Sahara rainfall drops to 100-200 mm/yr.

In the hyper-arid belt preciptation decreases from west to east, reaching in the eastern Sahara as low rainfall as less than 10 mm/yr. The Ahggar and Jibesti highlands in the center of the Sahara are characterized by somewaht higher precptation (up to 100 mm/yr).

The Arabian peninsula is generally characterized by low rainfall of great temporal and spatial variability. The average annual rainfall ranges from 70 to 130 mm/yr, except in the Asir, Sarat and Omani mountain ranges located in Saudi Arabia, Yemen and Oman, respectively, where rainfall may vary from 300 to 1000 mm/yr. Rainfall distribution is influenced by the escarpment ridge of the Asir and Sarat mountains, which runs parallel to the red sea. Along the coastal area near the sea the annual rainfall is often less than 50 mm/yr. The elevation gradually increases from sea level to 500 meters over a distance of 50 kilometers, with a corresponding increase in rainfall which averages between 250 to 300 mm/yr in the escarpment. At the top of the escarpment the elevation reaches between 2000 and 3000 meters, and rainfall ranges between 500 and 1000 mm/yr per year in the higher elevations. The highest amount of rainfall occurs in Yemen and the amount of precipitation received on the western slopes decreases in a northerly direction.

The eastern side of the escarpment receives less rainfall than the western slopes. The mountain range blocks the westerly and northwesterly winds that carry moisture from the western slope, thus preventing any significant contribution to precipitation on the eastern slopes. In the winter, however, movement of air masses across the Arabian peninsula from the Arabian Gulf results in precipitation on the eastern slopes. The total amount of rainfall in this area ranges from 150 mm/yr in the interior areas to 400 mm/yr in the escarpment. Isohyetal maps of the mean annual rainfall distribution in the southwestern region of Saudi Arabia and most parts of Yemen, show wide rainfall variations from the coast to the internal areas, mainly due to the influence of the escarpment.

Mauritania, Somalia and Sudan receive rain mainly in the summer. The whole of Mauritania north of latitude 14 N has an annual average rainfall of less than 300 mm/yr. The same goes for Somalia where 80% of the country lies within an isohyte limit of less than 300. In Sudan, rainfall decreases from 1800 in the far south of Sudan to 25 mm/yr at the borders of El-Atmour desert north of Atbara. This is the principal characteristic that distinguishes Sudan from all other Arab states, as it enjoys an abundance of rainfall estimated at more than half of what the Arab World receives.

Variability

The coefficient of rainfall variation, C.V., in the Mediterranean sub-region ranges from 25 to 50%, while it varies from 30 to 50% in Sudan, Mauritania and Somalia. In drier areas the coefficient exceeds 100 %. Under moderate climatic conditions a single value ranges from 75% to 125% of the average with a 95% probability i.e at the rate of 15 years in every 20 years. However, in the drier regions the range between the maximum and minimum annual precipitation exceeds the above values, also the probable distribution diverges more from the uniform distributions. When the depth of annual rainfall ranges between 200 mm and 300 mm, the singular annual depth ranges between 40% and 200% in 19 years out of 20. If this depth drops to 100 mm/year, the range becomes between 30% and 350% in 19 years out of 20. Needless to say that the drier regions may have several years without any rainfall. (ACSAD-UNESCO-IIHEE, 1988). It is clear from the above that the coefficient of variation of the annual precipitation over a certain point, is inversely proportional to the average annual rainfall.

Rainfall in the Arab peninsula is generally characterized by a great temporal and spatial variability. Average rainfall values have little meaning. Many areas receive no rainfall for months or even years, due to extremely random storm patterns. Seasonal variations in rainfall indicate that during the winter season (December-January) the area is influenced by the Mediterranean depression and Sudan Low trough (Al-Ehaideb, 1985). The largest amount of rainfall usually occurs along the northern part of the Asir escarpment. Spring rainfall (February-May) is sometimes influenced by the southeasterly monsoon and westerly winds that reach the area from the Mediterranean depression. During this season the eastern side of the escarpment receives more rainfall than the western side. Summer rainfall (June-August) is influenced mainly by the summer southwesterly monsoon flow which is characterized by moist air. Due to the direction of the monsoon wind, rainfall is influenced predominantly by orographic effects. During this season the southern foothills and the western slopes receive more rainfall than the remainder of the escarpment. In autumn (September - November) rainfall is usually minimal. In mid and late autumn, the pattern is usually influenced by the Red Sea trough and the Mediterranean depression. The western foothills receive most of the rain during this season.

Interannual variability in the Mashrek semi-arid zones has been illustrated in Jordan by calculating the coefficient of variation for 55 stations for the period 1954-1978 (Kawasma, 1983). The value of C.V. seems to be dependent on total annual rainfall. In general the higher the rainfall the lower the interannual variability .

The following table illustrates the relationship between annual rainfall and coefficient of variation (Kawasma , 1983).

REGION	RAINFALL (mm)	C.V.%
North Jordan Valley	above 350	18-25
Mid Jordan Valley	250-300	20-30
North hilly region	above 500	21-30
South hilly region	200-400	30-45
Steppe (east)	100-200	40-60
Steppe (southeast)	less than 100	above 55

As far as the monthly mean values are concerned, their interannual variability is much higher than those of the yearly values.

Central Tunisia provides an example of rainfall variation in the semi-arid zones of the Maghreb. In the period 1931-60 the annual average of seven stations whose records are fairly continuous, ranged from 658 mm in 1932 to 128 mm in 1946 and the median was about 277 mm. The progressive 5 year average precipitation in several localities in central Tunisia. Alternating wet and dry periods are generally less pronounced at Tunis than at stations in central Tunisia although the drought of 1941-48 and the wet period of 1949-56 were more pronounced than those expressed in the Sahil Susah.

4. RUNOFF CHARACTERISTICS

When rain falls, a portion of it is retained as "basin recharge". It comprises interception (water intercepted by vegetation), depression storage and soil moisture. Runoff develops when rainfall intensity exceeds the infiltration rate of the soil (Horton, 1933). According to Dune and Black (1970) runoff is generated when the volume of water exceeds the storage capacity of the soil. It seems that Horton's concept is more appropriate on upper slopes, whereas Dune and Black's concept is more suitable for areas near drainage channels. (Tauer and Humborg, 1992). Direct runoff includes surface runoff (overland flow) and inter flow. Streamflow (or wadi flow) consists of both direct and groundwater runoff.

Since recharge is low in arid zones compared with temperate regions, groundwater runoff into wadis usually constitutes a minor proportion of the total flow. Direct runoff dominates the cumulative runoff in semi-arid catchments. However, when runoff is generated from rainstorms, and therefore surface water infiltrates into wadi fill and becomes interflow or groundwater, the "rising water" which results in perennial flow in certain reaches of principal wadis indicates that there have been infiltration into permeable materials somewhere upgradient from the point of discharge. The base flow of perennial wadis released naturally from the groundwater reservoir is the surface water most readily available for use by man. Few wadis in the Arab region flow, perennially, and therefore storm flow needs to be regulated to form appropriate water source for diversion to beneficial use. Such water can be salvaged for use by man after it has been stored in the soil, in surface reservoirs or underground. The reservoirs on the surface include sabkhas where water accumulates naturally. Similarly underground reservoirs might store water received naturally by seepage from wadis or artificially in recharge projects that might be developed. An example of sabkha water development is provided from Syria where large Hafirs have been constructed within the context of pilot wadi development project completed in 1994. Feedback from the Tenf pilot project in Syria and a similar pilot project implemented in Wadi Ruweished in Jordan could provide lessons for similar wadi developments in the Arab region. Properly constructed Hafirs could minimize quality problems which are usually encountered in sabkhas in arid and semi-arid zones.

The factors governing the runoff process can only be described in general terms. The more significant factors can be divided into two groups, namely rainfall-event dependent and catchement-area dependent (Tauer and Hamborg, 1992). Most studies are based on lumped parameters and estimates of mean values of the hydrologic behaviour that represent a catchment area. The most widely known lumped parameter in hydrology is the runoff coefficient. Runoff coefficients are not, however, constant factors since their values depend on rainstorm characteristics and catchment specific factors. When plotting the runoff coefficients against the relevant runoff depths a satisfactory correlation is usually obtained. A better relationship would, however, be obtained if in addition to rainfall depths the corresponding rainstorm intensity, duration and antecedent soil moisture are measured (Siegert, 1948).

Apart from rainfall characteristics such as intensity, duration and distribution major factors which have direct effect on the rainfall-runoff process include, geomorphologic factors, slopes, size of catchment areas, channel characteristics, soils, vegetation and land use.

Rainfall-runoff models are used to predict a runoff event from physical and climatic parameters. An important use of models is for the assessment of the magnitude of the flood to be used in the design of hydraulic structures. Rainfall-runoff models can, however, be employed for assessing the potential of water harvesting. Several computer models which simulate the hydrologic processes on the basis of satellite data have been developed (Tauer and Humborg, 1992). Spatially distributed parameter models cannot yet replace conventional universal lumped parameter models. Remote sensing systems can, however, assist in supplying data and GIS that incorporates diverse spatially distributed characteristics such as land, soil, rainfall, runoff and infiltration can be used. These data bases could be superimposed and projected, in conjunction with raster or vector oriented data, onto the study area.

In the Sahara, it was shown that rainfall intensity is of primary significance in the generation of surface runoff. Dubief (1955) has demonstrated that intensities of about 30 mm/hr can cause floods in the Ahggar (Algeria) even if rainfall depth is as low as 5 mm.

Detailed studies of rainfall-runoff relations in semi-arid zones were carried out in central Tunisia (Dutcher and Thomas, 1967). It was shown that the pattern of runoff follows closely the pattern of precipitation. Hydrographs of selected wadis show several distinctive streamflow characteristics of which the most pronounced are the sharp peaks, representing the storm flow. In a single day that heavy precipitation occurs the rate of discharge may increase several hundreds times. After each storm peak the discharge falls rapidly at first and then at a progressively decreasing rate.

The relation between monthly precipitation and mean monthly discharge for the period 1925-60 varied somewhat according to season. In the first part of the rainy season (September-November) the rainfall that caused runoff ranged from 50 to 200 mm per month. The corresponding runoff was at a mean monthly rate of 5-10 m3/s and did not increase proportionally with precipitation. A part of the runoff in this period was absorbed by the terrain after the hot dry summer. Later in the rainy season (December-April) the rainfall that caused significant runoff ranged from 20 to 470 mm per month. In these months, widely varying amounts of rainfall have produced approximately the same runoff and equal amounts of rainfall have produced a wide range of runoff amounts.

Several factors are clearly involved in the pattern of streamflow in the semi-arid zones of central Tunisia. The high maximum and short duration of flood runoff and the negligible flow in rainless periods. The distribution channels which results from the sediments carried by wadis in floods and deposited as velocity of flow diminishes, are common characteristics of wadis in semi-arid and arid zones of the Arab region.

Available records indicate that the streams draining the mountain ranges of northwest and central Tunisia have high maximum flash flood runoff and negligible flow in rainless periods. These characteristics suggest that much of the rain falls on relatively impermeable surfaces, because there is evidence of very little release from (and therefore of infiltration to) groundwater reservoirs. The wadi systems which drain the ophulites of Oman mountains and the basement rocks of red sea mountains in Yemen and Saudi Arabia exhibit similar runoff characteristics. Studies of wadi flow in these countries revealed similar problems and constraints such as the unpredictable, character of spate floods, the serious problems arising from destructive floods and high sedimentation.

In contrast to wadis draining impermeable terrains the greater part of flow of wadis draining carbonate massives such as the Lebanon, Anti-Lebanon (Syria) and Ajloun mountains (Jordan) come from groundwater. The annual runoff of wadi Barada in Syria is estimated at 441 MCM. Of this amount some 346 MCM or about 80 % is groundwater seepage.

The knowledge of runoff from individual storms is essential to assess the runoff behavior of the catchment area and to obtain information on the runoff peaks which the structure of the water harvesting scheme must withstand and the needed capacity for temporary storage of runoff such as the size of an infiltration pit in a microcatchment system (Crichley and Siegert, 1991). In order to determine the ratio of catchment to irrigated area it is necessary to assess either the annual or the seasonal runoff coefficient. This is defined as the total runoff observed in a year (or a season) divided by the total rainfall in the same year (or season).

5- WATER RESOURCES AND WATER DEMAND IN THE ARAB REGION; PROBLEMS AND PERSPECTIVES

Renewable water resources in the Arab region have been estimated at 340 Billion Cubic Metres (BCM) (ACSAD, 1994). Of this total some 161 BCM is available in shared river basins, and about 179 BCM is generated within the region. Average annual recharge to groundwater systems is estimated at 45 BCM, whereas some 135 BCM is available in perennial streams and ephemeral wadi systems. Hydrologic studies, on the other hand indicate that the average annual runoff is about 191 BCM (ACSAD, 1994). It seems therefore that losses in perennial and ephemeral drainage systems are as high as 100 BCM, however, considerable amounts of this value are seepage losses, which are no more considered losses, since they recharge aquifers and about 50% of these potential resources could be harnessed. Losses in natural water courses and existing water supply networks should be minimized in the future in order to meet water deficits at the local and national levels.

Water problems in the Arab region stem primarily from rapidly rising water demands. As a result of high population growth rate (3.0 per cent on the average), population size of the Arab region is expected to increase from about 225 million at the present to about 300 million by the year 2000 and about 500 million in the year 2020, whereas the per capita availability of water will decrease from about 1500 m3/Yr, to about 700 m3/Yr, by 2020. However these estimates, although they give an indication of the order of magnitude of the regional water situation, do not reflect the critical issues encountered at the national level. Severe shortages, which even affects drinking water supplies, are manifested by comparing the per capita water availability of various countries. Of the 22 Arab countries the per capita water availability in 8 countries does not exceed 500 m3/Yr and they range from 500 to 1000 m3/Yr in seven countries. By 2020 the per capita share of water will drop by about 50%. Population of countries with scarcest water resources are concentrated in large urban centres which are distributed mainly in coastal areas. Cities with growing municipal water demand such as Kuwait, Dhahran, Abu Dhabi, Mascat, Jeddah, are dependent on desalinated water, blended with brackish groundwater. Large urban areas such as Damascus, Amman, Riyadh, Sana'a which are located inland are confronted with acute water problems. Nearby Aquifers developed for the water supply of these towns have been depleted at alarming rates. Water authorities, have implemented costly water transfer projects to meet an almost exponentially increasing water demands. Desalinated water has been transported to Riyadh from the Gulf for a distance of about 400 Km. New water sources of Damascus and Amman are progressively becoming more remote. In these and other several cities in the Arab region, as population and economic activities expand, a considerable amount of water used for domestic and industrial purposes have to be diverted away from irrigation. In spite of major efforts directed towards the development of new sources of water supplies the arid pace of urbanization has necessitated water rationing. Starting in 1988 water rationing was implemented in Amman urban area. Supply shortage rose from 3 MCM in 1986 to 13 MCM in 1990 (Bilbeisi, 1991). Water rationing is now a common practice in many towns in the Arab region.

About 90% of developed water resources in the Arab region is used in irrigated agriculture. In spite of the large proportion of water allocated to agricultural use and efforts directed towards controlling salinization, raising irrigation efficiency and increasing productivity, food gad in the Arab region is widening progresively.

There is a growing recognition in the Arab region of the important role of rainfed agriculture for implementing a strategy for food security. The semi-arid zones which extend along the eastern and southern coast of the Mediterranean and in higher latitudes south of Sahara and Arabian deserts comprise important grazing lands and rainfed crop lands. These rainfed areas receive high priorities in the present and future national development plans. Countries endowed with extensive rainfed areas have stressed the importance of increasing their productivity through introduction of modern production techniques and applied research findings of national, Arab and international research centers such as ACSAD and ICARDA. Some 40 million hectares of rainfed croplands and about 500 million hectares of natural grazing lands could benefit from research findings of these international regional and national centres concerned with rainfed cropping and grazing systems. Experience of farmers in this context should not be overlooked. Response farming practices which aim at institutionalization of the farmers, role and incorporating information and rainfall expectations and crop responses to water should be promoted (Stewart, 1988). The present report places special emphasis on rainfall management for agricultural purposes.

In spite of variety improvement, fertilization and development of packages of production practices for the improvement of productivities of rainfed croplands, average yield remains as low as 1.5 t/ha. By applying some 20 mm of water to arid germination in fall and 30 mm in spring average yield of wheat and barley increased in Turkey from about 1.7 t/ha to 3.75 and 4.0 t/ha respectively (Perrier and Salkini, 1987). Rainfall water management does not only offer definite possibilities for increasing productivity in the vast drylands farming belts, but has also the potential for addressing a number of water supply problems in urban and rural areas in addition to its contribution to the development of steppe rangeland. Certain floodwater harvesting techniques can be used effectively for combating desertification in marginal lands and restoring deteriorating rangelands. Much can be done in the upper catchments of wadi systems which are subject to erosion. Enhanced knowledge of wadi hydrology could help in developing strategies for the use of appropriate rainfall management techniques. An integrated approach based on the conjunctive use of wadi-flow and wadi aquifer seems to be an efficient method of water resources management in the middle and lower reaches of major wadis. Furthermore, management of flash floods and spate irrigation is an area of research which merits the greater attention of desert research centers and arid zone institutions.

6. RAINFALL WATER MANAGEMENT; STATE-OF-THE-ART

Rainwater harvesting is defined as the collection of runoff for its productive use (Critchley and Siegert, 1991). A "Water harvesting system" is a facility for the collection and storage of runoff water. Systems which harvest water from roofs or ground surfaces are grouped under rainwater harvesting, whereas systems which collect water from water courses are classified as "floodwater harvesting".

"Rainfall water management" deals with all methods which augment precipitation, manage rainfall and runoff and store them in the soil or underground for later beneficial use. Rainfall water management techniques should be not only technically sound and economically feasible but need also to be socially acceptable to the users. Traditional water systems which are still in use should not therefore be neglected or underestimated and replaced by new methods unless they become unadaptable with present socio-economic conditions. A comprehensive systematic survey of traditional water systems, conducted by ACSAD and UNESCO (ROSTAS) has revealed that some 25 systems are used in the Arab region. Of these, ten systems are directly related to rainfall water management (ACSAD-UNESCO, 1986). Promising traditional water systems have been grouped into four categories;

a. Water harvesting and storage systems
b. Water harvesting and spreading systems
c. Groundwater systems
d. Water lifting systems

Table (1) shows the distribution of the different traditional water harvesting techniques in the Arab countries.

(Table 1) - Distribution of traditional water system in the Arab States

Name of system	Jordan	Un.Arab Emirates	Bahrein	Tunisi	Algeria	Saudi Arabia	Sudan	Syria	Iraq	Oman	Qatar	Kuwait	Lebanon	Libya	Egypt	Morocco	Moretania	Democratic Yemen	Arab Yemen
Cisterns	x	-	-	x	?	-	-	x	x	-	-	-	x	x	x	x	-	x	x
Small dams	x	x	-	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x
Hafirs	x	-	-	-	-	x	x	x	x	-	x	x	x	-	-	-	x	x	x
Tree trunks	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Koroum / Ghadirs	x	-	-	-	-	x	x	-	x	-	-	-	x	-	x	x	-	-	-
Terraces / Masateb	x	-	-	x	x	x	-	x	x	-	-	-	x	x	-	x	-	x	x
Irrigation diversion dams	x	-	-	x	x	-	x	x	x	-	-	-	x	-	x	x	-	x	x
Water spreading dykes	x	-	-	-	x	x	x	x	x	-	-	-	x	-	x	x	x	-	-
Miskat	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Artificial recharge	x	x	-	-	-	-	x	-	-	-	x	-	-	-	x	x	-	x	-
Check dams	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Foggaras	-	x	-	x	x	x	-	x	x	x	-	-	x	x	x	x	-	-	-
Surface wells	x	x	-	x	x	x	x	x	x	x	x	-	x	x	x	x	x	x	x
springs	x	-	-	x	x	x	-	x	x	x	x	-	x	x	x	x	x	x	x
Ghoutas	-	-	-	x	x	-	-	-	-	-	-	-	-	x	x	-	-	-	-
Shadouf	-	-	-	-	x	-	x	-	x	-	-	-	-	-	x	x	x	-	-
Saquia / Naoura	-	-	-	x	-	-	x	x	x	-	-	-	-	-	x	x	-	-	-
Tambour	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Bucket and pulleys	x	-	-	x	x	x	x	x	x	-	-	-	x	x	x	x	x	x	x
Wind mill	-	-	-	x	-	-	x	x	-	-	-	-	x	x	x	x	-	?	?
Hydraulic mill	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	x		

Source: ACSAD-UNESCO/ROSTAS,1986

ACSAD-UNESCO study comprises a detailed description, evaluation and means of improvement of these techniques. The importance of traditional systems has been also recognized in sub-Saharan Africa (Critchley and Reis, 1989). Simple stone bunds are used in Burkina Faso and earth bundling systems are found in Eastern Sudan and Central Somalia (Critchley and Siegert, 1991).

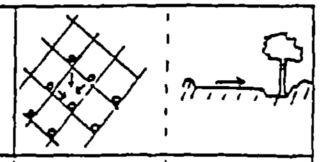
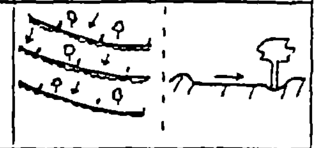
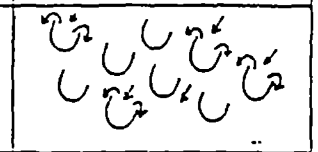
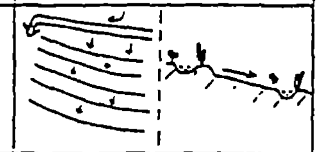
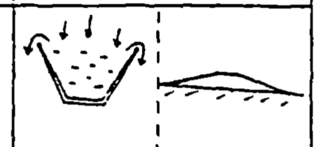
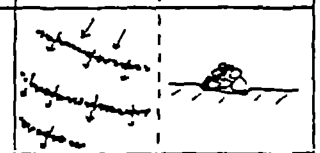
Several classifications of modern water harvesting techniques have been proposed in the past decades (Bazza, and Tayaa 1993, Nissen-Peterson, 1982). Their diversity attests the urgent need to streamline terminology in this field. A general classification has been established within the context of "sub-Sahara water Harvesting study" undertaken by the World Bank in 1986-89. This classification and summary of the main water harvesting techniques are presented in Table(2).

The most important traditional and modern rainfall water management techniques are highlighted in the following sections. They comprise methods for managing rainfall and runoff. Those which are considered of relevance and significance to the Arab region can be grouped as follows;

a. Precipitation enhancement
b. Evaporation reduction
c. Water conservation in soils
d. Rainwater harvesting
e. Flood water harvesting; spate irrigation
f. Artifical recharge
g. Agrometeorological application.

According to the classification proposed by the World Bank and adopted by FAO (1991), rainwater could be stored either in the soil or by deep ponding. However, it is equally important to store water underground in wadi-beds or near-surface aquifers. Such a storage facilitates the conjunctive use of surface water and groundwater. The exploitation of runoff stored in alluvial cones, by Aflaj (Faggara) systems is a useful technique for the development and management of wadi-flow. The Ghayl falaj systems which are of common occurrence in Oman utilize the low flow of wadis which is diverted into a channel either by a low bund or short collector gallery.

Table (2) - Summary chart of main water harvesting techniques

	Classification	Main Uses	Description	Where Appropriate	Limitations	
negarim microcatchments	microcatchment (short slope catchment) technique	trees & grass	Closed grid of diamond shapes or open-ended "V"s formed by small earth ridges, with infiltration pits	For tree planting in situations where land is uneven or only a few tree are planted	Not easily mechanised therefore limited to small scale. Not easy to cultivate between tree lines	
contour bunds	microcatchment (short slope catchment) technique	trees & grass	Earth bunds on contour spaced at 5-10 metres apart with furrow upslope and cross-ties	For tree planting on a large scale especially when mechanised	Not suitable for uneven terrain	
semi circular bunds	microcatchment (short slope catchment) technique	rangeland & fodder (also trees)	Semi-circular shaped earth bunds with tips on contour. In a series with bunds in staggered formation	Useful for grass reseeding, fodder or tree planting in degraded rangeland	Cannot be mechanised therefore limited to areas with available hand labour	
contour ridges	microcatchment (short slope catchment) technique	crops	Small earth ridges on contour at 1.5m -3m apart with furrow upslope and cross-ties Uncultivated catchment between ridges	For crop production in semi-arid areas especially where soil fertile and easy to work	Requires new technique of land preparation and planting, therefore may be problem with acceptance	
trapezoidal bunds	external catchment (long slope catchment) technique	crops	Trapezoidal shaped earth bunds capturing runoff from external catchment and over-flowing around wingtips	Widely suitable (in a variety of designs) for crop production in arid and semi-arid areas	Labour-intensive and uneven depth of runoff within plot	
contour stone bunds	external catchment (long slope catchment) technique	crops	Small stone bunds constructed on the contour at spacing of 15-35 metres apart slowing and filtering runoff	Versatile system for crop production in a wide variety of situations. Easily constructed by resouce-poor farmers	Only possible where abundant loose stone available	
permeable rock dams	floodwater farming technique	crops	Long low rock dams across valleys slowing and spreading floodwater as well as healing gullies	Suitable for situation where gently sloping valleys are becoming gullied and better water spreading is required	Very site-specific and needs considerable stone as well as provision of transport	
water spreading bunds	floodwater farming technique	crops & rangeland	Earth bunds set at a gradient, with a "dogleg" shape, spreading diverted floodwater	For arid areas where water is diverted from watercourse onto crop or fodder block	Does not impound much water and maintenance high in early stages after construction	

Source FAO 1991,(Critchley and Siegert)

6.1 Precipitation Enhancement

Although weather modification has the potential of increasing precipitation, the quantity of additional precipitation that can be artificially produced is roughly proportional to the amount that nature produces (Koenig, 1988). It has been estimated, for instance, that cloud seeding in the high and Middle Atlas of Maghreb during the first half of the 1980s resulted in an increase of precipitation of about 10-15 %.

Many natural clouds are super cooled. They contain liquid droplets at temperature below 0°C. Naturally freezing nuclei facilitates the freezing of some cloud droplets into ice crystals. These crystals usually grow at the expense of the droplets and may lead to precipitation of the cloud. The concentration of natural nuclei could be sometimes extremely low and the process of precipitation can be very slow. In such cases the introduction of artificial nuclei (Silver iodide or carbon dioxide) can result in a rapid growth of particles at the expense of super cooled water drops. This would speed up the process of precipitation in the cloud and could result in augmenting the amount of precipitation. In addition to the formation and growth of a large number of ice crystals the latent heat which is released from this process increases significantly the buoyancy in the cloud and thereby enhances precipitation.

Several experiments have been conducted in various types of cloud systems including orographic winter connective and summer connective clouds. Some of them have produced either statistical or physical indications that seeding may have affected precipitation.

Although there is a keen interest in cloud seeding in arid and semi-arid lands, experience indicates that the best results are obtained in areas where cloud air masses are swept upward over mountain ranges (Arar, 1993). Prospects for increasing precipitation over the semi-arid lowlands do not seem to be promising. Thus during the 1980 drought in Maghreb, the government response plans included a precipitation enhancement project which was carried out in the Middle and High Atlas. Precipitation increase, resulted from cloud seeding over these highlands, generated runoff which was stored in surface water reservoirs. The impounded water was conveyed to drought-affected areas and was used for mitigating adverse impacts.

Beside the Atlas mountains in the Maghreb sub-region, the coastal Red Sea mountain belt in Yemen and Saudi Arabia seems to be a favourable area for precipitation enhancement. However, the technology in this regard needs further development in order to improve its efficiency and reduce costs. At the present time, most authors are of the opinion that it has not reached a sufficiently advance stage of development so that it could be considered among the viable methods for the augmentation of water resources in arid and semi-arid zones.

6.2 Reduction of Evaporation From Free Water Surfaces

In arid and semi-arid regions evaporation rates from water surfaces are high and conservation of water is of major importance. As stated earlier, high temperature and low relative humidity are important factors which increase losses by evaporation from free water surfaces. In the Arab region evaporation ranges from 750 to 3000 mm/year. To give an example about the volume of freshwater lost from large water bodies, the estimated water losses from lake Naser is about 10 billion cubic meters per year. Total losses from perennial and ephemeral streams in the Arab region is about 100 BCM. Nearly 50% of this loss is from natural swamps lakes and marshlands in large river basins. This aspect of water conservation is important in the Arab region, but so far has not received serious attention.

Many methods have been proposed, and tested, to control evaporation from free water surfaces. These methods are categorized by energy-reducing treatments like the water colours, using wind barriers, shading water surfaces and floating reflective covers. Floating covers were the most widely investigated and certain materials seem promising as "water harvesting storage facilities". They include covers of continuous paraffin wax, polystyrene rafts and foamed rubber. These three covers seem to reduce evaporation by 85 to 95% (Arar, 1991). Certain chemicals which form monomolucular layers over water surfaces are found to be effective in reducing evaporation from these surfaces. Strait chain fatty alcohol such as hexa and octa-decanol seems to be the most promising compounds (Mansfield ,1955, Arar, 1991). Experimental work in temperate climate has shown a reduction of evaporation of about 30-40% in warm summer period and about 10% during cooler periods (Roberts, 1957). The selection of the appropriate method depends on local conditions and economic considerations. Normally, the cost of water saved in arid regions compares favorably with alternative water sources.

Wind and wave action, do, however, often destroy the monomolicular film cover making frequent applications necessary. The use of this method in large reservoirs may not therefore be practical. On small reservoirs or ponds, the wind and wave action is not severe and, accordingly, the use of monomolicular films appears to be a feasible means of water saving in most areas.

Another practical method is using trees as wind breaks, for shading small hafirs and cisterns . Such a method is effective in reducing wind speed thus reducing evaporation.

6.3 Water Conservation in Soils

Rainfed agriculture constitutes an important component of the economy of several Arab states and has a substantial contribution to Arab food security. Rainfed areas are characterized by highly variable rainfall. Unreliability and variability of precipitation increase as aridity increases.

The conversion of vulnerable grazing land to cropped land in marginal zones has resulted in land degradation and has led, in some areas, to desertification. Farmers in arid and semi-arid zones of the world have devised methods for conservation and management of difficult environment by soil and climate. However, the problems facing rural imposed communities in dry land regions are that traditional methods for coping with risks and hazards of dry land agriculture are breaking down under population pressure (Jaradat,1988). Factors which contribute to efficient use of water must necessarily be given much attention if food production is to be increased to match the rapidly growing population.

Soil management practices, such as tillage ripping, mulches, seedbed preparation and fertilizer application, play a vital role in soil moisture conservation and efficient use of water. Factors in crop production which affect the water use efficiency include both soil and plant management practices (Ofori,1993). Cultivation practices and soil surface management greatly influence water use efficiency. One of the major factors in maintaining adequate water regime for crop production in semi-arid environment is soil structure, which facilitates water infiltration and storage. Improvement of the structural stability of the soil is, therefore, important. Crop residues, such as mulch can be used to protect soil structures and reduce the effects of raindrops on soil aggregates in order to prevent runoff and erosion.

In addition to soil and water conservation, plant nutrient management is important to enhance plant growth. Rapid vegetation coverage on soil surfaces reduces evaporation and intercepts raindrops causing crusting and sealing. Efficient water use by plant depends also on plant genotype and varieties. Several regional and national institutions could contribute markedly to the improvement of rainfed agriculture. In spite of recent achievements, there is still an urgent need to conduct joint research projects between plant breeders and soil management specialists to improve the water use efficiency in semi-arid environment (Ofori, 1993).

6.4 Rainfall Management for Agriculture

In dry areas rainfall data can be analyzed to maximize the use of low rainfall received from the long term averages. Characteristics of the growth season can be determined such as the beginning and end of the growth season and the length of the growth season. This can be done by considering the long term average rainfall and evapotranspiration. The ten day average rainfall is plotted on a graph together with 0.5 ETo. The first point of intersection is taken as the beginning of the season, the second point of intersection is the end of the season. From these two points the length of the season is calculated.

Also, for any current season, the sort of management will depend on whether the season is late or early compared to the normal . If it is going to be a late season then shorter duration varieties will be chosen with wide spacing and no fertilizers applied . The land preparation will be done in a way that increases the soil moisture content, such as using wide ridges and furrows. Rainfall data may also be analyzed to identify the length of dry spells in the area. Based on the expected longest dry spell , varieties tolerent to drought could be chosen to suit the rainfall regime in the area.

In rainfed agriculture, crop production depends on the rainfall amount and distribution. Many attempts to correlate production and total rainfall have failed. Many models were tried to use the distribution of rainfall rather than the total. Some of these models have succeeded. One of them is the water balance model used by FAO in all of their Early Warning System Projects.

The FAO methodology is based on a cumulative water balance established over the whole growing season of a given crop. The water balance is calculated over successive periods of 10 days (dekads). The water balance is the difference between rainfall received by crop and water lost by the crop and soil. When rainfall is more than water loss, the excess is retained by soil as a soil water reserve. This reserve is important in periods when rainfall is less than water requirements of the crop. In such periods the crop uses soil water reserves.

Calculation is carried out for each 10 days period (dekad) from sowing to harvest. If in each dekad the rainfall is equal to or more than the water loss from crop and soil then the crop should have a good water supply. If, however, in one or more dekads rainfall is less than water requirements, the crop should suffer from a water stress. The water stress is described by an Index; known as Water Requirement Satisfaction Index. The crop starts with an Index value of 100%. If in a dekad rainfall is less than the requirement, for example, by 20 mm and total water requirement of crop for the whole season is 400 mm, then the stress is expressed as (20/400) x 100 = 5%. This is subtracted from 100 and the Index becomes 95%. If in a subsequent dekad, another deficit of say 16 mm, then the Index falls by (16X400) x 100=4%, and its value becomes 95-4=91%. Thus the effect is cumulative. Once the Index falls it cannot increase. The damage by water stress is done. The higher the Index the better is the yield. The methodology also caters for excessive rainfall. For every 100 mm in excess of the water requirements and what the soil can hold, the Index is depressed by 3%. It is important to note here that the FAO method takes no account, at this stage, of soil fertility, technology, varietal differences, farming practices, pests and diseases etc.. These are brought in later at the final stage of yield assessment.

It is also important to realize that the Index is calculated for stations or points. These values have to be converted to averages over homogenous areas or administrative districts. It is crucial to calibrate the methodology locally. For this calibration good reliable yield data are required.

A promising method for reducing the problem of rainfall variability which is a major constraint in semi-arid lands is the "response farming" proposed by Stewart (1988). The response technique consists of an analysis of the dates of onset of rain followed by a decision for when to plant, the spacing to use and when fertilizers should be applied. Response farming is a refinement of what farmers in dry regions have always done. It requires a thorough understanding of crops-soil-water relations.

6.5 Rainwater Harvesting

The majority of water harvesting techniques have been developed for growing crops or for rehabilitation and development of rangelands in arid and semi-arid areas, where rainfall is inadequate for rainfed agriculture and irrigation water is lacking. Rainfall is collected from a natural, modified or treated catchment to maximize runoff for a specific site such as a cultivated area, cistern, stored in dams or soils or used for aquifer recharge. Water harvesting ensures that a greater percentage of rainfall is put to a beneficial use. Using a water harvesting technique, a rainfall of few millimeters collected on a catchment area can be equivalent to several hundred millimeters of rainfall when supplied to a cultivated field in a semi-arid area.

Water harvesting techniques have been developed and refined in the past decades within the context of projects which aimed at combating the effects of drought and desertification in sub-Saharan Africa and other semi-arid regions in the United States, Australia and the Arab World. Several important techniques have been reviewed, developed or adapted to natural and socio-economic condition, by FAO, CTA, UNDP, World Bank, UNESCO and other organizations and institutions.

Since all water harvesting systems consist of a catchment and concentration area (water supply or cultivated area), the size of the catchment seems to be most appropriate criterion for the classification of water harvesting systems into major categories. Three groups could be recognized (Tauer and Humborg, 1992, Critchley and Siegert, 1991):

1. Microcatchment water harvesting systems
2. Macrocatchment water harvesting systems
3. spate irrigation systems

In a microcatchment system, also refered to as "within field catchment system", the catchment area and cultivated area lie adjacent to each other, whereas the catchment area of a macrocatchment system is located upstream from the cultivated area. It is therefore referred to as "external catchment system". Both systems harvest overland flow whereas spate irrigation systems harvest flow from wadi channels. Their catchment area is obviously large and encompasses part of or the whole watershed of the wadi system. The former systems are, therefore, grouped together under "rainwater harvesting systems whereas the latter are named "floodwater harvesting systems".

Microcatchment systems which normally occupy a catchment length between 1 and 30 m, have the advantage that they can be designed to fit the individual requirements. Due to shorter paths of flow less water is lost by evaporation and infiltration, and the resulting runoff coefficient is high. The main disadvantages are that catchment areas are also potential arable land and cannot be mechanized and therefore limited to areas with available hand labor. The advantage of the macrocatchment system is that it requires less arable lands and the catchment is usually unfavorable for agriculture. However, relatively large terrain is needed to generate runoff because losses in the catchment areas are high, and accordingly the runoff coefficient is lower. The runoff efficiency (volume of runoff per unit area) usually increases with the decreasing size of the catchment.

The ratio between catchment and cultivated area (C:CA) is difficult to determine for system intended for growing trees (Fig. 1). Information on water requirements of indigenous species are often lacking or available as rough estimates. Furthermore, it is difficult to determine which proportion of the area is actually exploited by the root zone, especially during different stages of root development before a seeding has grown into a mature tree. It is therefore considered adequate to estimate only the total size of the micro catchment i.e the catchment and infiltration pit. The following formula can be used (Citchley and Siegert, 1991):

$$MC = RA \times \frac{WR - DR}{DR \times K \times EFF}$$

Where;

MC	=	Total size of microcatchment (m2)
RA	=	Area Exploited by the root system (m2)
WR	=	Annual Water Requirement (mm)
DR	=	Design Rainfall (mm)
K	=	Runoff Coefficient (annual)
EFF	=	Efficiency Factor.

Efficiency factor takes into account the uneven distribution of the water within the field as well as losses due to evaporation and deep percolation where the cultivated area is leveled and smooth the efficiency is higher. Microcatchment systems have usually higher efficiencies. Selection of the factor is left to the description of the designer based on his experience and the technique used. Usually the factor ranges from 0.5 to 0.75 (Critchley and Siegert, 1991).

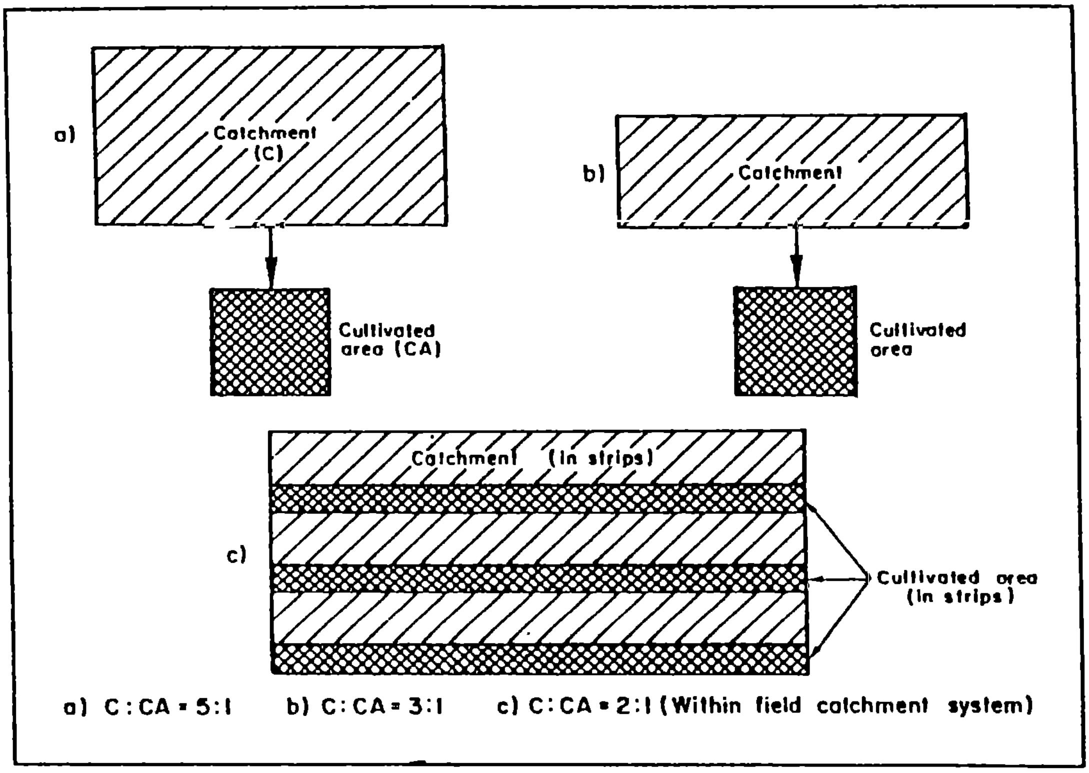


Fig.(1)- Water harvesting system .

Source :(Critchley and Siegert, FAO, 1991)

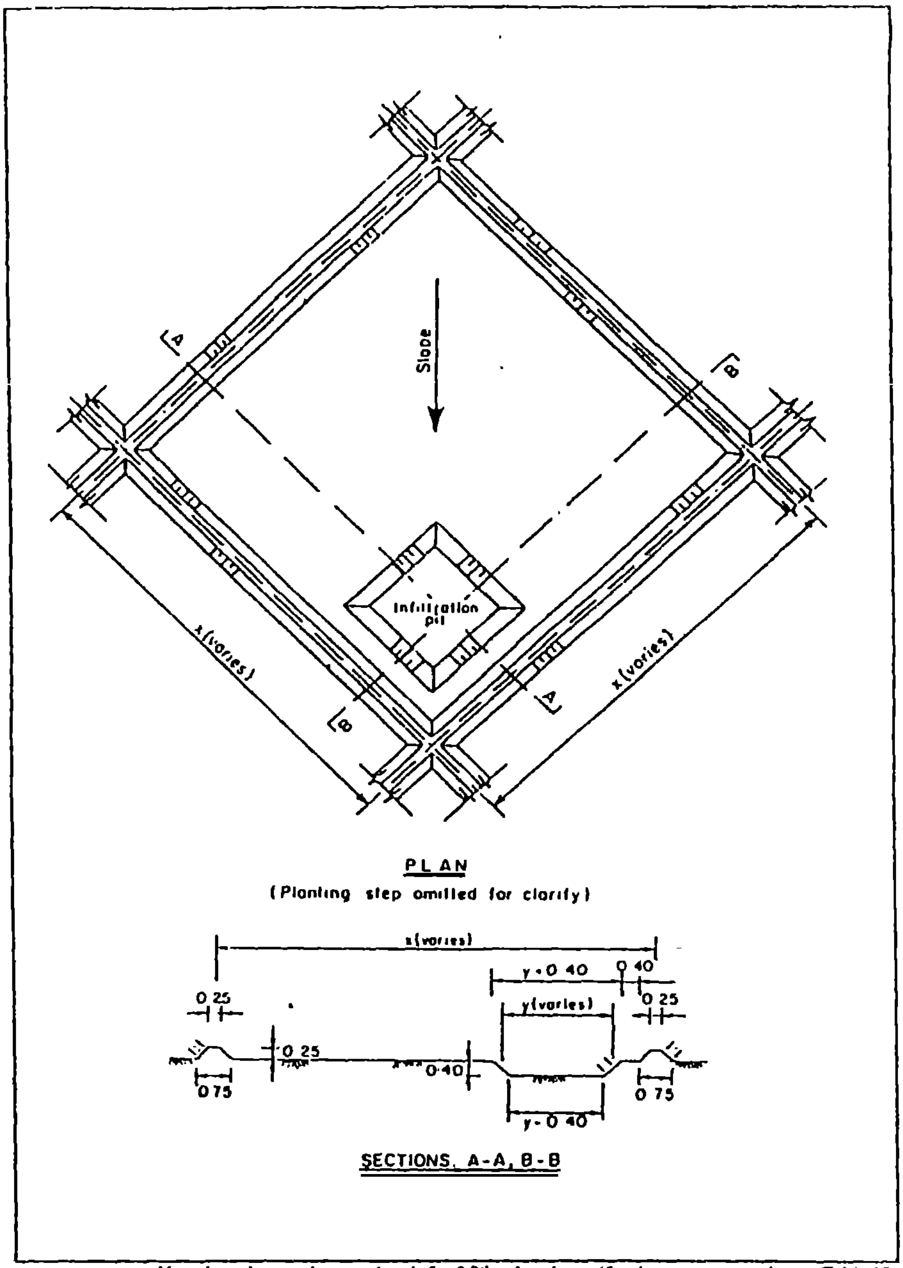
The microcatchment area (per tree) in semi-arid regions usually ranges from 10 to 100 square meters, depending on the degree of aridity and the species grown. For systems designed for use for fodder production or rangeland rehabilitation and development, it is often not necessary to calculate the ratio C:CA. For microcatchment it ranges usually from 2:1 to 3:1.

Important microcatchment systems include negarim microcatchments, contour bunds and semi-circular bunds. Examples of long slope systems are trapezoidal bunds and contour stone bunds. These techniques are described in detail in a manual on water harvesting prepared by FAO and published in 1991. Figures 2 through 6, compiled from the publication of FAO illustrate the main features of these systems.

Some rainwater harvesting techniques have been successfully applied in the Arab countries. Roof-harvesting, for example, is widely used in Jordan. The total annual amount of rainwater harvested from the greater Amman area is estimated as 9.5 MCM. (Al-Labadi,1993), and is expected to increase to 16 MCM by 2015.

During the severe drought which hit Morocco in the 1980s, state interventions to develop rainwater harvesting practices were undertaken to alleviate the water shortage in rural areas. Special attention was given to the development of "Matfias" and "R'Dirs" (Tayaa and Bazza, 1993). The latter are circular or crescent shaped storage ponds 10 to 30 m in diameter. Rainwater is collected through one or several outlets. Construction programmes of collective cisterns were launched in the arid and semi-arid zones of Morocco as a component of large integrated rural development projects. High cost modern technology was introduced in the design without taking into consideration the traditional practices used in the area. Even catchment of the cisterns (up to 700 m^2) were lined with concrete. Field observations in the region of Safi revealed that local population have limited interest in these large structures (Tayaa and Bazza, 1993). Similar conclusions were reached in Jordan and Syria. Simple low-cost small hafirs were appreciated more than large twin hafir systems.

Effective traditional rainwater harvesting techniques currently used in the Arab region comprise cisterns, hafirs, and terraces (ACSAD-UNESCO/ROSTAS,1986, Dijk and Reig, 1993). Many others are practiced at the national or sub-regional level. These will be deseribed in a later section of this report.



Negarim microcatchment: details for 0.25 m bund size (for dimensions x and y see Table 18)

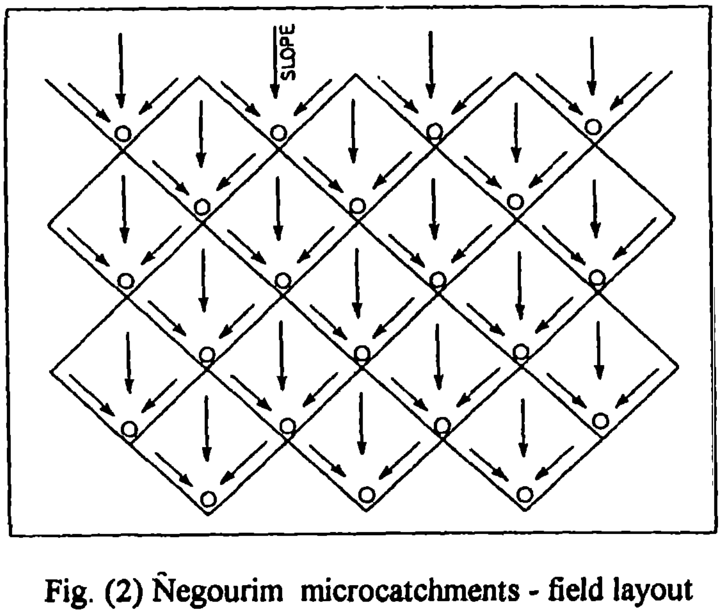
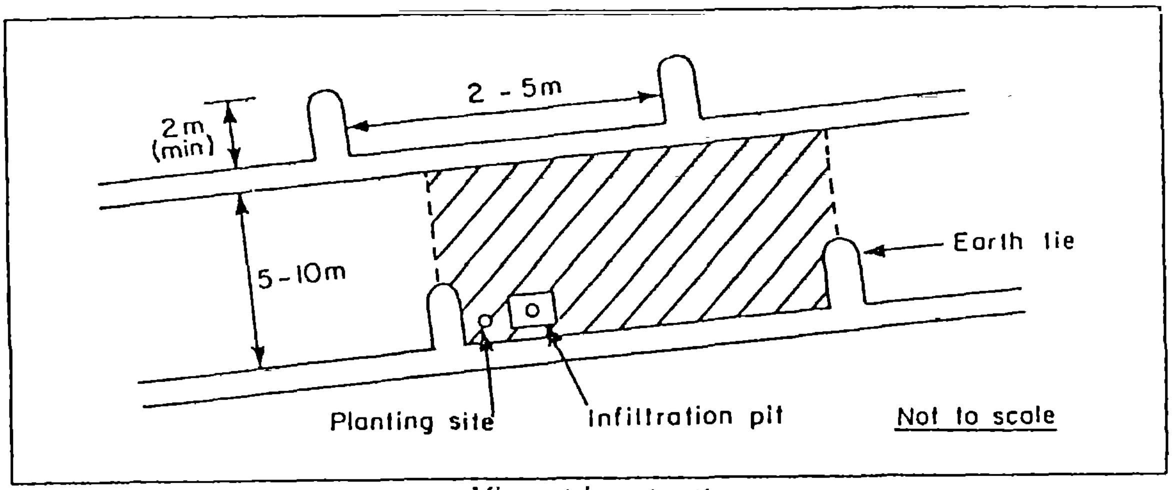
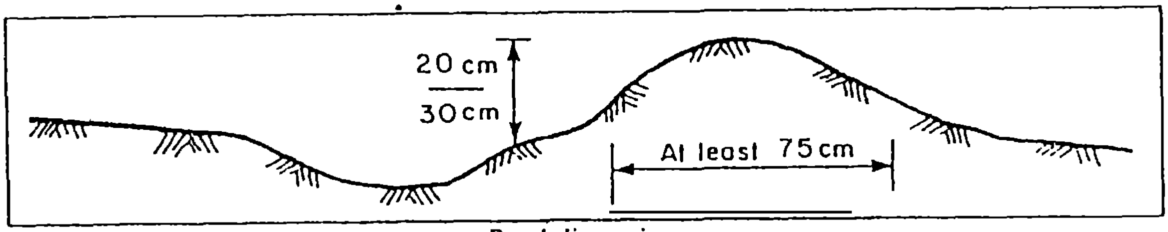


Fig. (2) Ñegourim microcatchments - field layout

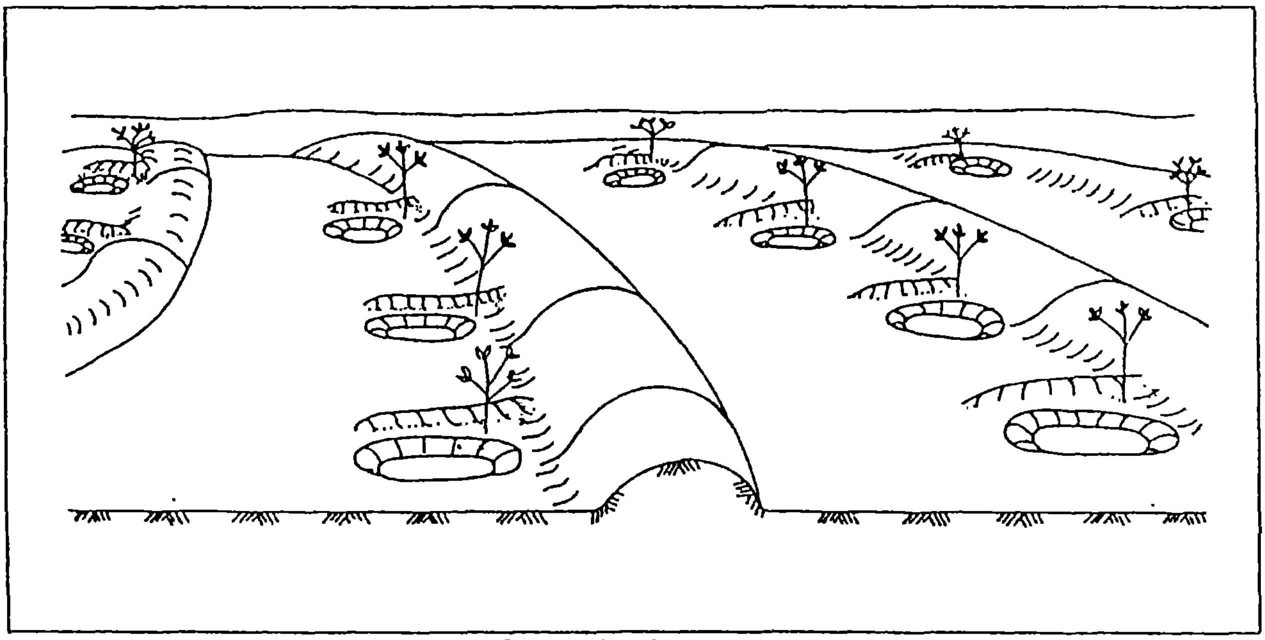
Source : Critchley and Siegert, FAO, 1991.



Microcatchment unit



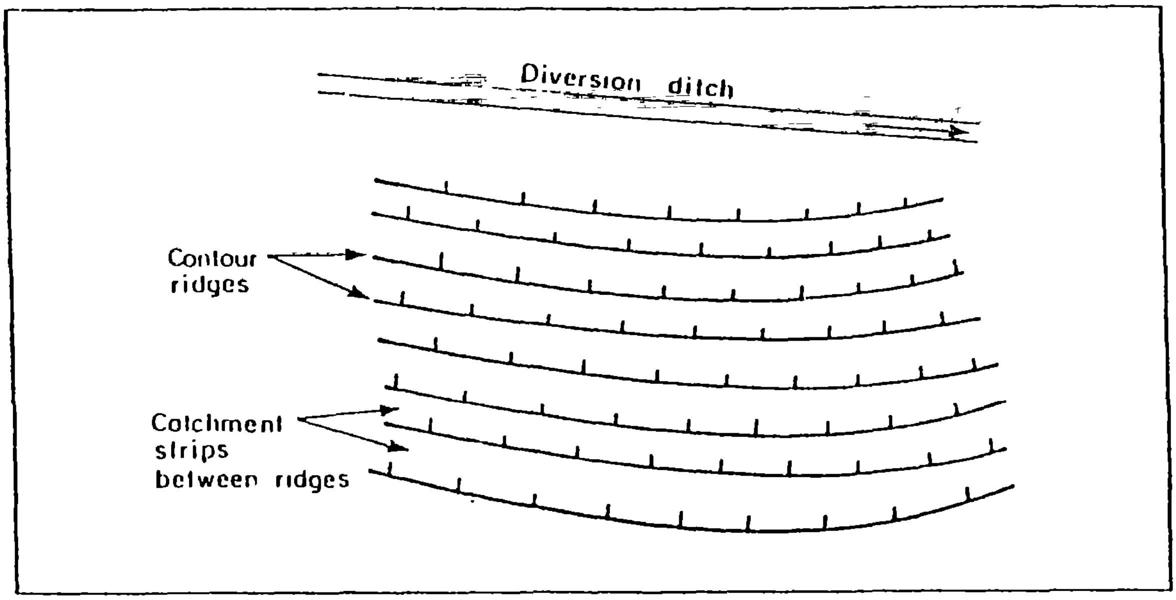
Bund dimensions

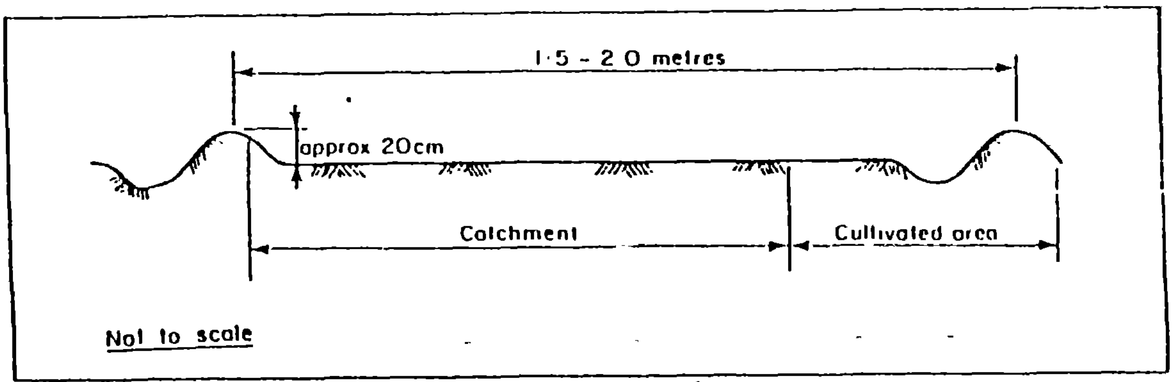


Contour bunds

Fig. (3) Microcatchment unit, bund dimensions and contour bunds.

Source : Critchley and Siegert, FAO, 1991.

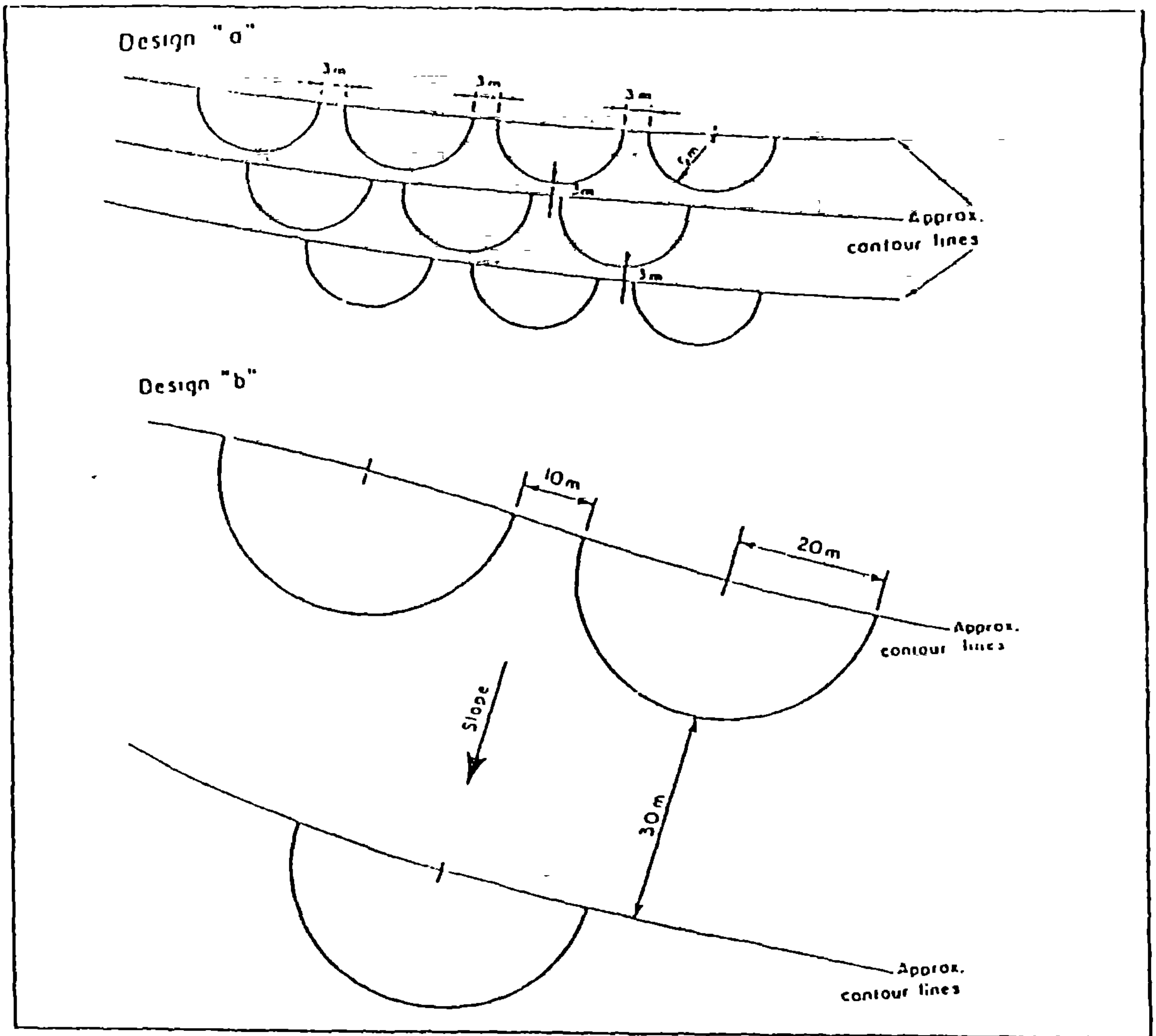




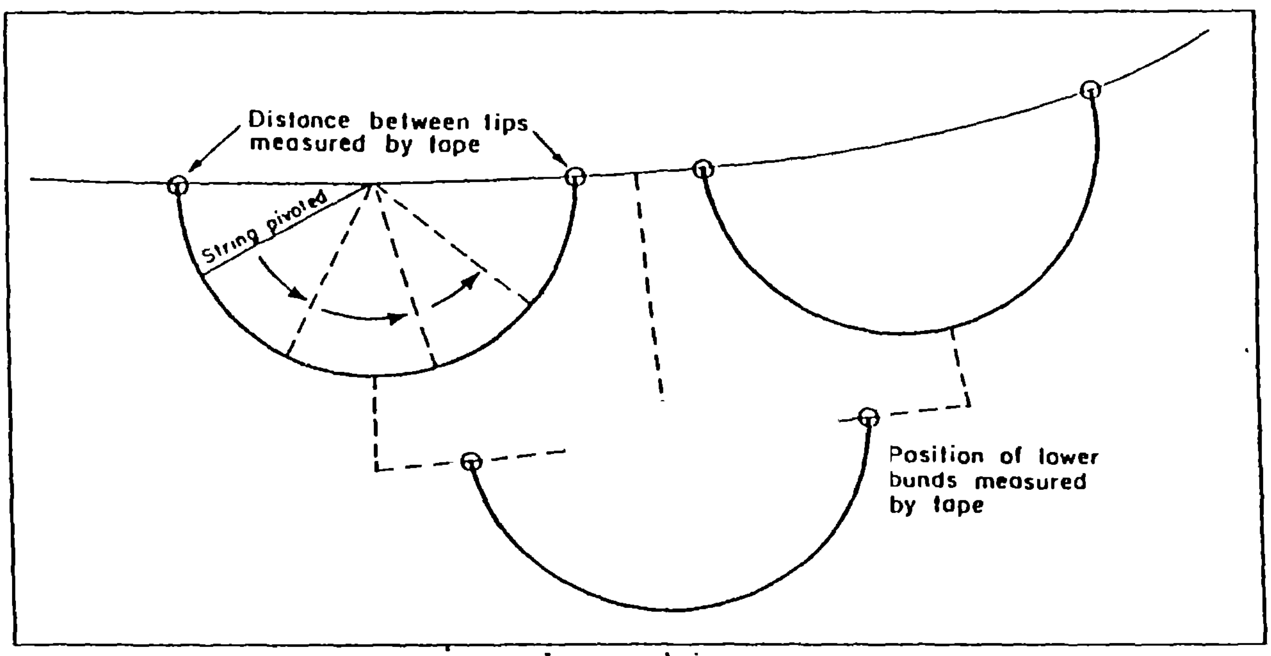
Contour ridge dimensions

Fig.(4)- Contour Ridges

Source: Critchley and Siegert, FAO, 1991.



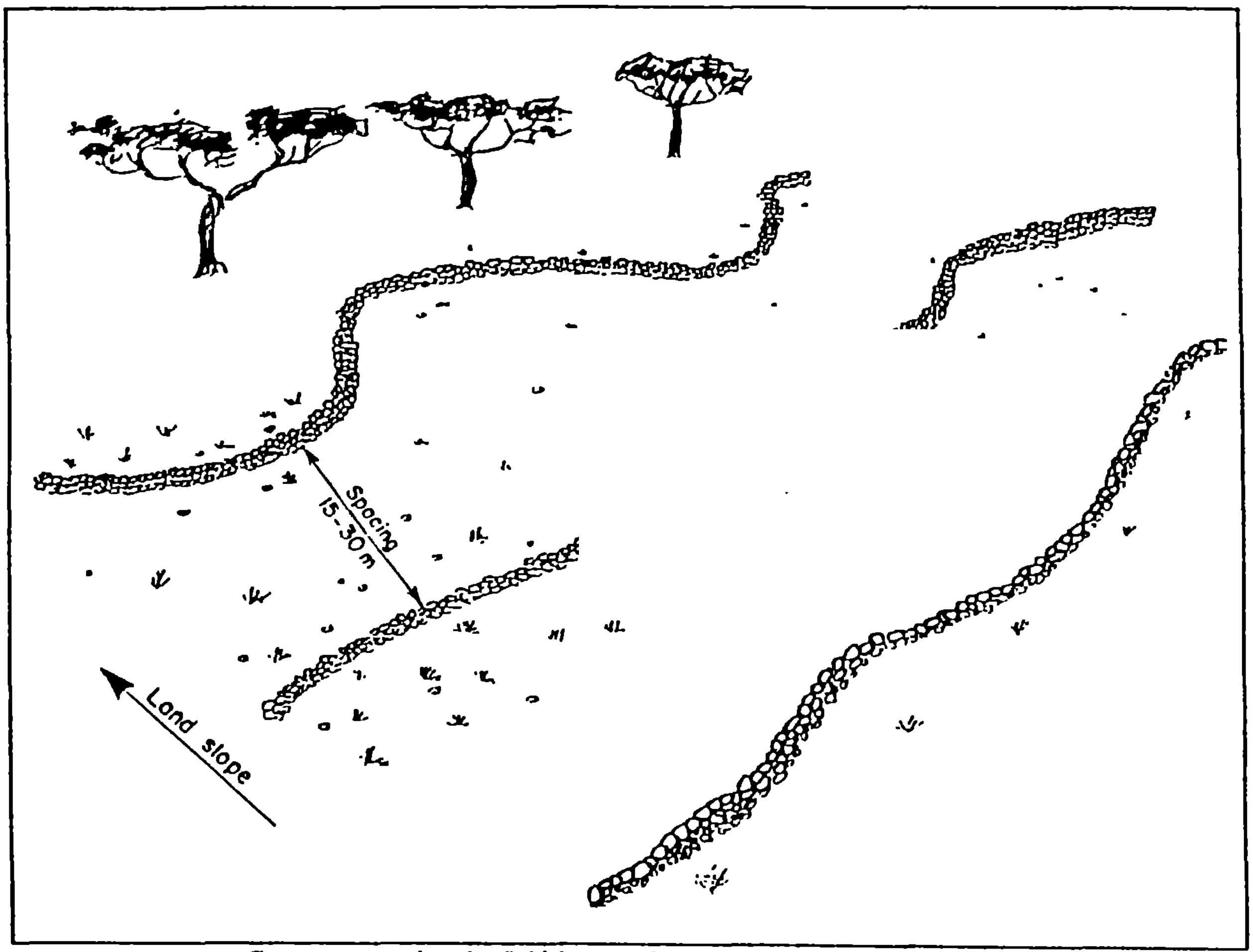
Semi-circular bunds: field layout



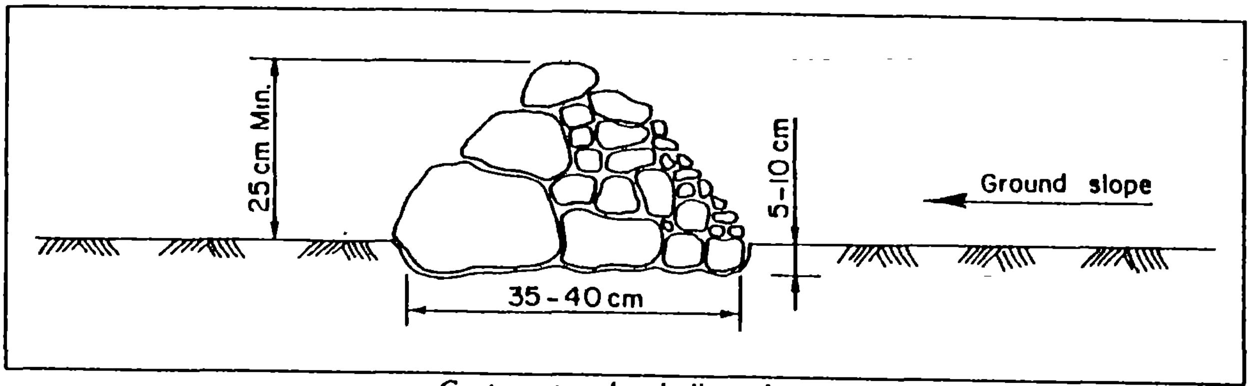
Layout technique

Fig. (5)

Source : Critchley and Siegert, FAO, 1991.



Contour stone bunds: field layout (Source: Critchley and Reij 1989)



Contour stone bund: dimensions

Fig. (6)

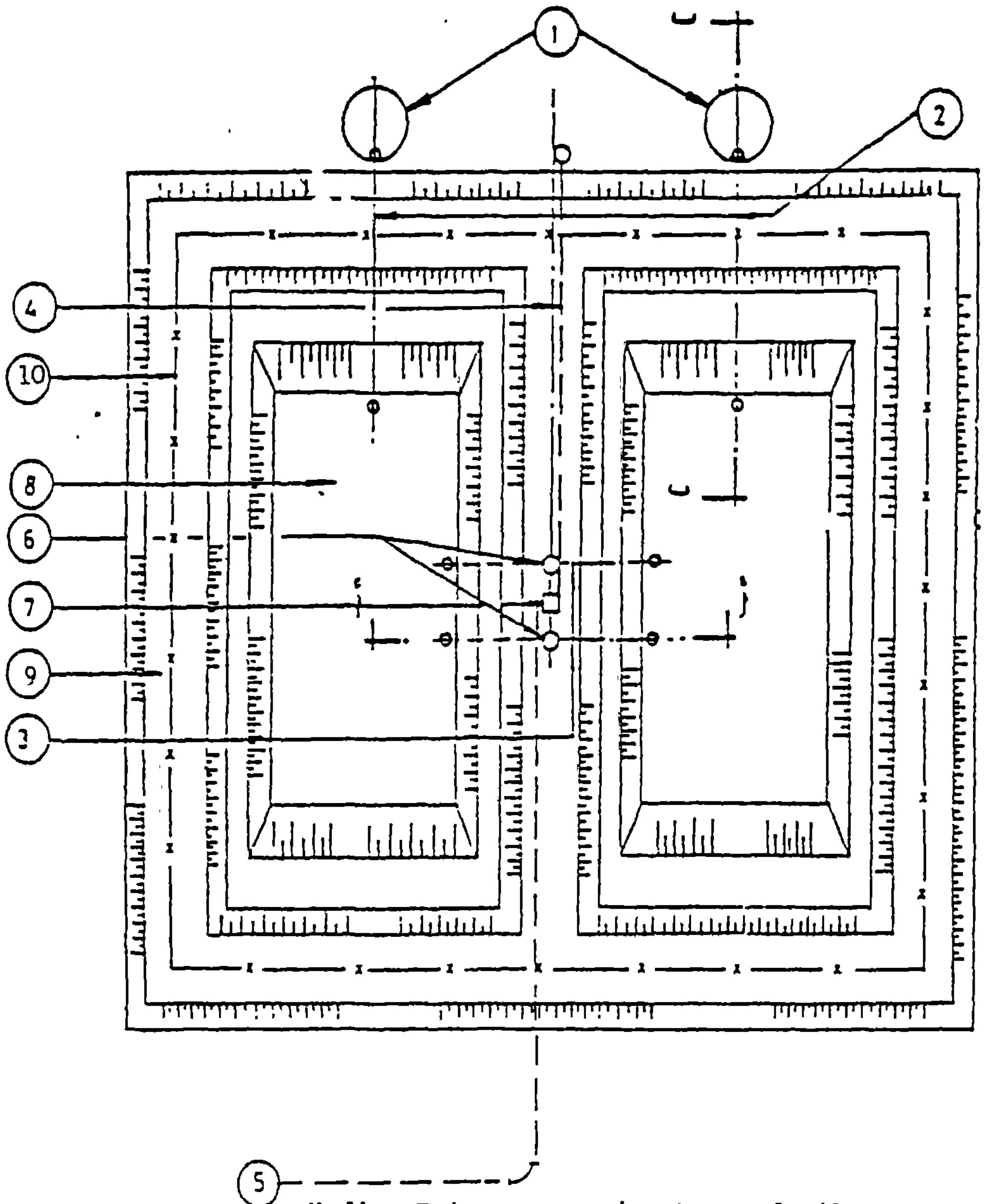
Source: Critchley and Siegert - FAO, 1991

Hafirs are known since early historic times, as communities living in arid and semi-arid environment sought to increase water supplies. It is considered as one of the primary systems used for water supplies in rangelands in general and savanna belt of Africa in particular.

Hafirs are artificial reservoirs often dug below ground surface in a soil which is naturally impervious or treated to become impervious. Digging is now performed by heavy duty bulldozers, whereas in the past it was manual. Hafirs may be classified under the group of long-slope catchment techniques since they are replenished by surface runoff flowing over mountain slopes. They may also be constructed in shallow natural depressions or even Sabkhas and receive water either from runoff or diversion from wadis. An example of the latter type is a new improved hafir system implemented in the Syrian steppe within the context of the Hamad Basin Project and is intended to supply water for drinking and livestock watering (Fig. 7). In some Arab states hafirs are considered as the nucleus of social stability for the rural and Bedouin (nomadic) communities especially in regions where other water sources are not available. They can be planned in pasture areas according to their growing capacity or in dry farming regions to supply drinking water (Fig. 8). The design of hafirs can be improved by increasing runoff in their catchment by treating the soil artificially or using a twin system whereby operation and maintenance works are facilitated.

Cisterns were known since the early times of civilization (Fig. 9). Ruins indicate that use of cisterns flourished during the time of Romans in the first and second centuries A.D . Today, there are several thousands of these cisterns still suitable for use, they are scattered essentially in the mountains along the coasts of the Red Sea and the Mediterranean Sea, and on the slopes of the Atlas mountains.

Generally, a cistern is an artificial reservoir constructed in most cases by digging unconsolidated rocks. The depth of the reservoir varies between 3 and 7 m and the capacity ranges between 50 and 1000 m^3 or more. Generally, cisterns are covered and their walls are made smooth with no cracks. Occasionally, cistern are lined with a mixture of cement and sand or with a reddish clay paste. Modern cisterns are built with cement blocks, burned-clay red blocks or reinforced concrete in a rectangular shape.



1. Sedimentation tanks
2. Inlet pipeline
3. Pipe connecting the two hafirs
4. Pipe line to upper reservoir
5. Pipeline to R.C. Water tanks
6. Controlling pipline
7. Pumping station
8. Base of hafir
9. Earth fill
10. Fance

Fig.(7)- Hafir, Twin system, in the Tenf Pilot area, Syria, implemented 1994
(Source : Hamad Studies , ACSAD, 1983)

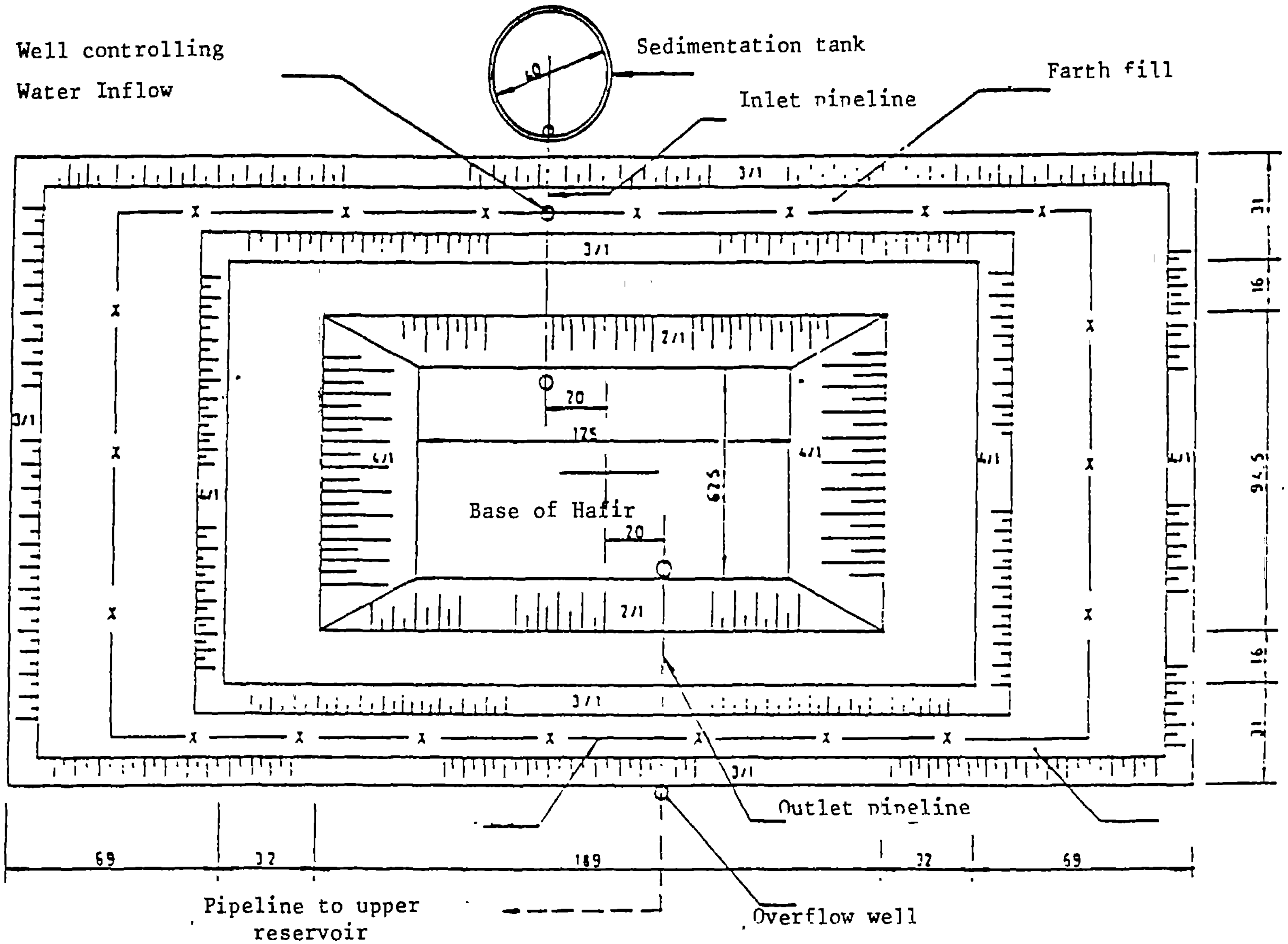


Fig. (8) Hafir in Rashid Wadi, Jordan, implemented 1994

(Source: Hamad Studies, ACSAD, 1983)

Fig. (9) An ancient Roman cistern

Source: ACSAD-UNESCO/ROSTAS,1986

A cistern consists of the following parts;

(a) main reservoir;

(b) settling basin used to receive surface runoff, it helps in settling the majority of suspended sediments before entering the reservoir via an orifice which is covered by a steel mesh used to catch the large sediments;

(c) one or more openings in the roof of the cistern intended to extract water by traditional methods as the bucket or the reciprocating hand pump;

(d) walls, check structures or channels, used to collect and divert rainwater toward the stilling basin.

Cisterns are replenished by rain water falling on the roof of houses (Fig. 10), on sloping lands (Fig. 11&12) where part of the runoff water is diverted using a canal, check structures made of stones or soil fill from the mountain slope to the stilling basin which leads to the entrance of the cistern. In some cases artificial materials are used to improve surface runoff (Fig. 13).

Despite the fact that cisterns are old water systems and their storage capacity is somewhat limited, they are still considered as one of the successful techniques in solving the problem of water supply of small communities of coastal rural regions or scattered communities in mountains with adequate rainfall (400 mm). Cisterns require in their design a number of scientific rules for successful operation, as:

- Adequate knowledge of the properties of rainfall in the region.

- Proper selection of the area used to harvest rain water and to divert it to the cistern, and to prevent all sources of water pollution.

- Adequate knowledge of geology of rock formations in the cistern location to make sure of the absence of defects such as large fractures.

In general, the construction cost of a cistern is high. However, the cost may become reasonable in case other alternatives are not available, while maintenance costs are quite limited. Terraces are common in the Arab states, especially in the hills of the Atlas highlands extending through

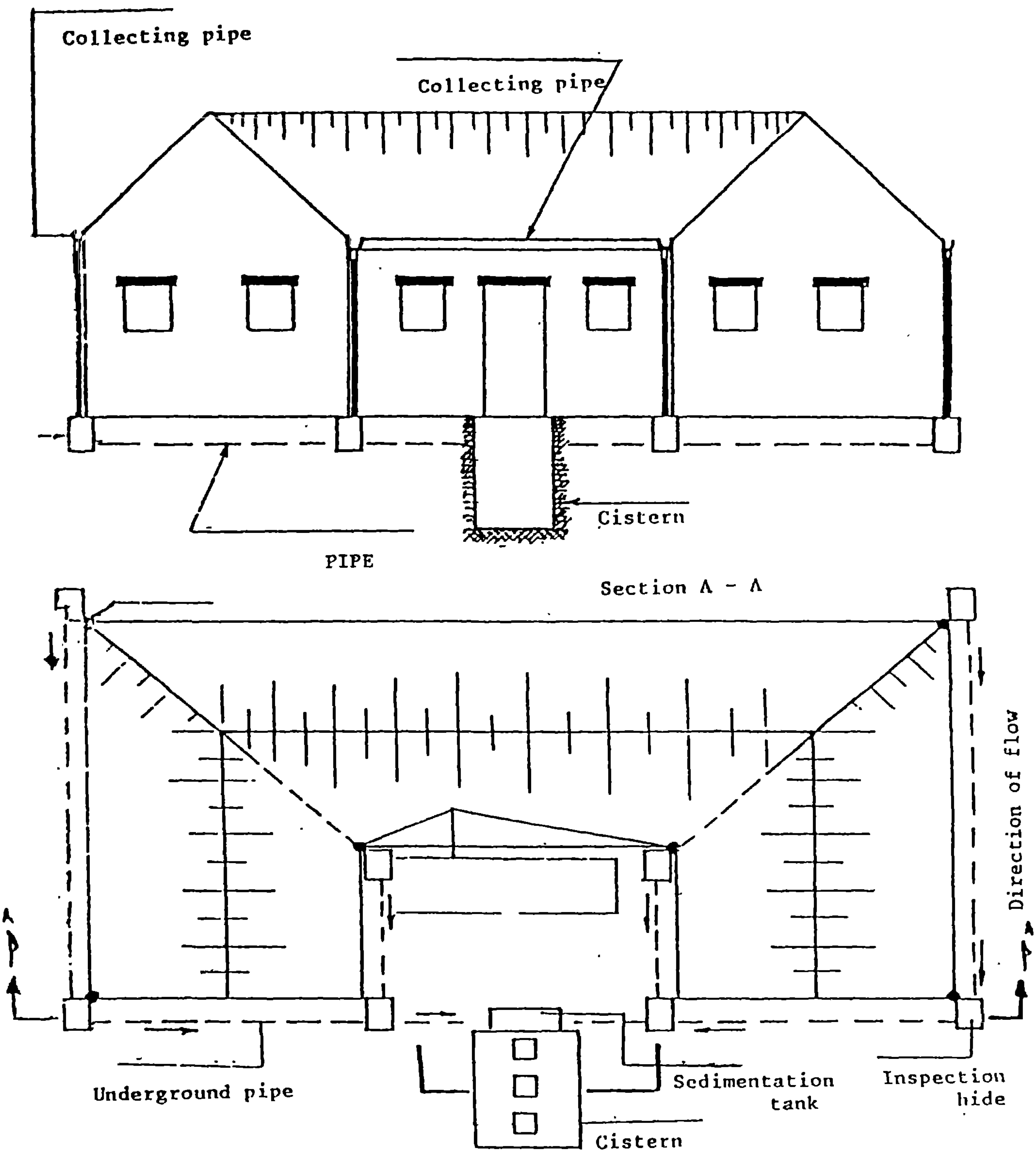
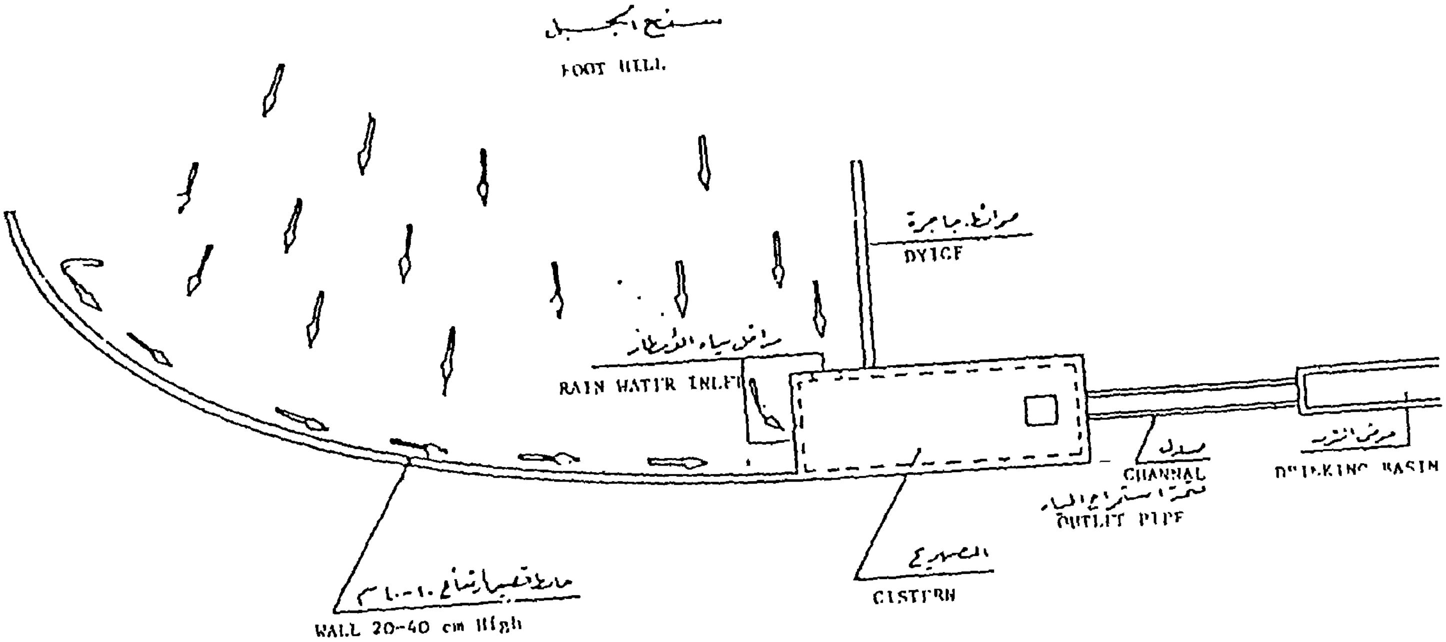


Fig. (10) Use of house roof for filling the cistern

Source: ACSAD -UNESCO/ROSTAS,1986

Fig. (11) Use of mountain slope for filling a small cistern.

Source: ACSAD - UNESCO/ROSTAS,1986



Use of Mountain for Filling the Cistern.

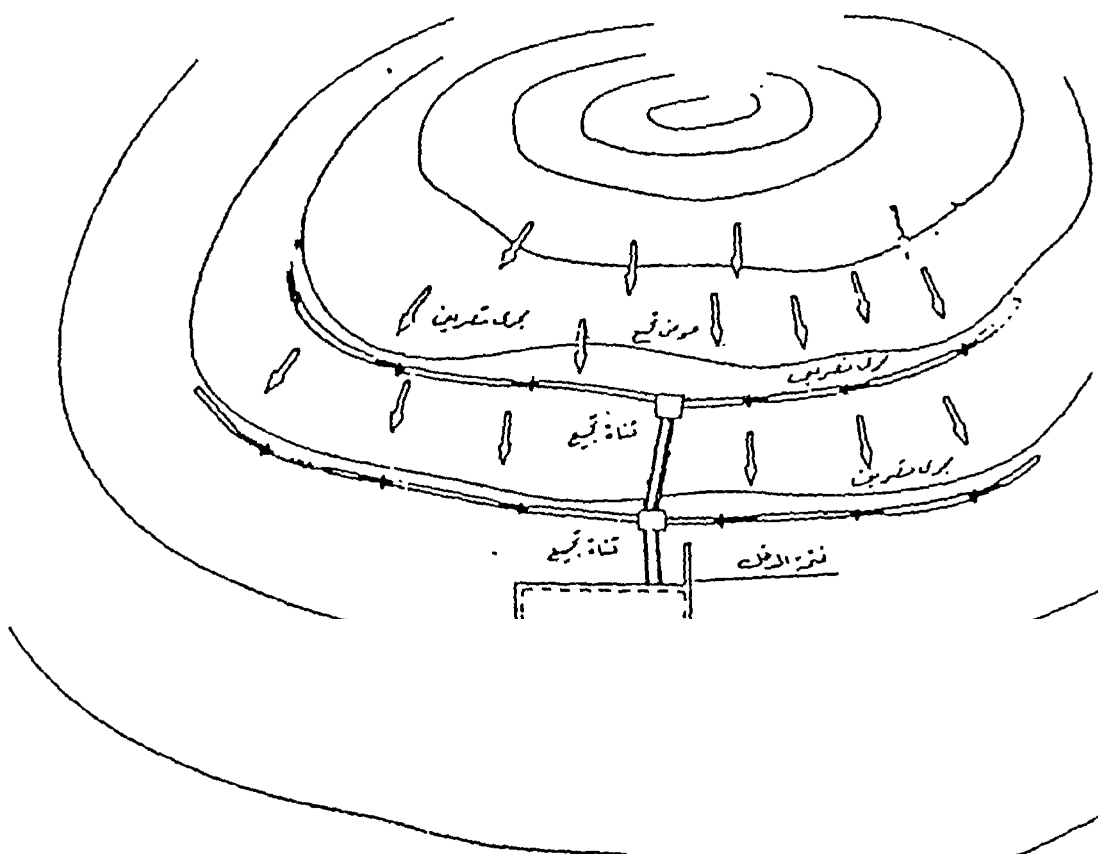


Fig. (12)Filling cisterns by surface drainage canal on a sloping area.

Source: ACSAD-UNESCO/ROSTAS, 1986

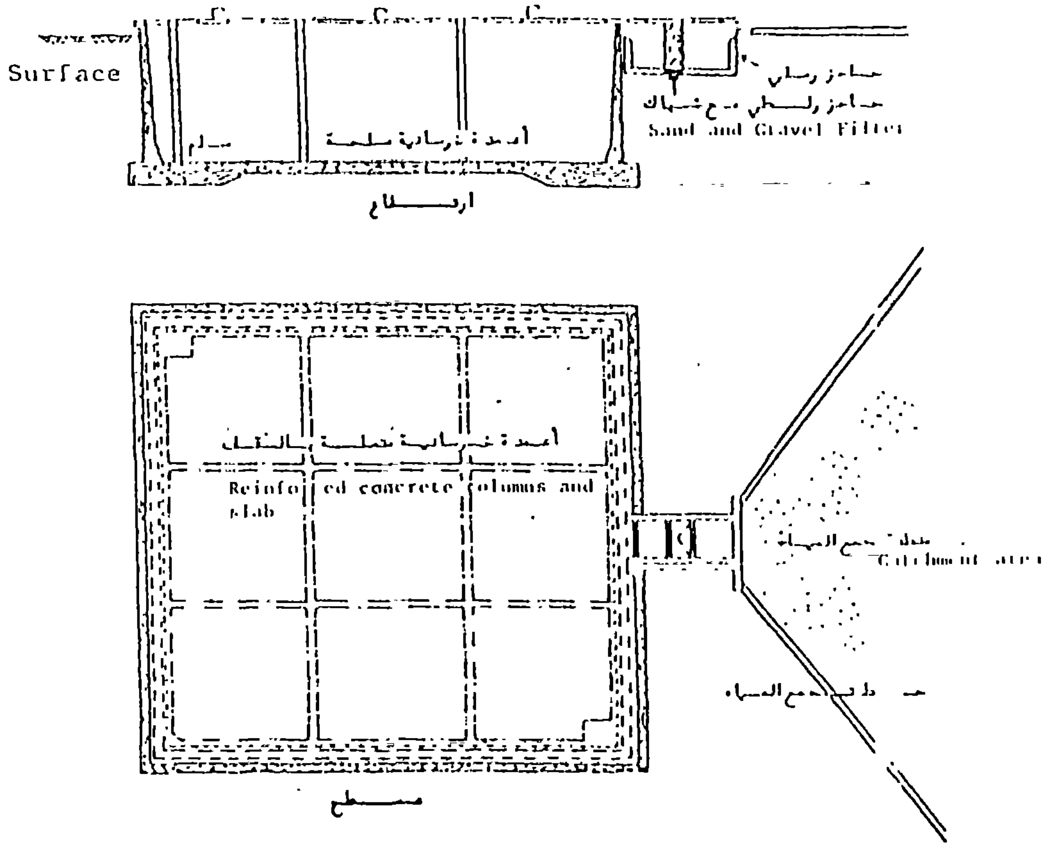


Fig 13 -A)

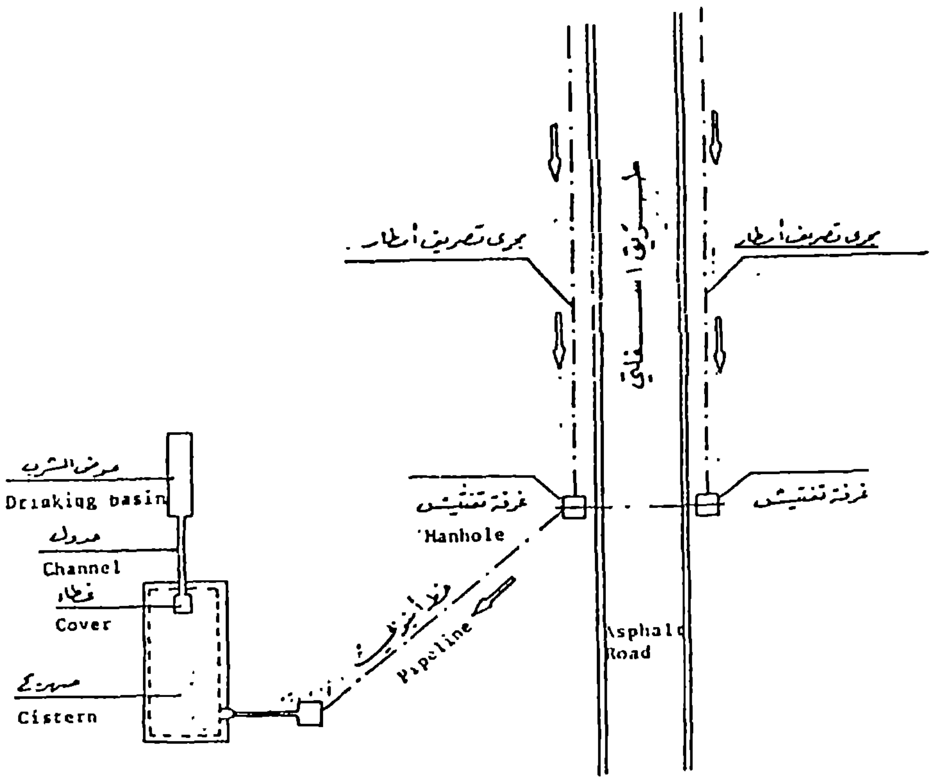


Fig. (13) Filling cisterns by rain water on asphalt roads

Source : ACSAD UNESCO, 1986.

Algeria, Morocco and parts of Tunisia, on the mountains of Nafusa and the Green Mountain in the People's Arab Socialist Jamaheria of Libya, and the mountains of Lebanon, Syria and Jordan (Figs 14&15). Terraces constructed in the central mountains of Yemen are considered excellent examples for the application of such a system(Fig. 16). In spite of the high cost involved in this system and the need for patience and accuracy during construction, it is the only way to produce crops from vast areas in mountain regions where annual rainfall reaches 500 mm. Terraces are used to produce fruit trees and crops, while they also help in protecting top soil from erosion.

Terraces are the most efficient method for combating soil erosion on steep lands; particularly on lands with slopes ranging between 10 and 30 percent. Major works are involved in the construction of terraces (Fig.17). They are considered to be the best way to convert poorly productive lands into highly productive farms. Rainwater that falls on the terrace is harvested and used to improve soil moisture. Excess water should be drained to minimize damage to lower lands.

6.6 Floodwater Harvesting

Floodwater harvesting, often refered to as spate irrigation, has been practiced for millennia in several parts of the Arab region. This unique form of irrigation which makes use of spate (heavy flood of short duration) is predominantly found in arid and semi-arid regions. The spates are diverted into fields and one or two waterings are usually sufficient to sustain a deep rooting crop. Spate irrigation is the principal irrigation system in the Arabian peninsula. It is also important in the steppes of the Mashrek and in the semi-arid belt north and south of Sahara of North Africa. Spate irrigation greatly affects the livelihood of inhabitants of these dry regions as they largely depend on agriculture and animal husbundry.

Semi-arid regions are highly vulnerable to drought and their sensitivity to this phenomenon increases with increasing aridity (UNESCO-IAH, 1994). In such regions there is need for a better control of spate flows and improved irrigation practices. Since a part of wadi-flow infiltrates into wadi-fill or alluvial fans which are made of permeable sand and gravel deposits, the conjunctive use of spate and groundwater resources is an approach adopted in many Arab countries. The drainage area of wadis which rises in semi-arid mountains such as the Anti-Lebanon, Sahara Atlas, Asir and Oman mountain ranges, can be divided

Fig.(14) Terraces Constructed on a Mountain Slope (Libya).

Source : ACSAD - UNESCO/ROSTAS,1986

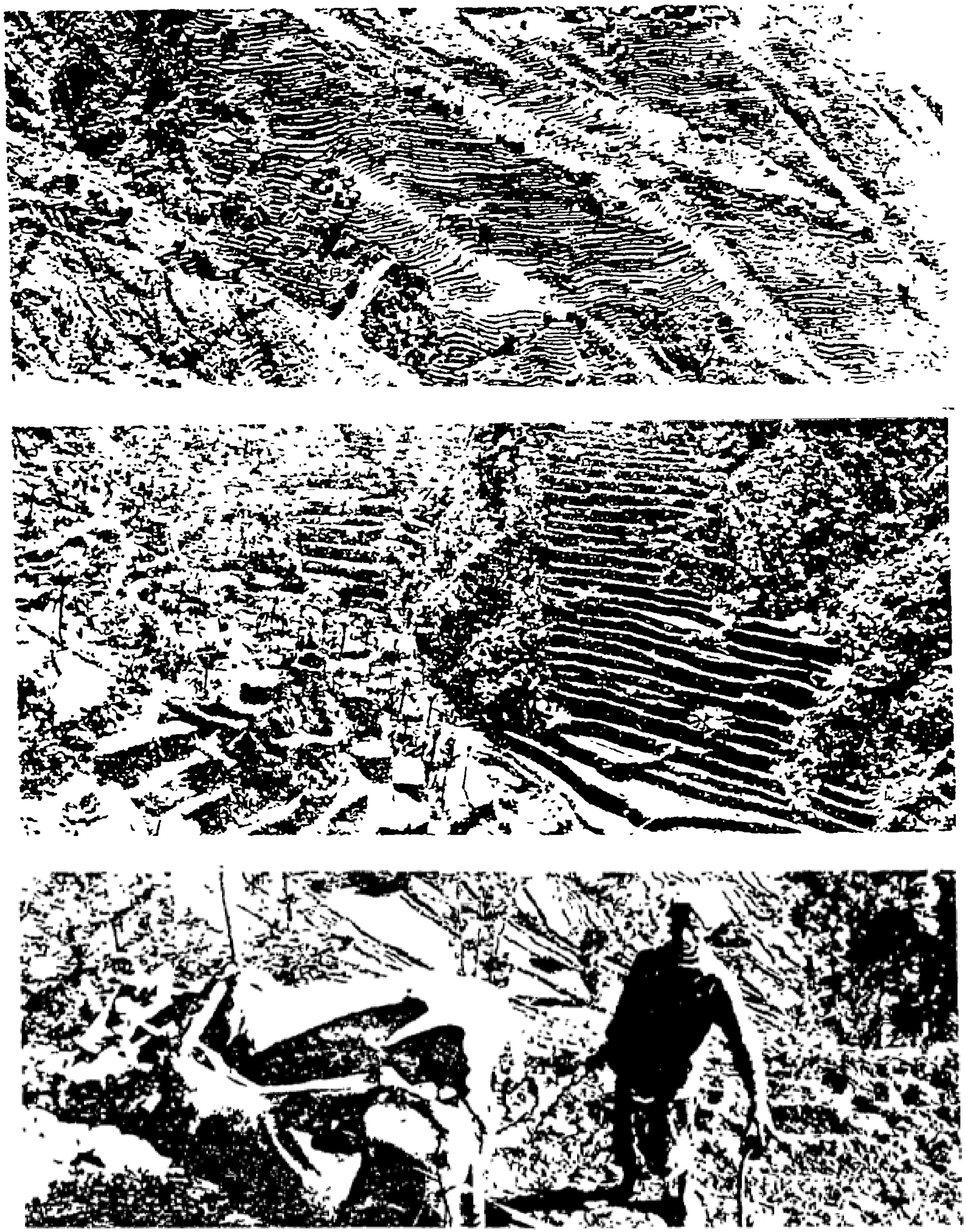


Fig. (15) Examples of Terraces in the Arab Yemen.
Source: ACSAD - UNESCO/ROSTAS, 1986

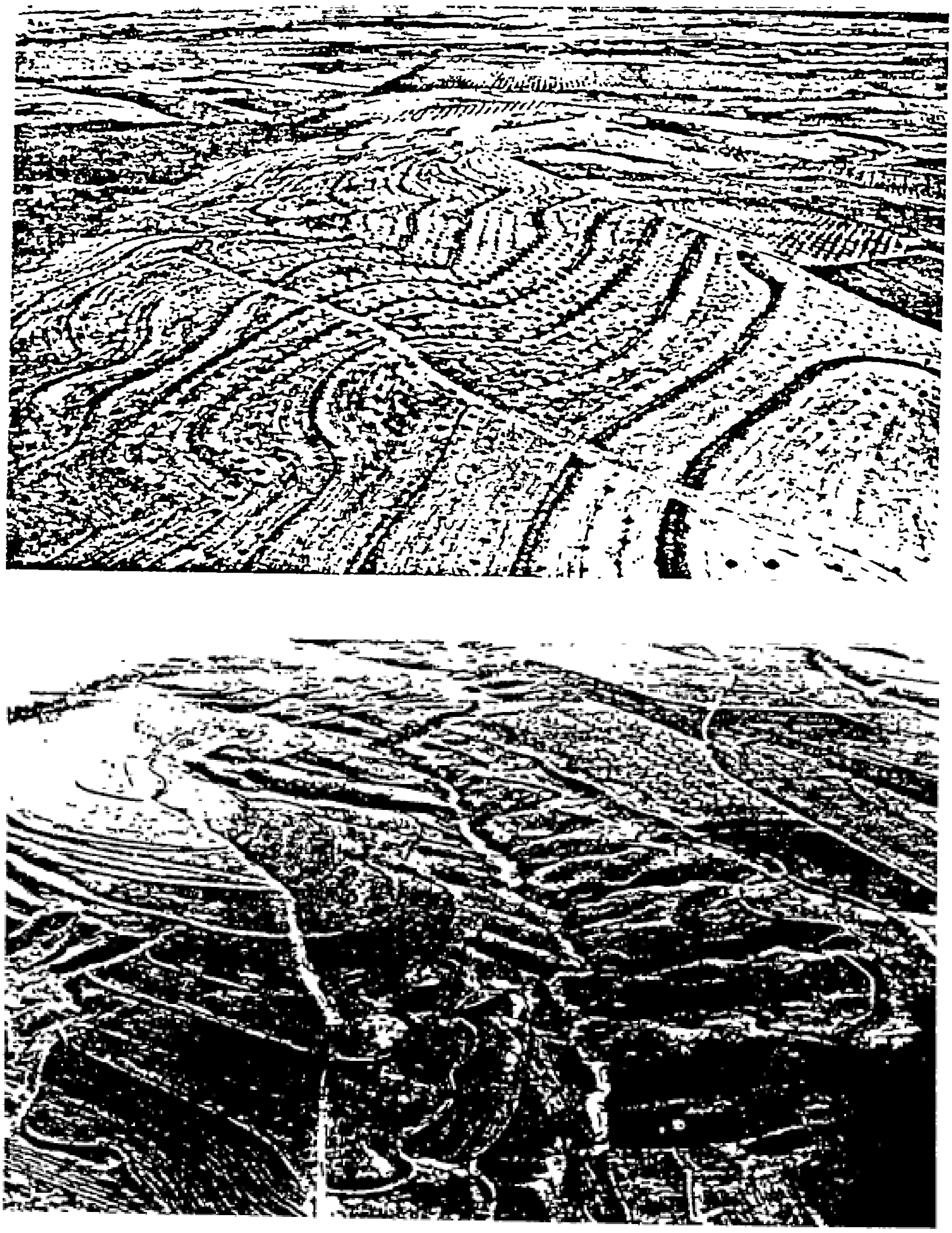
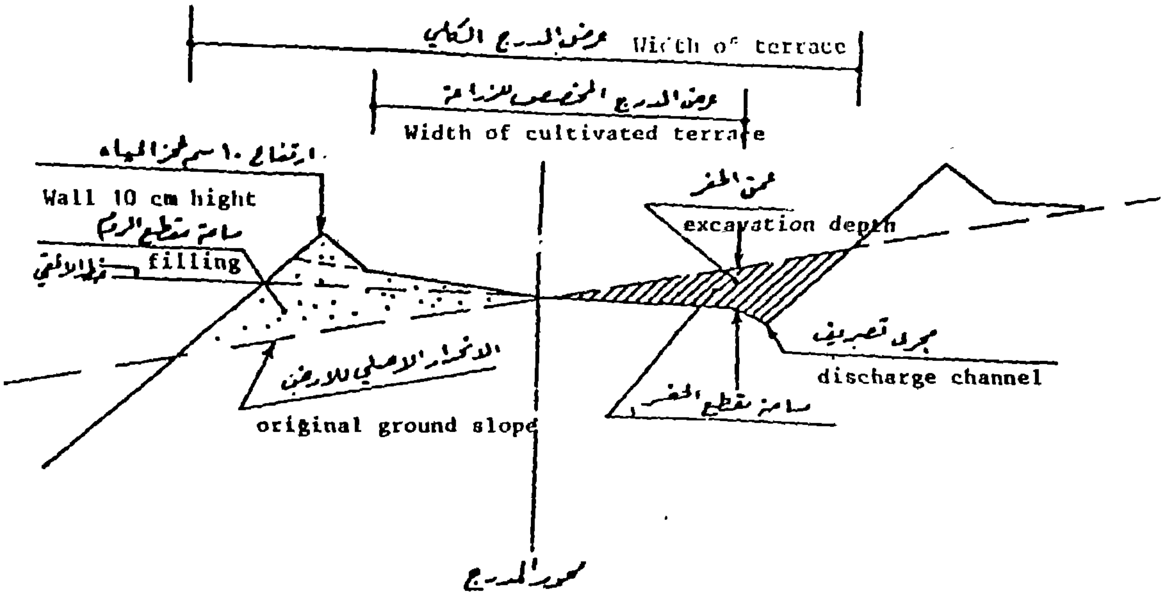
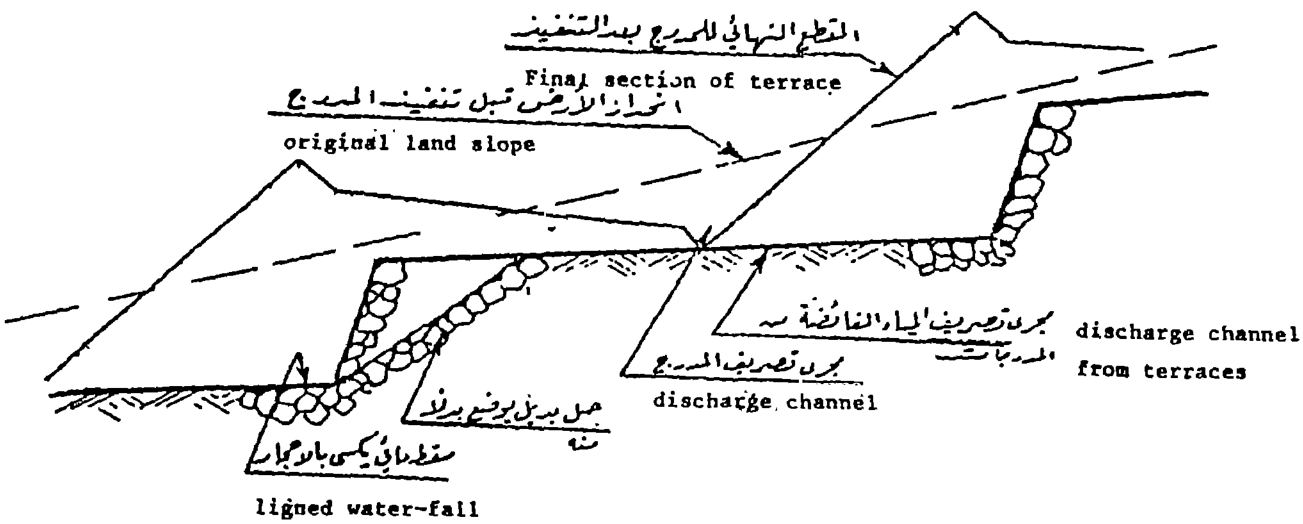


Fig. (16) Two Views of Modern Terraces to Combat Erosion in Medjerda Valley Basin (Tunisia).

Source : ACSAD -UNESCO/ROSTAS,1986



(A) Cross Section for the Design of A Modern Terrace.



(B) Cross Section for the Design of a Drainage of Terraces

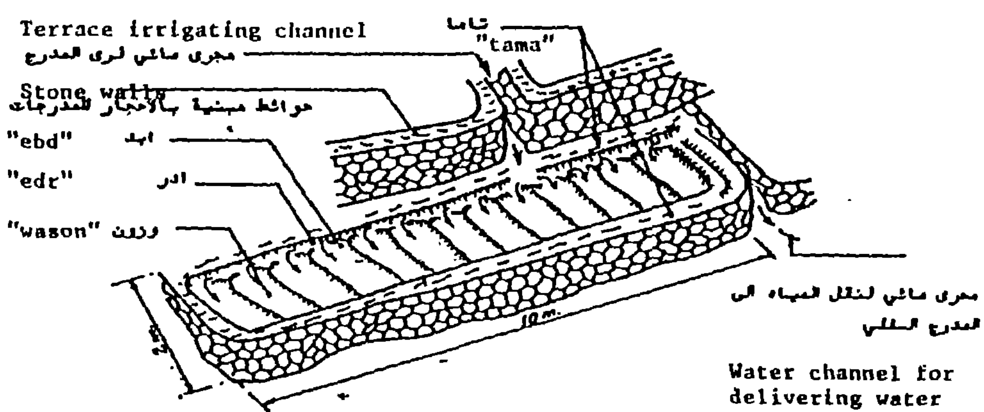


Fig. (17-C) Examples for preparing terraces and their irrigation (Morocco)

Source: ACSAD - UNESCO/ROSTAS ,1986

into higher catchment areas of runoff and lower areas of runoff and percolation. Where surface runoff reaches the lowlands significant part of flow could be diverted for spate irrigation. The remainder evaporates or infiltrates into the groundwater reservoir. Water quality deteriorates as the flow approaches discharge areas such as the sea or sabkhas. It is important to capture and use a significant part of the flow before it becomes brackish or saline. An integrated management of surface and groundwater resources in lower reaches of wadi basins could prevent or reduce sea water or sabkha water intrusion and lead to a sustainable development.

There are many forms of traditional and modern floodwater harvesting techniques. ACSAD-UNESCO-ROSTAS (1986) recognized the following types, on the basis of a survey carried out at the regional level:

a. Uncontrolled water spreading
b. Controlled water spreading
c. Water spreading by ponding
d. Collection of runoff by check dams

Uncontrolled water spreading systems involve the diversion of water via artificial or natural outlets towards the lands which are usually located near the wadi channel. Once diverted runoff is left to spread over the land (Fig.18). In large wadis with high discharge a temporary earth dam is created in order to retard the flow and receive the first wave of flood. Then measures are taken to spread the water over adjacent lands.

Controlled spreading consists of building a check dam with a height of 3 to 4 m for diverting water via a diversion canal towards the land to be cultivated (Fig.19). Spreading is effected with the help of a series of earth bunds which facilitate infiltration.

Water spreading by controlled ponding is accomplished by constructing a check dam which directs the water towards the land to be cultivated. Earlier the land was divided into basins. After filling the basins, the excess water is drained through outlets to neighboring basins (Fig.20).

A check dam is a traditional system which consists of constructing small earth fill or rock fill dam on the beds of ephemeral wadis in order to collect water and sediment and therefore serves in accumulating soils suitable for crop production in addition to slowing down surface runoff. The process allows water to infiltrate into the soil which is used for planting fruit trees and crops (Fig.21,22).

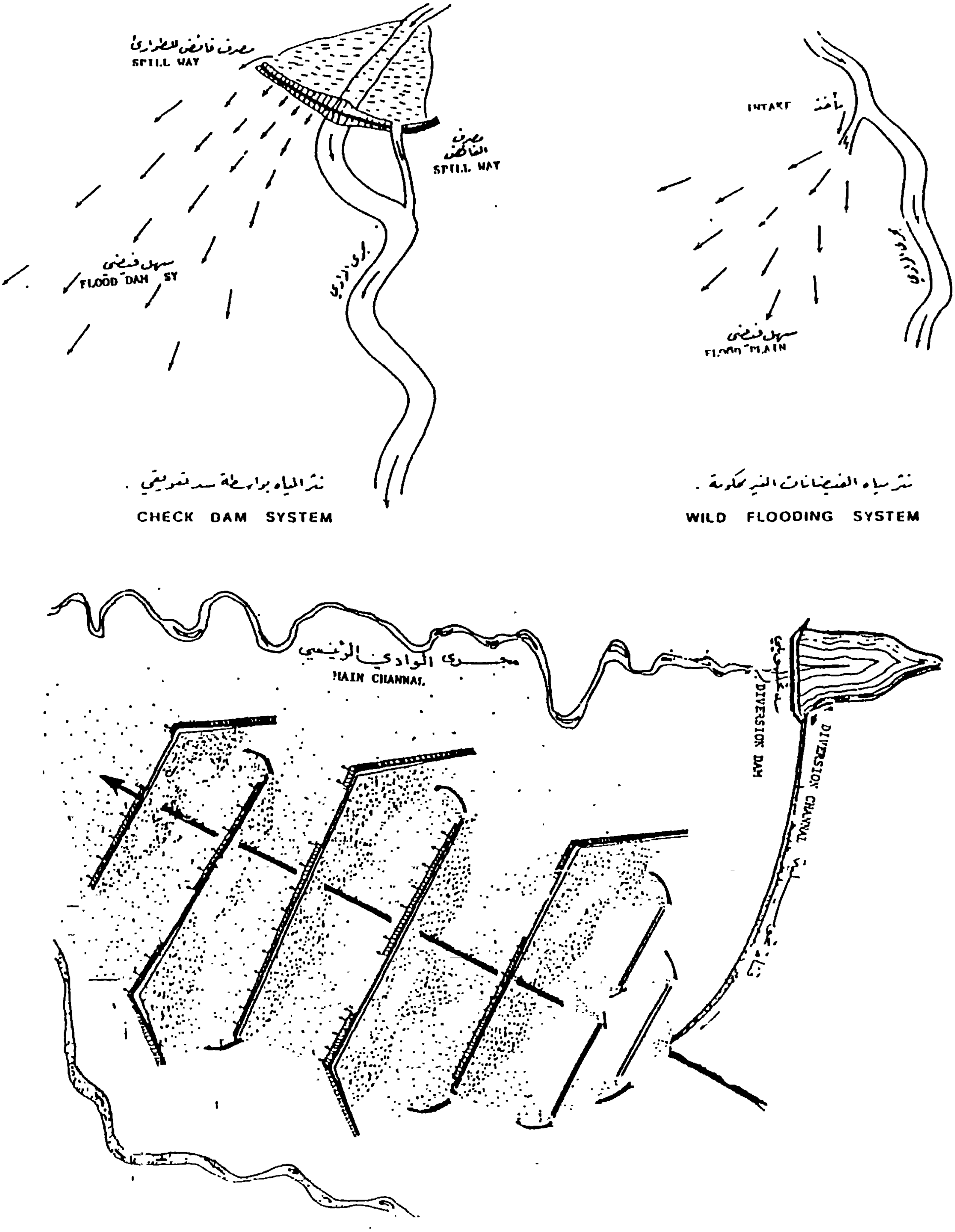


Fig.(18)- Controlled Spreading of runoff water

Source : ACSAD-UNESCO/ROSTAS,1986.

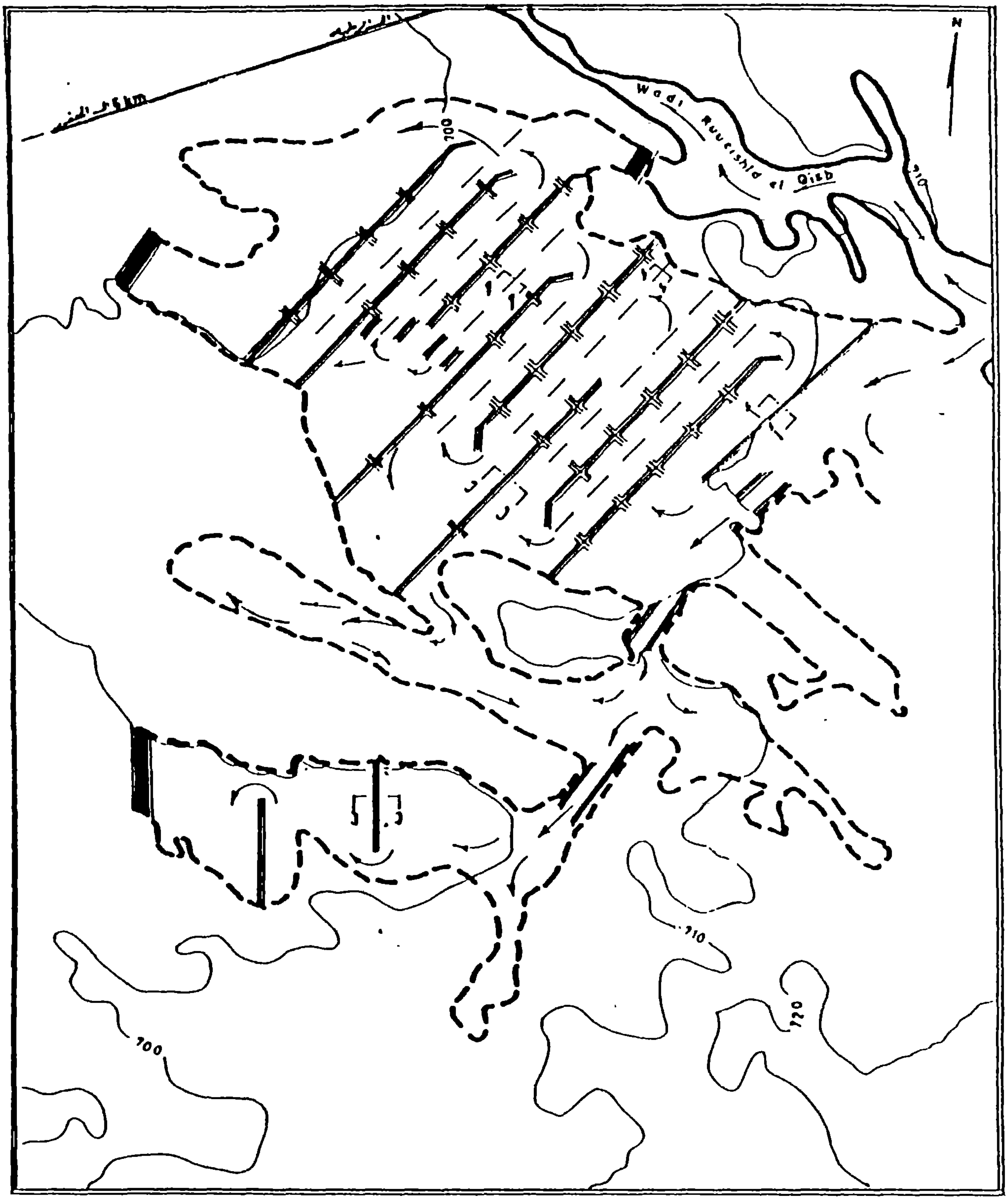


Fig. (19) Water spreading for rangeland development, in Ruished pilot project,
(Source: Hamad Studies , ACSAD,1983)

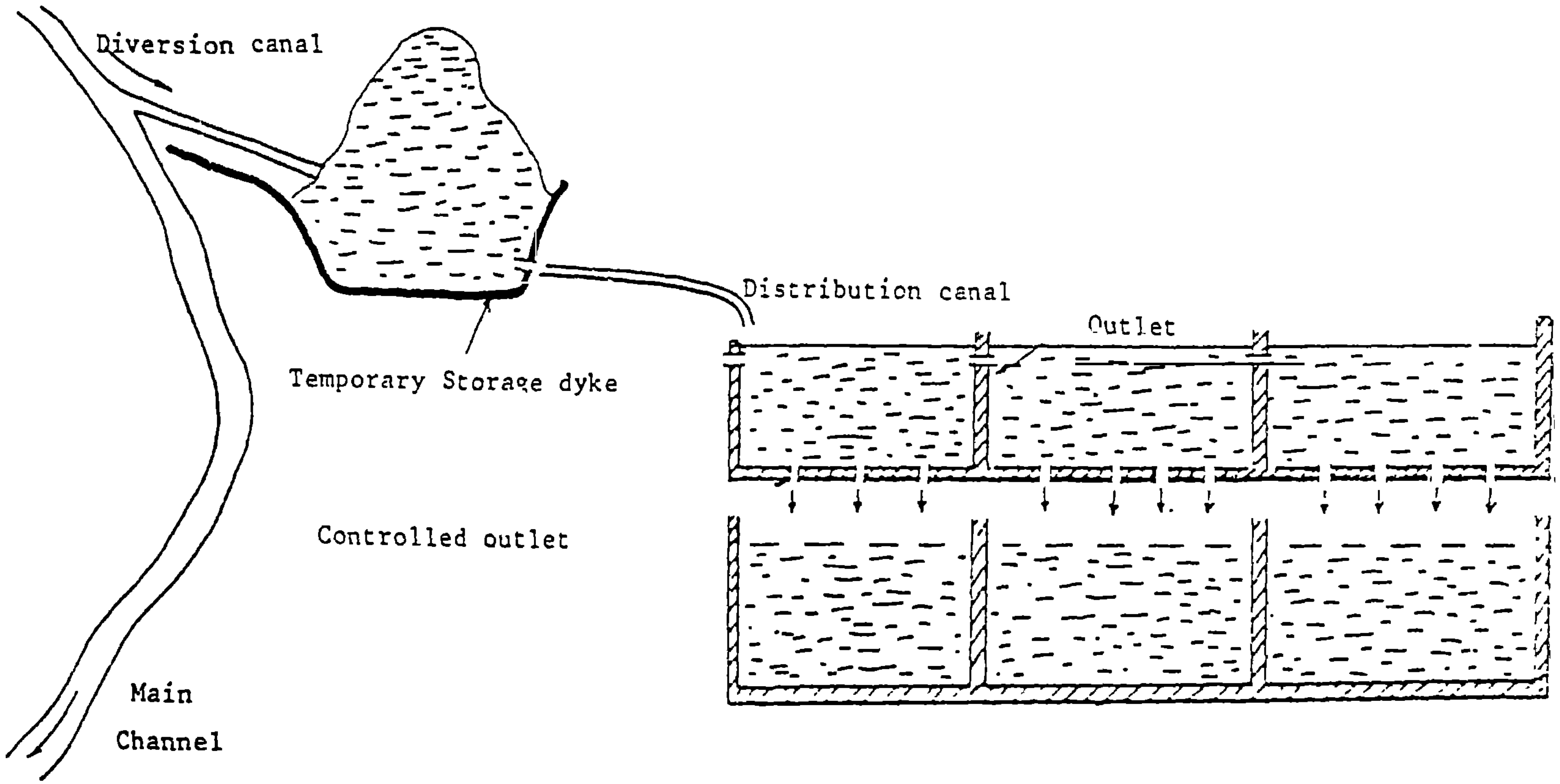


Fig. (20)- Water Spreading by Ponding
Source: ACSAD - UNESCO/ROSTAS, 1986

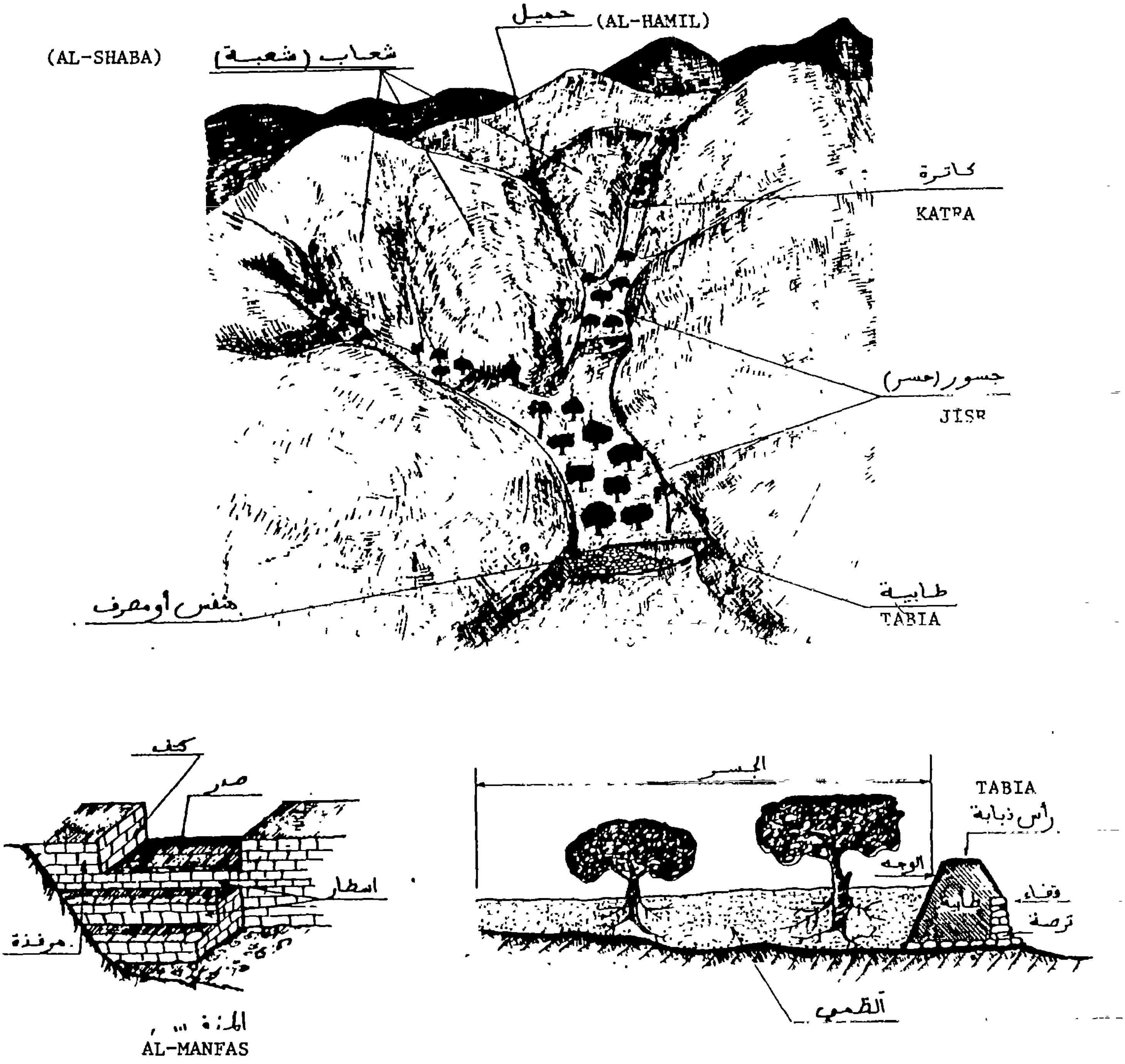


Fig. (21)- DIAGRAM OF THE CHECK DAM COMPONENTS NEAR MATMATA (TUNISIA)

Sources : ACSAD - UNESCO/ROSTAS ,1986

Source: ACSAD - UNESCO/ROSTAS,1986

Fig. (22) Terraces near Jado Town in a valley (Libya).

Water spreading projects implemented in the past decades utilized one or more of the floodwater farming methods described above. In sub-Saharan Africa at least two floodwater harvesting systems are commonly used. These are permeable rock dams and water spreading bunds. The latter system is identical with "controlled spreading techniques" described above. Permeable rock dams are floodwater harvesting techniques aiming at spreading runoff waters in valley bottoms for improved crop production (Fig.23&24). Permeable rock dams can be considered a form of "terraced wadis". The concept is that runoff which concentrates in the centre of the valley will be spread across the valley floor. Excess water filters through the dam. Sediments which will be built up behind the bund is rich in nutrients and this will further improve the crop growth. Usually a series of dams are built along the wadi floor. The technique is thus similar in several respects to check dams which are built in Tunisia.

The traditional methods practiced in Yemen and several Arab countries consist of constructing earthen bunds (Ogmas) across the wadi channel to direct part of the flow to the fields. Large spates cause failure of the ogmas. Thus, although ogmas are relatively cheap to build, the cost of their maintenance and repair is high. Over the past decades a series of techniques have been developed to achieve a better regulation of spate flow. The impacts of improved systems have not been thoroughly assessed. It seems that the results are variable, and several problems still need to be solved. They include technical, agricultural, legal, institutional and socio-economic problems.

Wadi flow and spate irrigation contribute substantially to aquifer recharge, particularly when the flow leaves the mountains and debouches upon the alluvial fans. The bifurcation of stream channels which occurs usually on recent alluvial fans facilitate infiltration into the alluvial deposits. The conjunctive use of ground and spate water could contribute to the optimization of crop production per unit volume of water.

Although priorities in most countries have been directed towards the development of conventional irrigation schemes, there is a growing awareness of the importance of improving and modernizing spate irrigation in view to its importance to countries which have limited perennial surface water resources or completely lack such renewable sources. Spate hydrology is characterized by a great variation in the size and frequency of floods. Crop production which is dependent on spate varies considerably over the years, due to large variations in wadi runoff, from year to year,

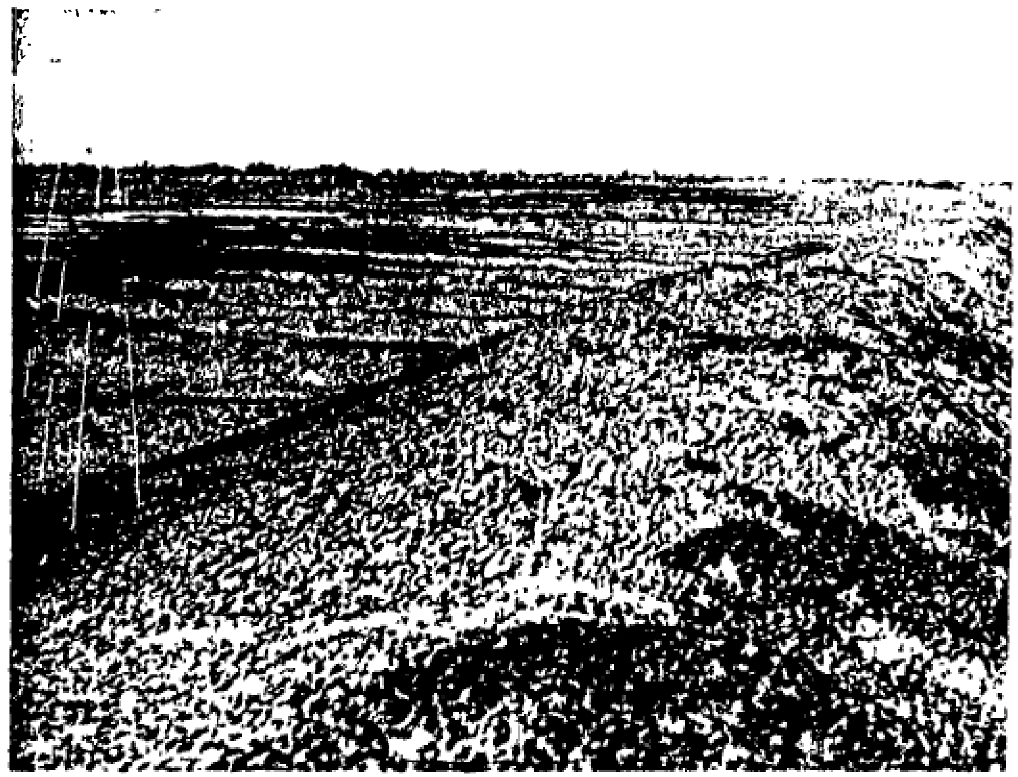


Fig.(23) An Earth Embankment for Water Spreading in Eastern Sudan.
Source : ACSAD - UNESCO/ROSTAS ,1986

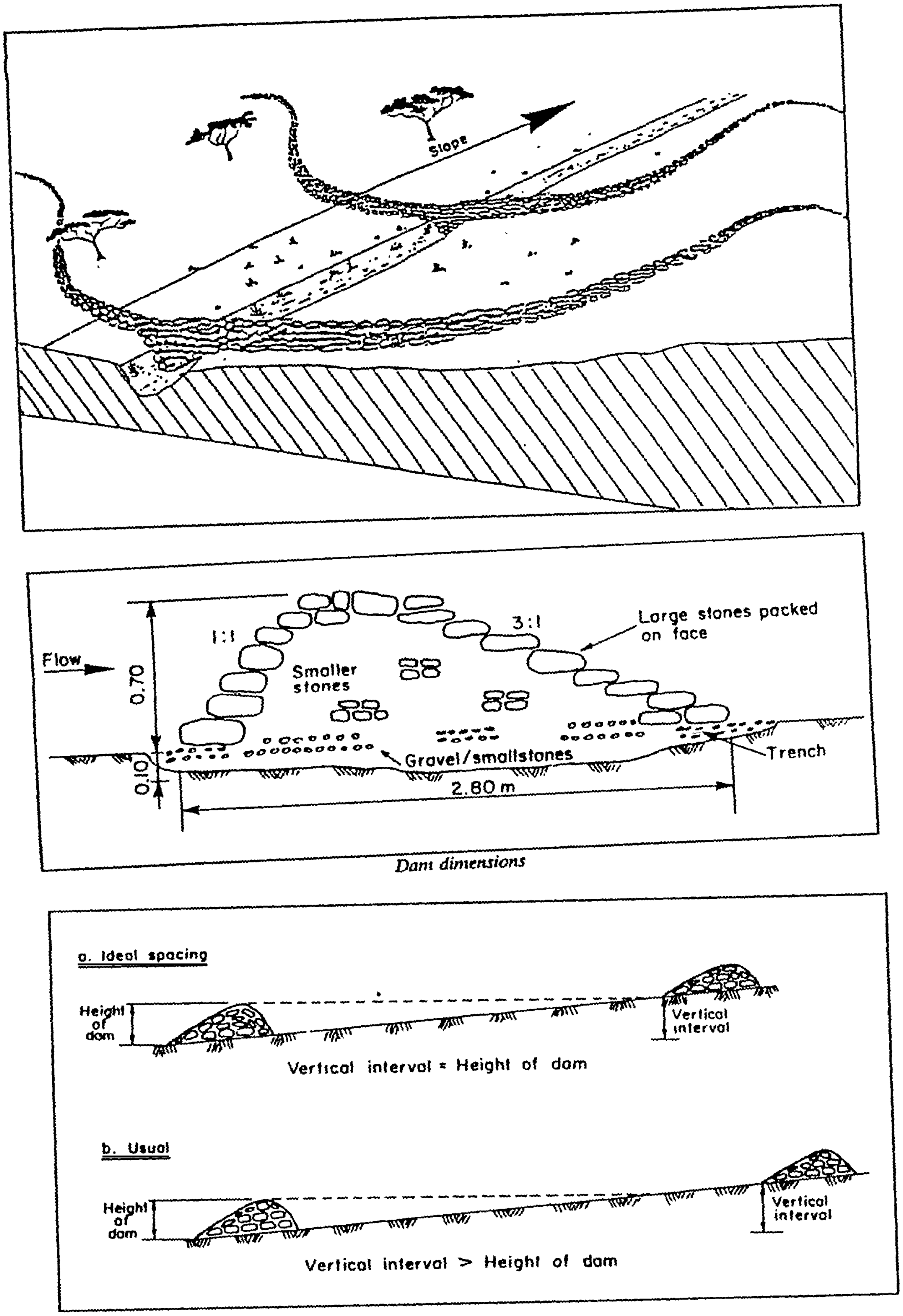


Fig.(24)- Permeable rock dams. (Source : Crichley and Reij, FAO, 1989) season to season and day to day. Furthermore wadis are subject to devastating floods which damage or destroy irrigation structures or agricultural lands. The flow in wadi Tuban in south Yemen increased on 8 September 1959 from 14 m3/s to 2114 m3/s. On 4 April 1969 the flow rose from 114 m3/s to 3400 m3/s in two hours (Camacho, 1987). Similarly in Tunisia several large floods occurred in wadi Zaroud during September and October 1969. Flood flow ranged from 6000 to 17000 m3/s. Total volume of annual flow reached 2 BCM which is about 20 times of the average annual flow, estimated at 100 MCM.

Wadi development must take particular account of critical factors such as climate, rainfall runoff relations, flow frequency and exceptionally high sediment load. The key issue in wadi development is the definition of the appropriate development concept (Camacho, 1987): should a dam with a storage reservoir be constructed or a spate breaker and series of diversion structures or one or more diversion weirs with wadi-training?

Social, technical and economic aspects need to be reviewed. These should comprise alternatives for the optimal use of surface and groundwater to maximize overall agricultural production per unit volume of water. This entails choice concerning overall project irrigation efficiencies, optimal spate application depth and extensive versus intensive use of land (Camacho, 1987).

Overall efficiency of a wadi development involving a series of diversion weirs is usually of the order of 30 to 40 per cent i.e the water developed is about one third of mean annual flow. However replenishment of groundwater through wadi recharge and spate irrigation would allow greater groundwater withdrawal. Schemes with higher efficiencies may not be a better alternative, since groundwater irrigation could mitigate the impacts of drought and rainfall variability on agricultural production. However, if aquifer recharge constitutes an important component of wadi development plans a thorough study of aquifer characteristic should be implemented in order to ensure that attributes such as quality, productivity water table rise or decline do not constitute major constraints to a viable groundwater development for irrigation purposes.

The optimal spate application depth for a single irrigation in the majority of spate areas in Yemen is 400 mm (Camacho, 1987). This will allow extensive rather than intensive agriculture production and a large area for spate spreading and groundwater recharge.

In the wadis of southwest Arabian Peninsula, large storage dams involve high capital investment per hectare. Dams, impounding reservoirs and spate breakers may provide an optimal solution in flood regulation, but require a thorough study to justify the normally high construction costs and short life span due to rapid siltation. A spate breaker is a small dam which would be sufficient to absorb large spates with high peak flows that would otherwise wash away most "Ogmas" . Spate breakers, however, beside being costly, have shorter life than that of storage reservoirs due to rapid sedimentation.

Permanent diversion weirs allow much better regulation of spate flow. The high cost of construction seams, however, only partly compensated by reduced maintenance costs. Low cost diversion weirs (gabions) could provide an attractive alternative to the traditional ogmas, in particular in the lower reaches of wadis. New designs have been proposed which may overcome problems of sediment control and headwork regulation. Traditional ogmas still provide considerable advantages because their large numbers along a wadi provide substantial diversion capacity and can easily be repaired after each breaching flood. Their main disadvantage is their high maintenance cost, increased risk of flood damage and unreliable flood regulation

6.7 Artificial Recharge

Artificial recharge is a technique which is used under different climatic conditions for conserving runoff and flood water supplementing available groundwater resources and reducing or preventing salt-water intrusion. Recharge installations have steadily increased in the Arab region in the past decade. In the Maghreb sub-regions, several countries have developed national plans for a more extensive use of artificial recharge techniques. These techniques constitute a major component of an on-going UNDP Mashrek-Maghreb project. Countries of the Arabian Peninsula which use spate irrigation or Aflaj (canats) systems are giving increasing attention to artificial recharge. Certainly, it is evident that there is a growing recognition of the importance of artificial recharge as a tool for improved groundwater management in the Arab region.

Advantages of artificial recharge in arid and semi-arid zones are two fold: It reduces high losses by evaporation and mitigates the impacts of rainfall variability on agriculture, because the water stored in near-surface aquifers could be tapped and used as needs arise. Artificial recharge could deal with a variety of problems, such as aquifer depletion, salt water intrusion, water level decline and contamination control. It is therefore considered a valuable tool for groundwater protection in terms of quantity and quality.

Artificial recharge could be used effectively for the storage of harvested flood water. In several semi-arid areas it constitutes the only viable method for the conservation of water that would otherwise be largely wasted.

Several traditional water spreading methods currently in use in the Arab region serve the purpose of groundwater replenishment. Recent methods include recharging through spreading, pits, shafts, wells and pumping to induce recharge from surface bodies (UNESCO, ROSTAS,1994). These spreading methods have been classified as flooding, basins, furrow, natural channel and irrigation. In the Arab region common methods include spreading, "recharge dams", wadi beds, spate canals, spate fields, wells and small scale water structures. Certain dams and water structures used in Tunisia and Morocco are multi-purpose and their impounded waters serve artificial recharge projects either directly or indirectly.

One of the earliest applications of artificial recharge is Beyrouth artificial recharge project. Surface water has been diverted from streams flowing in karstic terrain to the limestone aquifer in coastal areas and was recharged through a number of wells. It was pumped during dry seasons when the base flow of streams become insufficient to meet peak demand in Beyrouth. This pilot project demonstrates that artificial recharge could be used for addressing water supply problems arising from high degrees of karstification in the main channels of perennial or intermittent streams flowing in limestone terrains.

Important programs have been implemented in the Arabian Peninsula for integrated development and management of surface and groundwater resources. These programs comprised extensive dam construction projects in Saudi Arabia, Yemen, Oman and the United Arab Emirates. Dams of various sizes were built to increase water conservation, provide flood protection and promote groundwater recharge. The number of dams constructed within the last ten years has exceeded 256 dams and at least 60 new dams are planned for the next decade. Some 190 dams of various sizes have been constructed in Saudi Arabia and about 10 dams in

Yemen and 14 dams in Oman for the purpose of groundwater recharge, flood protection and limited irrigation.

The majority of dams built in Oman and UAE are for recharge of depleted aquifer systems. In addition to surface dams few "sub-surface dams" have been built to regulate groundwater flow. An example of such wadi-development is provided by ams built on wadi Aridah and Wadi Turba near Taif in Saudi Arabia (Al-Hajeiry and Shaikh, 1982). Prior to their construction the wadi alluvial aquifer lost significant volume of groundwater due to seepage of highly permeable wadi-fill deposits. After construction of the dams additional 6.5 MCM of water were made available.

Surface water stored behind the dams in Oman usually remains for a period not exceeding 15 days, after that the stored water is diverted to spreading grounds beside the natural channels of the wadi courses. These areas usually exist downstream and water reaches them through channels dug for this purpose.

In general small dams which have been constructed are multi-purpose. They regulate wadi flow, protect lands downstream from hazards of floods and increase the amount of water in storage underground. In addition to these benefits critical problems such as depletion of aquifers and sea-water intrusion are also dealt with.

In addition to traditional water systems which contribute to the recharge of unconfined aquifers, Tunisia has developed a national plan for a wider-scale application of artificial recharge techniques. The main problems addressed are aquifer depletion and salt-water intrusion in coastal areas, and increasing scarcity of freshwater resources. Some 30 wells were used in Tabalbah coastal area for injecting an alluvial aquifer. About 1400 MCM were recharged underground during a period of 757 days (Reqaya,1992). The basin method was used in Manzel Bou Zelfeh in southeast Tunisia for underground storage of about 100.000 m^3.

In Morocco, surface water was diverted from wadi Muharhar for recharging sandstone and limestone aquifers of Sharaf El Ouqab near Tangir. A rise in water levels of about 9 m was observed. Other artificial recharge projects were implemented in Marakesh and Agadir areas.

The feasibility of artificial recharge projects have been assessed in Morocco and Tunisia. In the latter country, according to Rekaya (1992) artificial recharge is a method of vital importance for addressing problems of aquifer depletion and deterioration of groundwater quality. A study based on comparison of different methods has indicated that recharge through wadi fill is the most viable method in semi-arid zones. Basins could be used if wadi fill and underlying aquifers do not furnish suitable media for artificial recharge. Recharge by spreading basins is costly because silt-free water is required to prevent scaling of basins and because most basins need periodic cleaning. Recharge by wells involve clogging of the recharge wells and the aquifers. Principal reasons of clogging are air entrainement, suspended partials in the recharge water and microorganisms. Flood water spreading, however costs least (Rekaya, 1992).

On the basis of previous evaluations of the different artificial recharge methods, 1993 artificial recharge programmes were implemented by applying mainly the wadi-bed recharge as can be seen from the following figures;

METHOD	PERCENTAGE
Wadi bed	96.5 %
Open wells	1.2 %
Spreading basins	2.2 %

The primary purpose of the natural wadi channel method is to extend the time and area over which water is recharged from a naturally influent channel.

Amounts of water which entered the recharged aquifers in Tunisia ranged from 55 to 75% of the volume of utilized water . Amounts of water stored underground increased from 12 MCM in 192 to 40 MCM in 1994 and is expected to reach 100 MCM by the year 2000. The Tunisian experience is of great significance for the entire Arab region since it demonstrates that recharge under semi-arid condition is a viable method for water conservation. The methodology is being now tested in Syria, and it is envisaged that artificial transfer of technology between Mashrek and Maghreb in the area of artificial recharge could yield important results which contribute to the solution of water problems confronting this sub-region.

Sources of water for artificial recharge could be flood flow, treated or untreated waste water. Sewage recharge has been practiced in a variety of cases throughout the world. In recent years several investigations have been undertaken to evaluate technical and economic feasibility of sewage spreading. It has been concluded that effluent recharge is an effective method of improving water quality (Montgomery, 1988). Earth materials act as natural filters which screen out certain contaminants. However, groundwater systems in different areas have varying capacities for attenuating contaminants.

An important method which seems to be well adapted to hydrologic conditions in arid and semi-arid zones was suggested by Dabbagh (1988). The source of water is wadi-runoff. In order to tackle the problem of silting a combination of two systems have been proposed. One for the collection of water and the other for recharge. The type of collection systems, however, depends on the hydrologic and hydrogeologic conditions.

Either surface or groundwater dams may be utilized. Surface dams provide a better control of discharge but reservoirs are prone to a high rate of evaporation and siltation. Small permeable surface rock dams could be used to zigzag the flow diverted from wadis (Fig. 25). The dam would retard the flow and purify it from suspended solids before using their waters in recharging wells (Dabbagh,1988). Groundwater dams, on the other hand, may be used for a temporary storage of water in near-surface aquifers. Two types could be built. The first is a sub-surface dam which is constructed below ground level and the second is a sand storage dam which impounds water in sediments caused to accumulate by the dam itself (Dabbagh,1988).

The recharging well is designed to absorb water coming from perforated pipes in the dams and their surface or sub-surface reservoirs. The recharging well is a radial collector well (Fig.26). It consists of a vertical shaft and radiating perforated pipes. When the well is in operation the water passing through the back pressure valves fitted at the end of delivery pipes build up in the well shaft. The resulting hydraulic head forces water to flow from the well shaft into the radiating recharging perforated pipes which ensure a large area of contact with the aquifer. After recharging the well is cleared of silt by pumping. Traditional wells have been used in this way in Qatar. However, the aquifer in Qatar is highly fractured and no radial screens are required.

Since many of the Aflaj (canats) systems have been constructed in wadi fill or in the alluvial fans, their hydrogeologic set up is well suited for artificial recharge. Wadi flow and groundwater form an interrelated

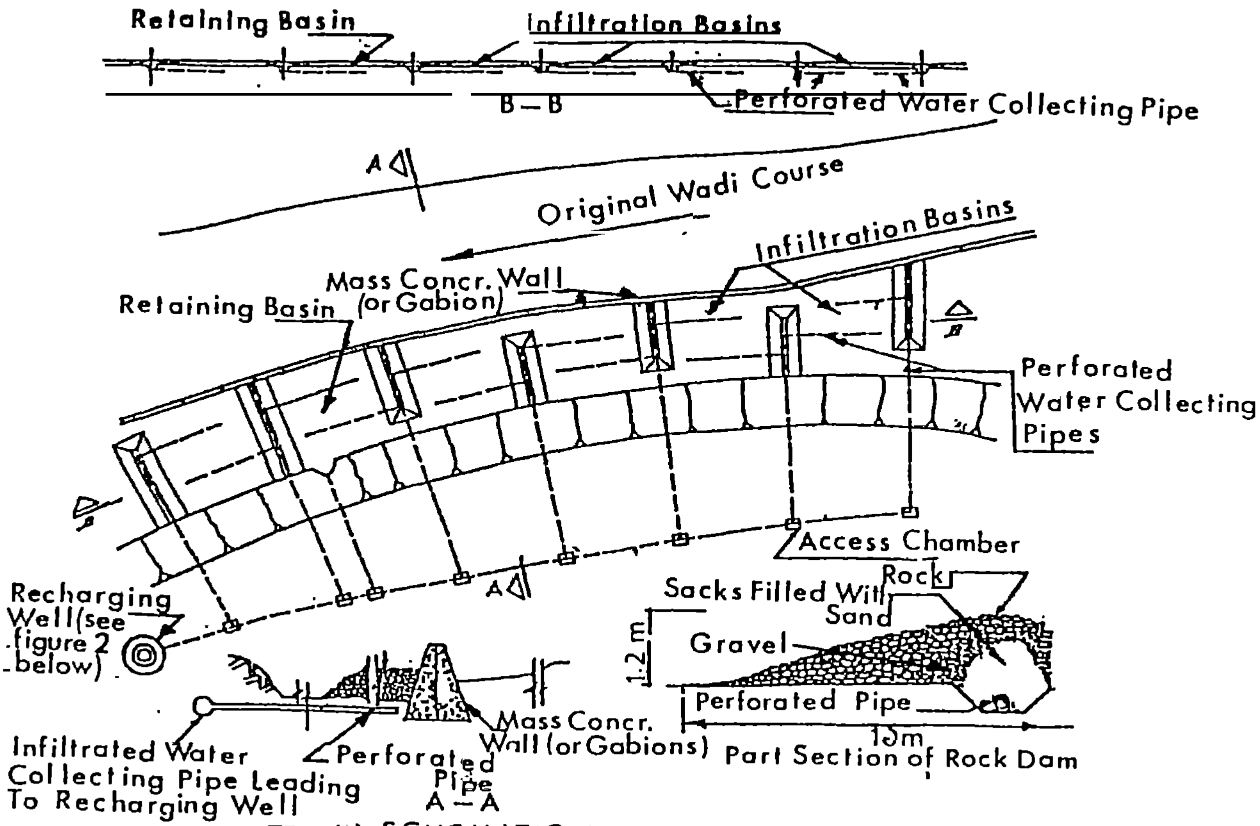


FIG. (1)-SCHEMATIC WADI RUNOFF RECHARGING PLAN

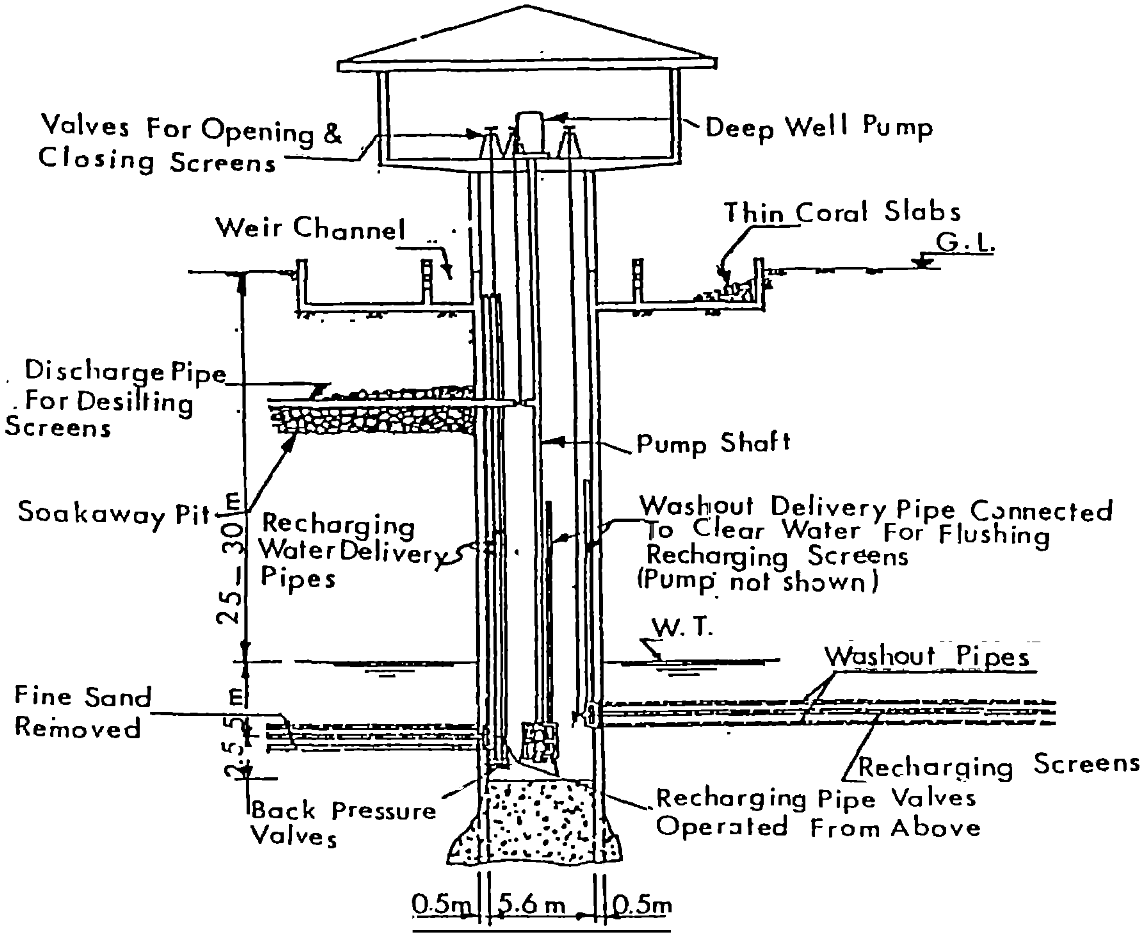


Fig. (26) Cross section of proposed recharging well

Source: Dabbagh, 1988

hydrologic system which includes sub-surface and groundwater flow. An appropriate artificial recharge method could therefore be used effectively to sustain the flow of foggaras.

7. APPLICATIONS OF RAINFALL MANAGEMENT IN THE ARAB WORLD

7.1 The Eastern Region : Mashrek and Arabian Peninsula

The Arab Mashrek comprises two main physiographic provinces. A western Mediterranean semi-humid province and an eastern arid inland province. The lowland which occupies the greater part of the region is circumscribed by a mountainous belt from the north, west and northeast. The western mountain range is sub-divided by the north-south rift faults into two mountain systems, a coastal western "Lebanon" mountain system and an eastern "Anti-Lebanon" system. The northern Taurus mountain range sweeps southeastward in an arch to form the Zagros mountains in northeast Iraq and Iran. A semi-arid belt extends from foot of the mountain systems in the Syrian steppe (Badia) which encompasses important parts of Syria, Iraq, Jordan and northern Saudi Arabia. Precipitation decreases eastward and southward, from about 1500 mm in the high mountain ranges to less than 100 mm in the interior. Precipitation which falls on the semi-humid carbonate massifs in the western mountain zone sustains the flow of perennial rivers which flow in the rift zone. These are the Orontes, Litani and Jordan rivers. The Euphrates and Tigris rivers which rise in the Taurus-Zagros mountain range, discharge into the Gulf through Shat El-Arab, whereas Orontes and Litani, which flow northward and southward, turn westward and discharge into the Mediterranean. The semi-arid belt encompasses the fertile plain of northwest and northeast Syria and the foothill zone of northern Iraq, and western Jordan. Rainfed farming is practiced on a major part of these semi-arid plains. Drylands agriculture in the plains is dominated by cereals, whereas drought tolerant tree crops are grown in the foothill zones and in parts of the highlands. The dry land farming systems which developed in the Mashrek were based on a delicate balance between crop and livestock systems. In a recent approach, rainfed farming, irrigated agriculture and livestock are produced in an integrated manner. Rainfed production is, however, vulnerable in the Mashrek region, due to high rainfall variability.

Nonwithstanding efforts made to improve and stabilize agricultural production in the Mashrek, these have been counteracted by increased population pressure and the harsh environment with its erratic rainfall pattern. Application of rainfall management techniques offers definite possibility for increasing productivity of rainfed areas. The harvested water could also be utilized to enhance water supplies and restore depleted aquifer systems. Groundwater could be used as alternative source for supplementary irrigation and water supplies in areas underlain by productive aquifers. Such aquifers, however, are already over-developed, and a large part of the foothills and plains in the semi-arid and arid areas are underlain by impermeable Tertiary and upper Cretaceous deposits. Water harvesting is often the only possible source for improvement of agricultural production and for rural water supply. Important applications in the eastern region are described below.

JORDAN

Jordan is one of the countries of the region seriously suffering from water problems. In 1993, about 983 MCM were supplied to a projected demand of 1126 MCM, thus recording a deficit of 143 MCM. In fact the actual deficit was much higher, because the overpumping of groundwater (243 MCM) beyond its safe yield has to be added to the deficit to make it 386 MCM in 1993. There is a good potential for the development of water resources in arid and semi-arid lands of Jordan which receive annual rainfall of less than 200 mm. Their cumulative volume largely exceeds all other utilized sources of water in Jordan, but nearly all of this water is presently lost by evaporation.

In 1985 the Faculty of Agriculture at the University of Jordan (FAUJ) initiated a major research project for these areas with help from the European Economic Community (EEC). The project was aimed at combating desertification in Jordan, through the evaluation of low-input agricultural alternatives and water harvesting. Three small earthen dams were constructed near the Muwaggar village, to harvest water from a watershed covering approximately 70 Km2 for use in supplemental irrigation of fruit trees and range forage species. Important quantitites of water were collected, and the experiment demonstrated the potential of small water retention schemes in terms of water harvesting. Before such a concept could be more widely disseminated, however, it was felt imperative to evaluate different water storage and utilization alternatives in order to arrive at the optimal, sustainable water harvesting and management strategies for entire watersheds.

The objective of an IDRC currently supported project is to develop an integrated model, adapted to arid and semi-arid regions, capable of devising optimal and sustainable strategies for planning, design, layout, and operation of water harvesting schemes in watersheds, and for sustainable use of harvested water to increase crop production and reduce soil erosion.

Given the specific climatic and edaphic conditions of the arid regions, the model will integrate the following components:

i) Accurate prediction of water runoff over both the micro and macro watersheds, necessitated by the random nature of storms in terms of duration, frequency and intensity.

ii) Formulation of a process for an optimal selection and design of water storage modes: harvested water can either be stored directly in soil for later use by crops or in surface reservoirs to be used for irrigation. However, each mode of storage has its requirements, advantages, and disadvantages in economical, technical, social, and environmental (particularly erosion) aspects, which need to be optimized.

iii) Determination of optimal and sustainable utilization and management techniques of the stored water. For instance, for the water stored in the soil profile, a process of optimal selection of techniques, crops, areas, time of planning etc., needs to be devised in relation to the stored amounts, soil, and climatic conditions. An optimization process is required to integrate these conditions with the overall ecological system. On the other hand, for water stored in surface reservoirs, an effective management program may include options such as timely emptying of some or all reservoirs to accommodate potential floods. Besides, other management alternatives need to be considered in relation with the prevailing conditions in order to elaborate an optimal management strategy.

Such an integrated model does not presently exist, and its development may have important applications for sustainable development of water resources of Jordan as well as other arid and semi-arid areas of the region. Hopefully, the model will become a valuable tool in planning and operation of a watershed harvesting system. It may also be used for assessing water conservation policies, various planning scenarios, and impact of future land development projects in arid and semi-arid lands. If successfully developed, the model will have several potential users such as planners of national development programs, the private sector, research institutions, and individuals working in arid and semi-arid regions of the Middle East and North Africa.

SYRIA

The use of groundwater for irrigation in Syria has increased steadily during the past two decades. The volume and rate of increase have exceeded those of the apparently more abundant surface flow in Syria's rivers. By 1975 the area irrigated by groundwater exceeded the area irrigated by river water. By 1984 groundwater was commanding an area just a little less than the total irrigated from surface flows, both gravity and pump fed. There are signs in many parts of the country that the recently observed decline in water levels will prevent further extension of uses. In addition, the viability of recent developments such as the extension of barley cultivation and the increase in flock numbers in the rangelands has resulted in highly degraded soils and vegetation.

In a recent attempt to reduce degradation of its rangelands resources, the Government of Syria has recently given top priority to the initiation of applied research programs aimed at the integrated development of soils, water and vegetation in the rangelands. The selected approach is to design sustainable land use strategies in watersheds with the objective of providing stable and sufficient forage reserves to pastoral communities year round and during drought seasons. Combined with the improvement of water collection, storage and redistribution and with soil conservation techniques, this integrated development plan should contribute to improving living conditions of nomadic populations while increasing the sustainability and diversity of the rangeland production systems in Syria and reducing groundwater overpumping.

An IDRC supported project is the first research oriented project to address the integrated development of watersheds of the Syrian steppe. There are 11 main watersheds in the Syrian steppe, with a total discharge of 23.8 MCM (probability 50%). Preliminary studies have identified more than 40 sites suitable for water harvesting and spreading projects. The potential to utilize project results to other sites is therefore quite important.

The general objective of the project is to develop a generalized model for sustainable development of arid lands watersheds through the integrated management of their water, soil and vegetation resources. It will evaluate various water collection, storage and redistribution methods, soil conservation technologies in view of increasing biomass production, crop diversity, reducing soil erosion and improving water use efficiency and water conservation, and the integration of water harvesting with other sources of water in the watershed, i.e. groundwater. It is hoped that results of these trials will be utilized in the development of other watersheds across Syria, presently considered by the Government of Syria.

PALESTINE

Present Status

Taking into consideration the scarcity and limitation of water resources in Palestine and pollution control of water resources and the current accelerating and future expected increase in water demands, all possible water conservation measures should be used including water harvesting.

Individual-house rainfed cisterns and rainfall harvesting from the roofs of greenhouses have been successfully implemented in the West Bank. Rainwater cisterns and ponds are used for domestic purposes in urban areas and for domestic, irrigation and livestock purposes in rural areas.

Rainwater harvesting in the Gaza Strip is much less extensive than in the West Bank. This is due to several factors such as:

- The nature of population distribution and density in the Gaza Strip, where about 67% of the population live in refugee camps, allows small, if any, space for rainfed cisterns.

- The higher rainfall intensity in the West Bank gave a higher feasibility for rainwater harvesting.

- The fact that access to water resources is more readily in the Gaza Strip than the West Bank (digging a water well in the Gaza Strip is much easier and cheaper than in the West Bank).

Roof catchment systems are very limited and were not reported to be favorable among Gaza residents. The Canadian International Development Agency (CIDA) and as an inter-sessional activity to the multilateral working group on water executed a small roof catchment systems (five cisterns). An evaluation of the feasibility of such systems is underway. Abu Hijleh, and Bruin et. al., indicated that enough rainwater can be captured and stored for drinking purposes for the Gaza Strip if the space problem is solved.

Four agricultural ponds were constructed in the Gaza Strip during the period 1990 to 1994 through funds rainsed by the Palestine Hydrology Group (PHG). Two of the ponds were made of reinforced concrete with a capacity of 250 and 160 m3 with a cost of 25 and 50 US $ /m3. The other two ponds were made of five meter deep earth basins with plastic lining. The capacities of these ponds were 3765 and 2125 m3, respectively..

Safe the Children Federation (SCF) supported and encouraged farmers to collect rainwater from their green houses and use it in irrigation. An example of such efforts is a large green house project near Khan Younis where runoff rainwater were collected by gutters and stored in a closed tank and used subsequently in the green house for irrigation.

There are two main types of single home roof rainfed cisterns found in Palestine, the pear shapo or Roman cisterns and the regular edges cisterns. To smaller extent (up to 4%), small over ground cylindrical steel tanks were used. The rainfed cisterns found in the West Bank were made mostly either from reinforced concrete or plastered soil. However, steel and stone cisterns were also used but with smaller share.

Regular edges cisterns are more popular in areas where soils are either too loose (in sandy and loose soils) or too solid (in mountainous areas). A cube or a rectangular parallelepiped shape is used for regular edge cisterns. A reinforced concrete slab is usually used with metal opening for covering the hall. The walls of the cisterns are mostly built of reinforced concrete and in some cases, it was plastered with cement mortar only.

Pear shaped rainfed cisterns are popular in coastal areas of Palestine (about 67% of the total number of cisterns) where the soild formation is mostly clay. This type of cisterns is constructed in soil and consists of two parts, a cylindrical opening 60 to 80 cm in diameter and about one meter in depth then a pear shaped hall with size depending on the volume of water to be harvested. For water proofing and for clean water, the inner walls of the cistern are usually plastered by hand using cement mortar after excavation. This type of cisterns is the most economic and requires smaller space.

Community Roof Catchment Systems, include the following types:

1. Neighborhood well (Bir El-Hosh): In which few houses in the neighborhood connect their roof areas (which might be joint in one roof or discrete) to one collection well that is used for domestic purposes. The size of neighborhood wells varies, depending on the number of houses connected and the rainfall intensity. Neighborhood wells up to 200 m3 were observed.

2. Mill well (Bir El-Mat-Haneh): This type of wells was constructed near the olive or wheat mills and used to serve the mill in the process or for cooling purposes. Users usually wait their turn for several days. Rainwater feeding the well comes from roof and yard of the mill. Mill wells with size of 100 to 150 m3 were observed.

3. Wayfarer well (Bir El-Sabil): This type of rain harvesting wells is constructed in the fields outside the village boundaries. This type of wells is characterized by its long construction time. Villagers used to build such wells in their spare time and when conditions permit. A catchment yard is prepared for each well which is owned by a family or a group of families. Women used to walk in groups several times in the afternoon from their homes to the well and back carrying their water jar (20 to 30 liters in size) on their heads. A small pit in the rocky ground is usually digged near the well and used by cattle steers-man for livestock drinking.

Water harvested in roof rainwater catchment cisterns in Palestine is used with variable dependency levels for domestic purposes. However, in addition to domestic purposes, 22% of the people use harvested water for poultry, 25% for livestock, and 35% in irrigation.

Runoff harvest has been practiced in Palestine for very long time (possibly thousands of years). Contour ditches and furrow structures were used in old times to harvest rainwater from hillsides. Harvested water was stored in earth or stone-wall pools and used by village community for irrigation and livestock. Other methods that are used for this purpose include stone walls terraces and conservation bench terraces. Field crops (barely and wheat) and trees (olives, grapes, figs, and almonds) are mainly grown on these lands.

Stone wall terraces are usually made of stone walls about 50 to 70 cm thik and 1 to 3 meters in height. The rainwater seeps through the stone wall and prevents it from accumulating behind the terrace bench. Conservation bench terraces are made of embankments with a size depending on hillside slope and with a spacing between terraces of about 80 to 120 meters.

These runoff harvesting facilities are now endangered by erosion problems due to lack of maintenance. To reduce the amount of runoff, it is hence recommended that contour and strip cropping, construction of terraces, and other methods to be practiced in Palestine, specially in the eastern slopes of the West Bank. Various types of natural terraces were found in Palestine and have an important role in runoff harvesting such as river terraces, platforms and shorelines of the Dead Sea, lithological steps, tectonic terraces, and others. River terraces consist of not more than five sedimentary embankments formed of fine and coarse stream sediments along wadis. Its existence is limited to the central and lower parts of the runoff wadis. In Palestine, these terraces can be found in the western wadis of the West Bank and some of the Dead Sea wadis.

Platforms and shorelines are found in the western and eastern sides of the Jordan river and its formation is related to the changes in the Dead Sea levels during early times. Lithological steps are widespread along West Bank hillsides and depend on the stratigraphic conditions of the rock layers. Tectonic terraces are formed as a result of faults and they are widespread along the eastern slopes of the West Bank from north to south.

Greenhouse use in the West Bank is a new practice which is growing up at accelerating rates nowadays. Table (3) shows that the area planted under greenhouses in 1990 was six times the area planted in 1980. It shows also that most greehnouses are used in the Tulkarm area which has a costal mediterranean warm climate. This climate encourages the planting of vegetables in greenhouses all year around specially during winter months.

Table (3) Development of Greenhouse areas in the West Bank

Year	Areas of greenhouses (donums) in the West Bank		
	Tulkarm area	Other areas	Total
1980	278	38	316
1981	364	33	397
1985			509
1989	1345	61	1406
1990	1844	115	1959

With the use of greenhouses, farmers realized that large amounts of rain water is lost as runoff from their roofs. This runoff water causes soil erosion and flooding in areas with many of greenhouses.

Three types of harvesting pools are available nowadays in the West Bank. The first type is using concrete pools to store water. Water is collected from the roofs of greenhouses and diverted through plastic pipes (usually 6" in diameter) to these pools. Where greenhouses are located next to the farmers house, water is also collected from the roof of the house. Concrete pools are usually covered with concrete roofs. Some farmers build their houses over their concrete pools. Others use the area over the concrete pool as an open living area after covering it with a grape arbor. Concrete pools have the advantage of serving for a long time without maintenance.

The second type of pools is establishing a large trench in the soil and line it with thin plastic sheet, to reduce seepage. This type is sually build to store 250 to 400 m3 of water (see Table 4). The width of the trench is 2 to 4 meters, the length is made 20 to 40 meters and the depth is around 3-4 meters. Usually the width and the depth are fixed but the length varies. This is because thin plastic liners are available at certain widths but can come with any length the farmer wants. The excavation is done using a regular bulldozer, free of charge, in return for the excavated agricultural soil. The plastic lining costs about 800 U.S. dollars for a trench of about 250 m^3.

The third type is a combination of the first two types and consists of a plastic lined pond with concrete walls to prevent soil movement; alluvial soil expands with increased water content. Another type suggested for use is a steel cylindrical container with 23 m diameter and 3 meters deep. Its volume is 1000 m3 and costs about 10,000 U.S.Dollars. This type should be available soon.

There is no regular design done for those harvesting ponds as the size per area is not fixed. The size is not critical up to now because few farmers are using harvesting ponds. Thus a lot of unused runoff is available. Therefore, farmers do not think they need to store large amounts of water as they expect that they can fill their pools from runoff resulting from short rain storms. As the use of harvesting increases, the need for engineering design increases.

Table (4) Sizes of harvesting pools in Tulkarm area

Pool type	Pool Size (volume m3)	Catchment area (m2)	Area Served (Donum)	volume/area (m3/donum)
Concrete	70-280	650-6000	0.58-6	46-120
Plastic lined	250-400	1250-5000	1.25-5	80-400

Assuming a utilization rate of 80% of rainfall and that irrigation demand is equal to monthly ET, then excess water is available on the average during December, January and February months. The excess over demands during these months is 54, 46 and 21 mm respectively. To store this excess for the following months, there is a need for a pool capable of storing 121 mm of water or of a size 121 m3 per donum of greenhouses. This size allows using the excess rain water during the following deficit months. Also, it allows using rain water during excess months as rain falls during few days of the month. Rain water will usually be fully utilized by May 1st.

Mizyed and Haddad (1993) simulated the operation of the harvesting pool and found that the farmers will be able to utilize 6318 mm in those 15 years or 421 mm/year when a storage pool (100 m3/donum) is utilized.

Farmers use ponds to mix spring and well waters in addition to being a water storage for harvested water from surface runoff. The maximum depth which is usually used is about 6.5 meters. The pond is lined with plastic mulches and the mulch is covered with soil for protection. Sizes of these ponds range from 300 to 20000 m3. A pond of the size 3000 m3 costs on the average 18.000 JD including land prices.

Runoff harvesting from greenhouses is another potential area for rainwater harvesting in Gaza Strip. Greenhouse farmers should be not only encouraged to harvest rainwater and use it in irrigation but also be helped by supporting them technically and financialy through establishing easy funding programs and procedures for farmer using these harvesting techniques.

West Bank

In the West Bank, natural springs are main sources of fresh water for the Palestinian irrigated agricultural sector. Out of 118 mcm of fresh water used by the Palestinian arabs annually, 55 mcm are taken from natural springs while the rest are taken from groundwater wells. Most of the natural springs are located in the western Ghore area.

Spring flow is usually high during winter and low during summer. However, irrigation demands are usually low during winter. This results in significant excess of fresh water during winter. As there are no large regional storage facilities available in the western Ghore, large amounts of fresh water are lost every year.

Large amounts of runoff water are also lost every year. It is estimated that more than 50 mcm/yr of fresh water are lost through runoff every year from eastern slopes. The volume of runoff water lost from western slopes was estimated to be about 20 mcm a year. Thus, the total runoff volume of 70 mcm/yr is more than half the present total amount of water used by the Palestinians (about 115 mcm/yr) which makes utilizing such volumes of high importance. Possible water harvesting programs including surface storage of runoff volumes on the micro and macro scale should be encouraged to utilize runoff volumes running to the west. Such programs enable Palestinians to utilize such waters before entering a shared groundwater aquifer.

Table (5) presents major Wadis in the Eastern Slopes of the West Bank and their Runoff.

Table (5) Contribution of major wadis in water runoff

Name of Catchment	Catchment area (Km2)	Estimated Runoff (mcm)
Wadi El-Malih	100	0.75
Wadi El-Fara	227	5.5
Wadi El-Ahmar	170	3.5
Wadi El-Auja	139	2.3
Wadi El-Qilt	119	1.0
Sum	755	13.0

From table 5, we see that the major wadis contribute only 26% of the total runoff of the eastern slopes. While 74% of direct runoff water flow through a large number of very small valleys, establishing reservoirs to store runoff water is not feasible on most of the small wadis. Therefore, artificial recharge of ground water from runoff from small wadis should be a more feasible option.

Urban storm water runoff in the West Bank is not used and mostly flowing in open channels through wadis and draining either to the west into the Mediterranean sea or to the east into the Dead sea. Various waste materials including inorganic and organic contaminants washed-out and carried by the storm water runoff are dispositioned and dispersed along open channels and represent a potential pollution source.

Most municipal areas in the West Bank are of mountainous terrain and with low developmental level, thus, water quality of the urban storm-water runoff should be of relatively good quality. However, urban storm-water runoff in the West Bank is not separated from domestic wastewater and solid waste collection and management practice is inefficient, therefore, its quality is questionable and close to that of diluted sewage.

Haddad and Mizyed, reported that storm-water runoff can be collected from November to April and one third of the storms produced runoff. This long duration makes it easier to benefit from the storm-water runoff with minimum storage needed since the stored water can be used at the same time of collection.

The same study indicated that the total annual urban storm-water runoff volume for the West Bank was estimated at 14.40 mcm (Table 5) which equals to about 13% of the present total water used by Palestinians in the West Bank for all purposes and about 75% of the total urban water use. About 64% of this runoff volume drains to the west towards the Mediterranean and the rest drains towards the Dead sea.

About two thirds of the population of the West Bank live in rural areas and about half of the rural population live in villages without water networks. About 27.75% of the present water demand of rural areas in the West Bank is being covered by these rainfed cisterns. Therefore, it is important to give the roof catchment systems more attention in the future either at the urban or rural level by initiating immediate programs obligating all people applying for new houses or buildings permit to `construct rainfed cisterns and encouraging house owners with no cisterns to construct them.

Rainfall harvesting provides additional 421 m3 of water per donum or 792000 m3 of water in Tulkarm area of the West Bank. Tulkarem area hosts about 94% of the green houses in the West Bank. This amount, plus that which will be harvested from other greenhouses in the same area, will allow planting additional 1700 donums of vegetables in greenhouses using the same available water resources in Tulkarm area. With the economic feasibility associated with greenhouse rainwater harvesting, it is expected that more greenhouse development in the West Bank will take place and therefore, rainwater harvesting projects from greenhouses should be strongly supported.

THE ARABIAN PENINSULA

Economic development and population growth in the countries of the Arabian Peninsula have resulted in extensive exploitation of the available water resources. Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates, Oman and Yemen, face both over consumption and supply limitations. They have been compelled to build additional desalinization plants and have increased their reliance on fossil ground water resources. Rapid increases in population are being experienced by most countries in the region. In addition, ambitious agricultural and water exploitation programs, aimed at meeting food and water requirements, have led to significant overdraft of water sources far in excess of the natural renewal capacity.

Solutions for the impending water crisis lie in the formulation and implementation of water management plans that emphasize demand management in conjunction with schemes to increase the water supply through management of rainfall-runoff water and improvement of institutional arrangements. Success of such programs will depend on implementation mechanisms, availability of funds and technical expertise, and social acceptance.

To better manage their limited water resources, some countries have initiated programs to increase available supplies. Most efforts have been directed towards the construction of storage facilities and conveyance systems to efficiently utilize runoff by increasing groundwater recharge, and divert flow to the flood plain to increase irrigation efficiency. However, the efficiency of collecting and utilizing runoff through better management practices can be further improved, especially in areas where frequent rainfall-runoff events occur.

In order to evaluate present water management practices, as well as suggest possible improvements, it is imperative to address the availability of water from rainfall and runoff events as well as the physiographic characteristics that influence its collection and movement in areas with resource potential. Historical perspectives, as they relate to past and present management practices, will also be examined. Among the major topics to be explored in this report are the water harvesting techniques of surface water impoundment, rainfall terracing systems and flood irrigation.

The Arabian Peninsula is devoid of rivers and natural lakes and usually receives only meager rainfall. The climate is considered to be extremely arid with severe hot weather, sparse natural vegetation, and fragile soil conditions. For the most part, this region can be considered desert area with the exception of the coastal strips and mountain ranges (Shahein, 1989, Abdulrazzak, 1992). Hydrometeorological parameters exhibit great variation: temperatures may range from 5 to 46 ^{o}C in the north, central and eastern parts of the peninsula. The coastal areas and the central and eastern parts of the peninsula. The coastal areas and the Asir, Sarat and Omani highlands in Saudi Arabia, Yemen and Oman have lower temperatures ranging from 5 to 35 ^{o}C. Humidity is generally low in the interior ranging 10-30% in winter to 48% in summer, while in the coastal areas it may range between 60 and 95%. The low percentage of cloudy days and high incidence of radiation over the region result in high evaporation rates. Consequently, potential open water evaporation is high, especially in the interior areas. The total annual evaporation ranges from 2500 mm in the coastal areas to more than 4000 mm inland. Water resources consist of surface water generated from rainfall and runoff events and groundwater in both shallow and deep aquifers. Surface runoff and groundwater of the shallow aquifers represent the only renewable resources (Table 6). In addition, rainfall and runoff constitutes the main source of recharge to the shallow alluvial and deep aquifers, taking place through the wadi bed, and outcrop areas, respectively.

Rain is the main source of water and it generates periodic surface runoff. the peninsula is generally characterized by low rainfall of great temporal and spatial variability. The average annual rainfall ranges from 70 to 130 mm, except in the Asir, Sarat and Omani mountain ranges located in Saudi Arabia, Yemen and Oman, respectively, where rainfall may range from 300 1000mm yr. Average rainfall values have little meaning since many areas receive no rainfall for months or even years, due to extremely random storm patterns. Rain in some areas is relatively abundant and can be utilized for rained agriculture. Floods resulting from intense rainfall in some areas directly recharge the alluvial groundwater aquifers, or is either diverted for flood irrigation or stored behind dams.

Isohyetal maps shown in Figures (28,29) of the mean annual rainfall distribution in the southwestern region of Saudi Arabia and most parts of Yemen, show rainfall variation.

Table (6) Water Resources in the countries of the Arabian Peninsula (1992)

Country	Area (km^2)	Population 10^6	Annual rain-fall (mm)	Annual evapor. (mm)	Runoff (mcm)	Shallow ground water reserve (mcm)	Runoff Utilization	Ground water recharge (mcm)	Ground-water Use (mcm)	Desalination (mcm)	Wastewater reuse (mcm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Saudi Arabia	2,149,690	11.78	75	3500-4500	2230	84,000	900	3850	14,430	795	217
Kuwait	17,818	1.52	70	1900-3500	0.10	162	-	-	80	240	83
Bahrain	652	0.52	70	1650-2050	0 20	90	-	100	160	58	32
Qatar	11,610	0.50	67	2000-2700	1 35	2500	0.25	45	144	83	23
United Arab Emirates	77,700	1 81	89	3900-4050	150	20,000	75	125	900	342	62
Oman	300,000	1.51	71	1900-3000	918	10,500	275	550	645	32	10.5
Yemen	550,000	13.12	122	1900-3500	3500	13,500	1450	1550	1200	9	6
Total	3,107,470	30.76	-	-	6800	130,772	2700	6220	17,559	1567	433

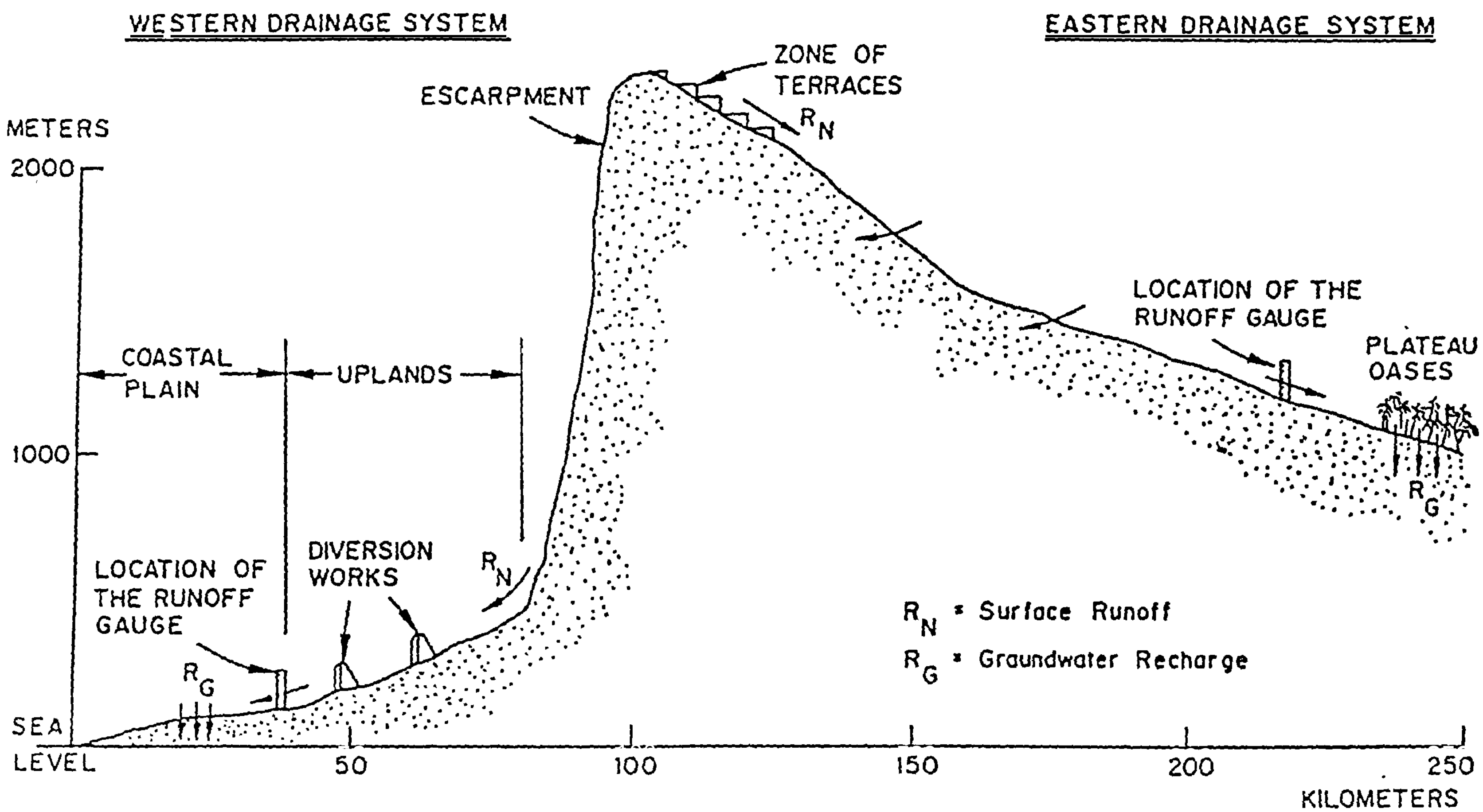


Fig. (27) Physiographic characteristics of the highlands along the Western Region of the Peninsula.

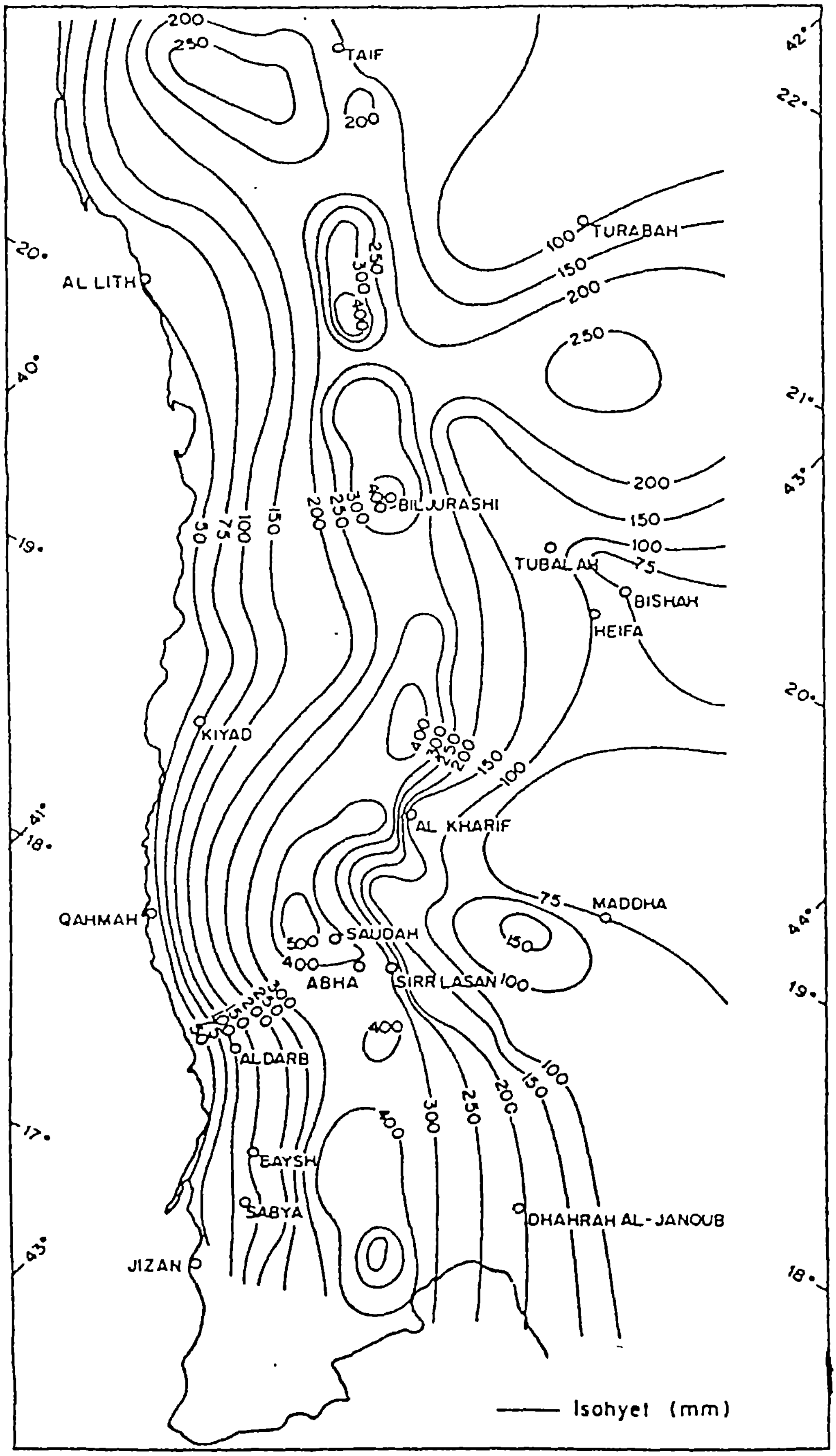


Fig. (28) Rainfall distribution over the Western Region of Saudi Arabia.

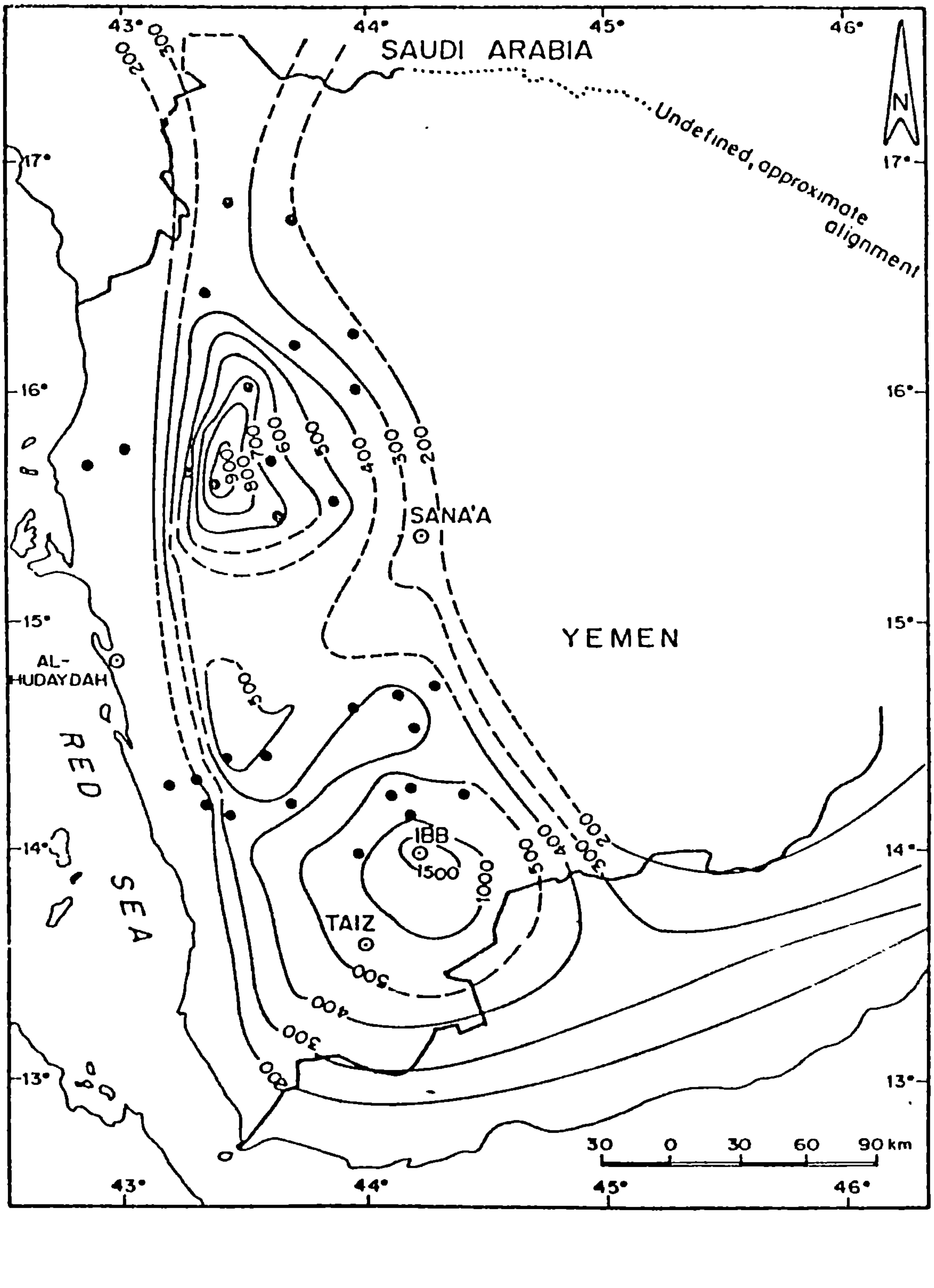


Figure (29) Rainfall distribution over Yemen

Rainfall patterns and orographic features of the Arabian peninsula govern the availability of runoff which, in turn, dictates the need for dam construction and the success of flood irrigation. Availability of surface water in relation to rainfall pattern is limited for the region as a whole with the exception of the southwestern part of saudi Arabia and Yemen, the southern parts of the United Arab Emirates and the northern and southern areas of Oman, as shown in Table (6) (Authman, 1983; Khouri and Droubi, 1990; and Abdulrazzak, 1992). Surface water availability and topography influence the potential storage capacity and size of dams, terracing and spate irrigation practices. The feasibility of using spate irrigation on the coastal plains is also determined by these factors. The south western region of Saudi Arabia, the interior parts of Yemen and southeastern Oman all have mountain ranges with a number of steep drainage basins that empty towards the sea, as well as a few moderate sloped basins draining inland. In general, drainage basins along the Red Sea are characterized by narrow flood plains in comparison to those in the east which drain into the Gulf. Runoff in these coastal basins runs down steep ravines and gullies until it reaches the coastal plain where extensive spate irrigation is practiced, in some cases runoff may reach the sea. The most striking feature of the coastal drainage systems is that they have similar relief and are all located 100 - 150 kilometers from the coastal belt. They are all characterized by hard rock, steep relief and sparse vegetation.

Given the prevailing climatic and topographic features, the southwestern parts of Saudi Arabia and Yemen, the southern part of the United Arab Emirates, and the northern and southern parts of Oman, receive relatively abundant rainfall when compared to the remainder of the peninsula. These areas have the potential for increased water utilization through the use of rainfall-runoff management practices.

Runoff events over most parts of the peninsula occur in the form of flash floods. Flood flow hydrographs are usually characterized by rapid rise to peak, ranging from 1 to 2.5 hours, followed by a rapid decline over a short time period. This gives way to a low stage succeeded by a long recession, until the wadi returns to its original dry state. The hydrograph time base may range from 7 to 50 hours. Sustained flow is rare and prolonged base flow occurs only through groundwater discharge when the water table is close to the surface. The annual runoff volume usually generated in the Red Sea coastal belt of Saudi Arabia is estimated to be 1450 mcm in comparison to a national total of 2230 mcm. Amounts of surface water available in Yemen, Oman and the United Arab Emirates have been estimated at 2400,918 and 150 mcm, respectively. The remaining countries have only negligible amounts of surface runoff and no hydraulic structures. In general, utilization of surface runoff is directed towards flood irrigation using spreading basins, and recharge of the alluvial aquifer through natural flow processes or from impoundment of water behind dams of various sizes that are usually located in the downstream portions of the basin. Rainfed farming is carried out on step terraces built on the steep slopes of many headwater catchments. Dams with limited storage capacity provide flood control and groundwater recharge as well as irrigation water for the mountainous areas.

During the last decade, extensive development, rapid population growth, and substantial improvement in the standard of living in most of the countries of the peninsula have led to an imbalance between increasing water demand and existing limited water resources. Most of the countries in this region have experienced a 20-40% annual increase in water demand over the last 10 years for domestic and industrial uses. Substantial increases in agricultural water use, ranging from 15-75% as shown in Table (7) are also being experienced, particularly in Saudi Arabia.

Domestic and industrial water requirements are satisfied through desalinization and a limited amount of groundwater. Agricultural requirements are met through abstraction of water from shallow alluvial aquifers located in the coastal strips and inland basins, but mainly from the deep aquifers covering most of the Arabian peninsula.

High population growth, further improvement in the standard of living and continuation of current agricultural policy are expected to result in increase in water requirements. Demand projection for the period 2000-2010 is shown in Table (8), assuming an agriculture growth of 1%.

Water-Harvesting

Water harvesting offers an effective methodology of managing the limited water resources available in arid regions such as the Arabian Peninsula. The method allows even the limited amounts of rainfall and runoff that may occur in such areas to be used in an efficient manner. It is a relatively simple and inexpensive water management approach. While it is used mainly on a small scale in rural areas, it could be used for large scale water development in some areas. Some of the disadvantages of the system are associated with the uncertainly of the climate, unavailability of labor force, the need for continuous upkeep and maintenance, and site design requirements.

Table (7) Water demand in million cubic meter (mcm) of countries of the Arabian Peninsula for the period 1980-1990

Country	1980		1900			Total demand 1980	Total demand 1990
	Domestic & Industrial	Agriculture	Domestic	Industrial	Agriculture		
Saudi Arabia	502	1860	1508	192	14600	2362	16300
Kuwait	146	40	295	8	80	186	383
Bahrain	46	92	86	17	113	138	216
Qatar	50	60	76	9	109	128	194
United Arab Emirates	229	560	513	27	950	789	1490
Oman	15	650	81	5	1150	665	1236
Yemen	98	1600	144	72	2500	1698	2716
Total	1,086	4,862	2,703	330	19,502	5,948	22,535

Table (8) Projected water demand in mcm for the years 2000 and 2010

Country	Populationx(10⁶ *)		Domestic and Industrial		Agriculture		Total demand 2000	Total demand 2010
	2000	2010	2000	2010	2000	2010		
Saudi Arabia	15.553	19.315	2900	3600	20211	21700	23111	25300
Kuwait	1.511	1.710	530	650	110	121	640	771
Bahrain	0.654	0.981	155	180	130	135	250	315
Qatar	0.425	0.525	140	184	185	204	334	388
United Arab Emirates	1.922	2.104	832	911	1400	1545	2232	2456
Oman	1.826	2.262	147	270	1270	1403	1417	1585
Yemen	17.75	23.45	360	640	3250	4000	3610	4572
Total	39.641	50.347	5064	6435	26,556	29,108	31,620	35,543

A number of factors affect the success of water harvesting methods including the amount of precipitation, size of the catchment, storage structures, funds available for construction and maintenance and potential socio-economic benefits. Areas with gentle slopes that receive annual rainfall in excess of 150 mm are suitable for water harvesting (Speece and Cook, 1981). Many areas of the Asir mountains in Saudi Arabia, as well as the Sarat mountains in Yemen, and Jabal Al-Akhdar mountains in Oman are suitable for water harvesting, particularly for livestock, farming and irrigation. In some areas water harvesting can be used for domestic purposes also. Old water harvesting techniques such as terracing and spate irrigation still exist in most areas of the region.

Three types of rainfall-runoff water harvesting techniques are currently being practiced in five of the Arabian Peninsula countries; Saudi Arabia, Yemen, Oman, United Arab Emirates and Qatar. These management practices consist of storage facilities such as dams, terracing and water spreading, which are being used in areas with adequate rainfall and runoff potential.

Current water management practices consist of storage facilities including the construction of dams of various sizes. Runoff is impounded behind these dams, thereby enhancing recharge to the underlying alluvial aquifers. Recharge to the alluvial aquifers takes place from within the dam reservoirs as well as through the downstream channels when water from the dam is released. In addition to enhancing the recharge process, the dams trap the majority of sediment load and reduce the magnitude of peak discharge, thereby reducing flood damage downstream. Most of the dams built in Saudi Arabia, the United Arab Emirates and Oman were built for the purposes of groundwater recharge and flood control. The majority of dams built in Yemen were intended to divert flood water for irrigation and for groundwater recharge purposes. A few large dams in Saudi Arabia were constructed to serve a variety of purposes including irrigation, flood control and groundwater recharge. These dams have been built either at the head waters of catchments in the mountainous regions or in the downstream portions of catchments in Saudi Arabia, Yemen, the United Arab Emirates, and Oman. Their construction and performance are addressed in the following sections.

"Recharge" Dams. As the countries of the region begin to face serious water shortages, the need to implement programs emphasizing water resource management, including management of surface water, become increasingly crucial. Some of the countries such as Saudi Arabia, Yemen, Oman and the United Arab Emirates initiated extensive dam construction programs to utilize the available surface runoff, and enhance the management of their limited water resources. Dams of various sizes were built to increase water conservation, provide flood protection and promote groundwater recharge, as shown in Table (9). The number of dams constructed during the last ten years has reached more than 256, and at least 58 new dams are planned for the next decade. Most of these dams have been built in Saudi Arabia, especially in the western and southwestern regions. Approximately, 190 dams of various sizes have already been constructed in Saudi Arabia, and ten in Yemen, for the purposes of groundwater recharge, flood protection, and limited irrigation, with a combined storage capacity of 475 and 72 mcm, respectively. Most of these dams in these two countries were constructed in mountainous regions because of the availability of runoff generated from the frequent occurrence of rainfall events. A few dams have been or are being constructed in the United Arab Emirates and Oman. Characteristics of dams built in the central, northern and northeastern parts of the peninsula include large reservoir areas, extensive length and limited height. They are usually of the earth fill type with large spillways. Those built in the western, southwestern and southeastern parts of the peninsula, especially in the mountainous region, are relatively small in terms of height and storage capacity, and are usually constructed of concrete or rockfill. Due to flat topography and limited runoff in the remaining countries of Bahrain, Kuwait and Qatar, small diversion structures are used instead of dams to create detention basins.

Topography and geological conditions usually impose practical limits on the height, size and type of dam that can be built at a particular location. The quality and quantity of available construction materials may predetermine design limits from the safety and stability standpoint.

The majority of dams are of the earth fill type. Earth fill dams are constructed of gravel and sand. Typical earth fill construction designs used in Saudi Arabia, the United Arab Emirates and Oman are shown in Fig.(30). They are commonly used in areas of flat topography, low elevation where the alluvial thickness is more than 15 meters, and wherever there is an abundance of earth material for construction. The wadi embankments are usually made up of sand, silt and clay, while the active flow channel usually contains poorly graded sand and graded sandy gravel. These characteristics favor the construction of earth fill dams from the economic point of view.

Table (9) Dam distribution in the countries of the Arabian Peninsual

Country	No. of Dams Constructed	Storage Capacity	No. of Planned Dams
Saudi Arabia	190	0.01-325	9
Yemen	17	0.5-369	12
Oman	14	0.01-12.5	32
United Arab Emirates	35	0.25-18.5	5
Total	256	-	58

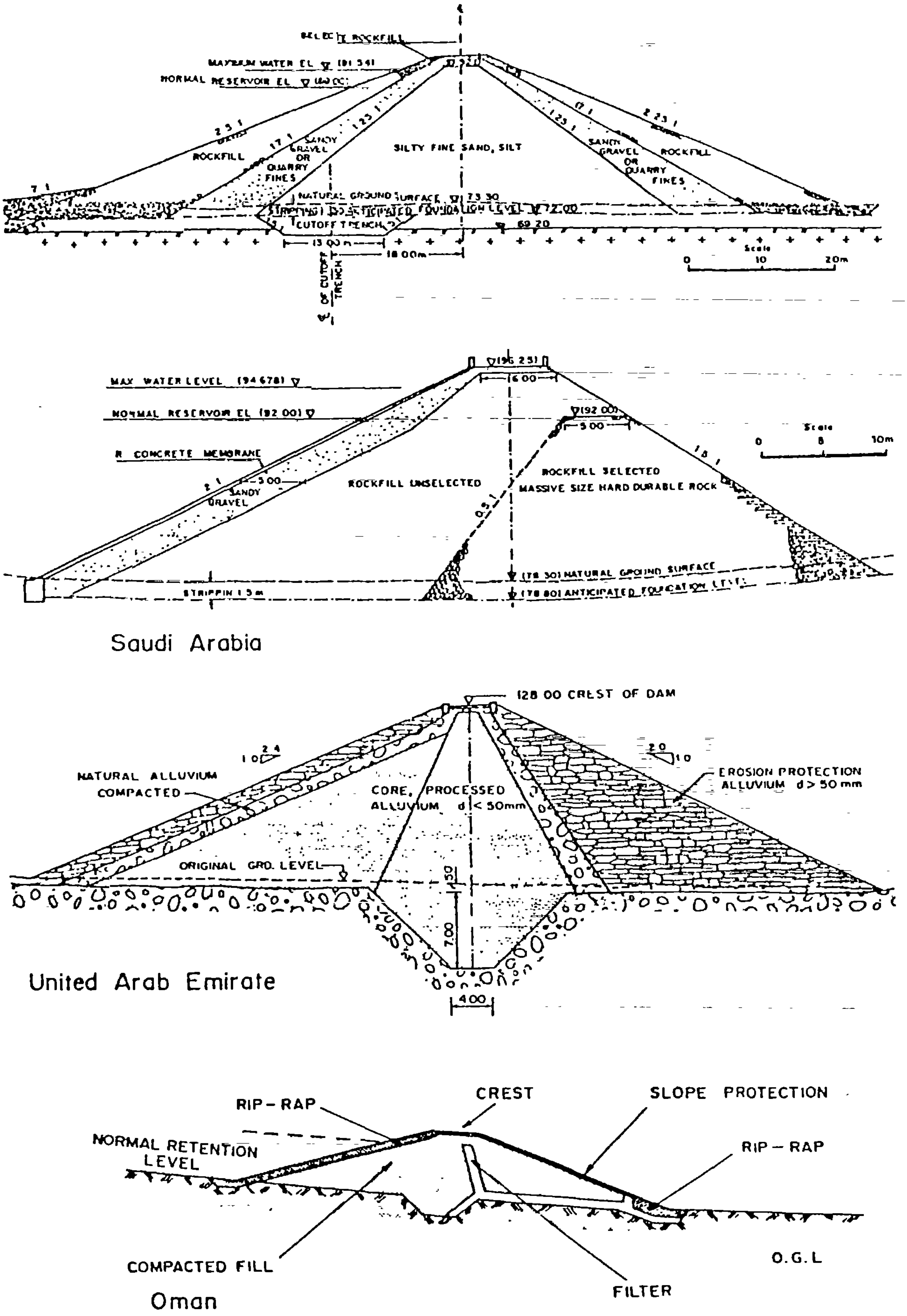


Figure (30) Types of small dams in Saudi Arabia, United Arab Emirate and Oman

Rockfill dams consist of crushed stone and sand. The material usually becomes available as a result of blasting of the hard rock outcrops at the dam site, or through spillway excavation. When rockfill dams are constructed in upstream locations, a concrete lining is used as a water barrier in order to prevent dam leakage and piping. If a fault is present, it is seated with concrete. Rockfill dams are usually constructed across narrow wadis in mountainous regions, particularly in Saudi Arabia and Yemen.

Concrete dams are usually constructed in mountainous regions on wadis with narrow cross-sections. They are more durable than rockfill dams and are more likely to withstand the intense runoff which could occur in the southwestern mountains. However, construction costs are much higher than for other types of dams.

The intended purposes of dams built in the peninsula are primarily to increase the rate of infiltration from the alluvial wadi channel to the underlying shallow water table, to provide flood protection to residents, and to provide water for irrigation.

Due to the natural coarse alluvial deposits in locations where dams are built across wadi beds, water impoundment usually contributes significant amounts of water to the underlying aquifer. During and after flooding events observation wells located upstream and downstream of dams in Saudi Arabia have shown significant responses, particularly in areas of flat terrain such as in the north, central and coastal areas. Recharge occurs through water impoundment in front of the dam, and/or from downstream water release. Infiltration recharge rates are usually more significant from downstream release than from the dam reservoir. Slow downstream releases offer a greater opportunity for infiltration through course wadi channel bed material. In addition, released water has less suspended material to hinder the infiltration process. In mountainous terrain, water stored in front of dams contributes significant volumes to the underlying aquifer. The magnitude, however, is usually small due to the limited storage capacity of the aquifer and steep groundwater gradient. Similar situations have been experienced in Yemen, Oman and the United Arab Emirates.

A study of selected dams in central Saudi Arabia (Al-Dalooj et al., 1983) revealed that, in general, most of the dams serve their intended purpose of recharging the alluvial aquifer. Downstream release and groundwater flow under the dams resulting from infiltration from the reservoir contribute to groundwater recharge, as shown in Fig. (31). Flood protection was provided for the rural communities downstream, and agricultural activities in the areas around the dams increased.

Recharge efficiency of two small dams located in the central part of Saudi Arabia was investigated by Al-Muttair et al. (1989) through field and theoretical analysis. This study concentrated on evaluation of recharge magnitude from dam reservoirs, with varying management options for silt removal and surface layer scratching. The dams studied were constructed of rockfill and concrete. Data on groundwater level, reservoir water level, climatic data and downstream releases were used to estimate the infiltration losses and resulting groundwater recharge. Results of reservoir water budgeting were checked against infiltration values and groundwater budgeting approaches. The study confirmed that significant volumes of water infiltrated through the dam reservoir even in the presence of silt and day deposits, as shown in Fig. (32). Upstream and downstream recharge was determined through observation well hydrographs (Al-Multair, 1989), as shown in Fig.(33). The efficiency of recharge from the two dams ranged from 68-94% while the evaporation losses ranged from 4-14%. However, evaporation losses increased to 60% during the summer season. Infiltration and recharge efficiency were shown to be dependent on the magnitude of runoff volume, silt and clay deposits, initial moisture content and thickness of underlying alluvial deposits. Limited silt removal and layer scratching enhanced the infiltration process by 3 to 14%. Cost benefit analysis of various management options including no, or gradual downstream release of flow into the natural channel or into infiltration basins, and silt and surface layer scratching resulted in a ratio greater than three. The study concluded that dams in the central part of Saudi Arabia serve their intended purposes of flood protection and enhancing the infiltration-recharge process to the underlying shallow alluvial aquifers. The study of Al Muttair et al.(1989) represents the most comprehensive evaluation of dam performance in the Arabian Peninsula.

In the United Arab Emirates and Oman most of the dams built in the lowlands achieved their objectives of groundwater recharge, flood protection to farmland and reduction of saltwater intrusion. The impoundment of water behind the Hod, Khilts and Quryat dams located in the coastal plain during flooding events of 1986-1988 (MAF, 1988 and Al-Asam, 1990) resulted in groundwater rises of 0.3 to 2 meters. As expected, high rises were reported in the main wadi channel and decreases

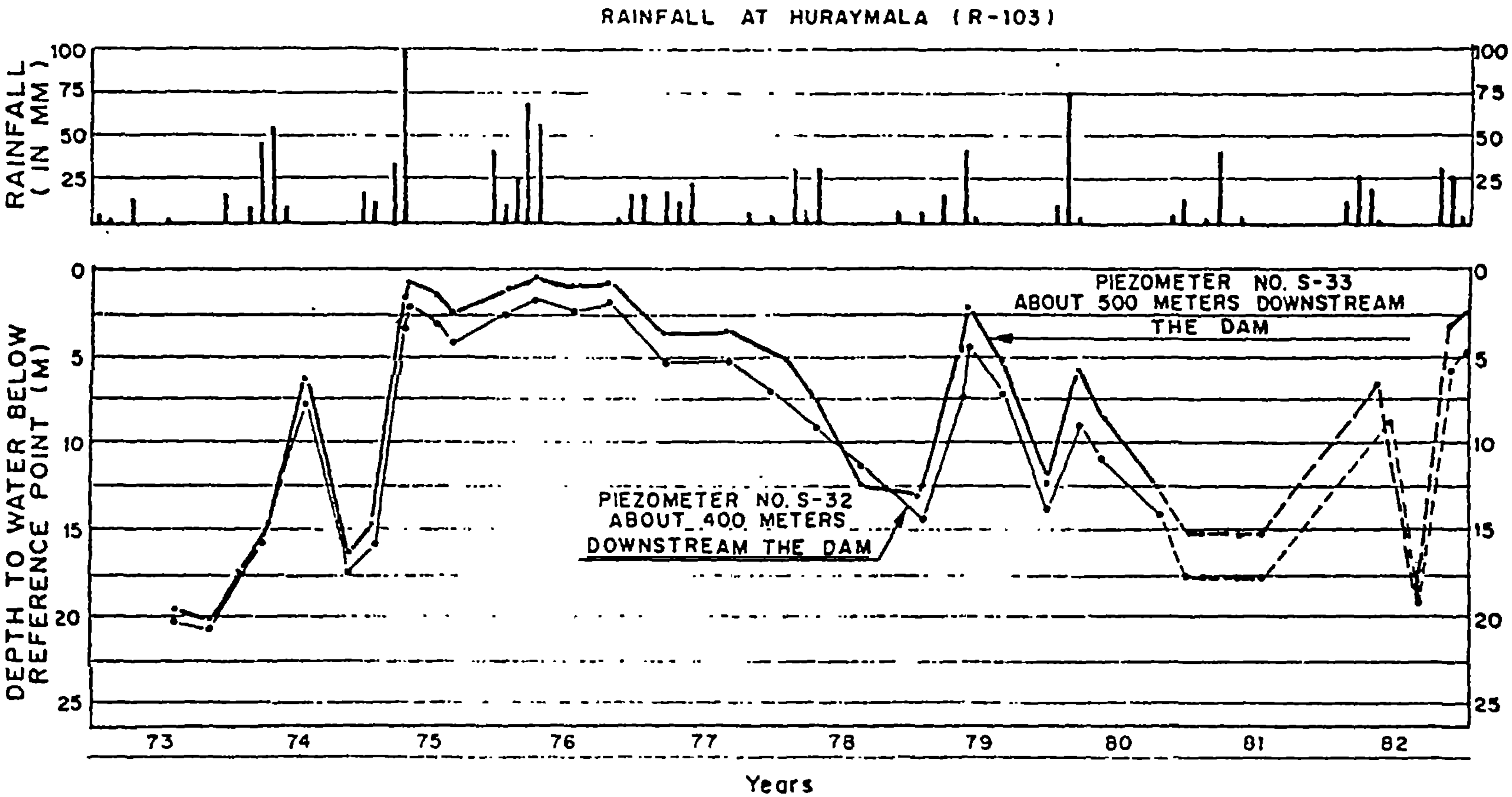


Fig. (31) Well hydrograph of Malham dam in the central region of Saudi Arabia.
(After Daloog 1982)

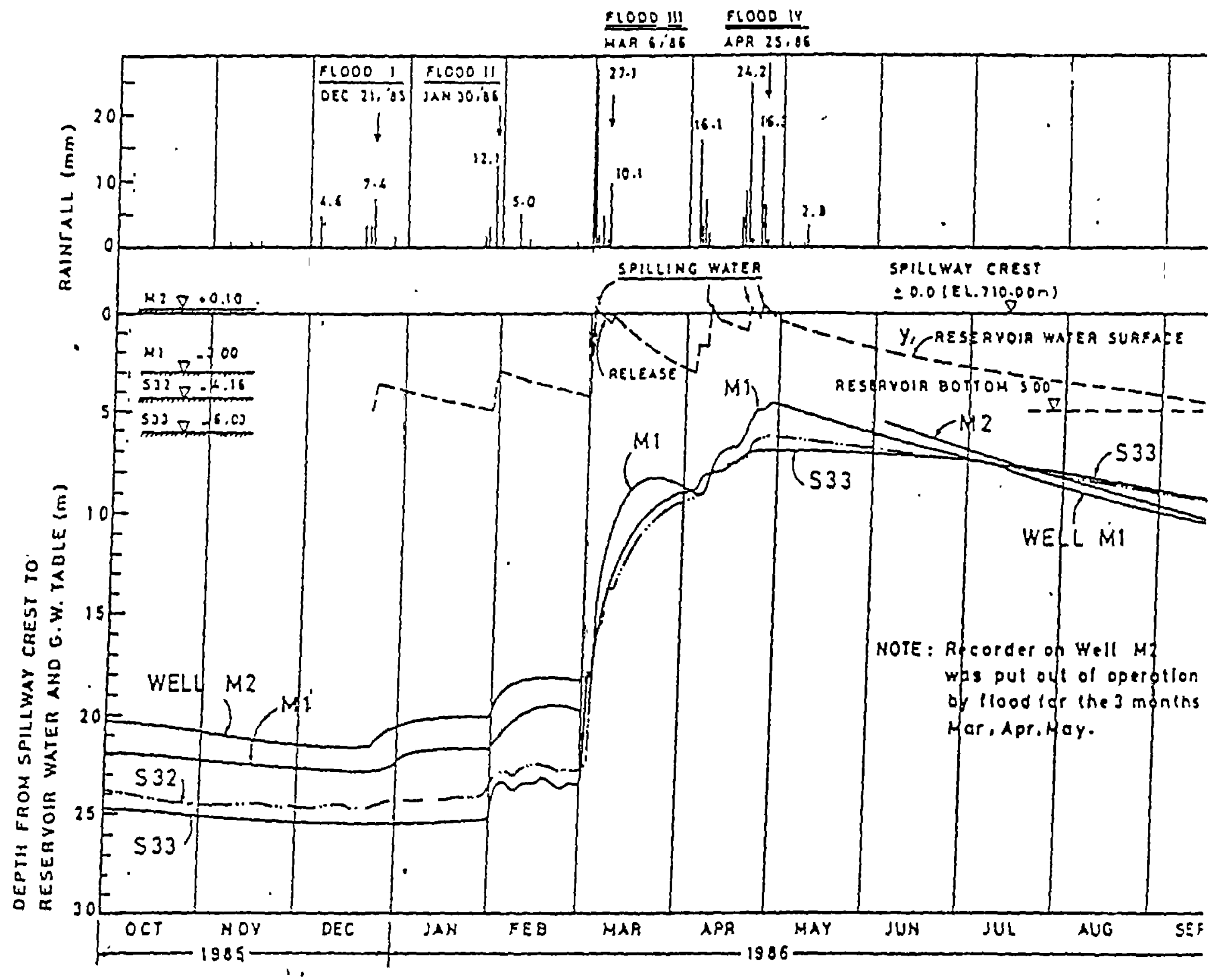


Figure (3,2) Weekly values of recharge volume, runoff value and rainfall depth in Malham dam in the central region of Saudi Arabia (After Al-Muttair, *et al.* 1989)

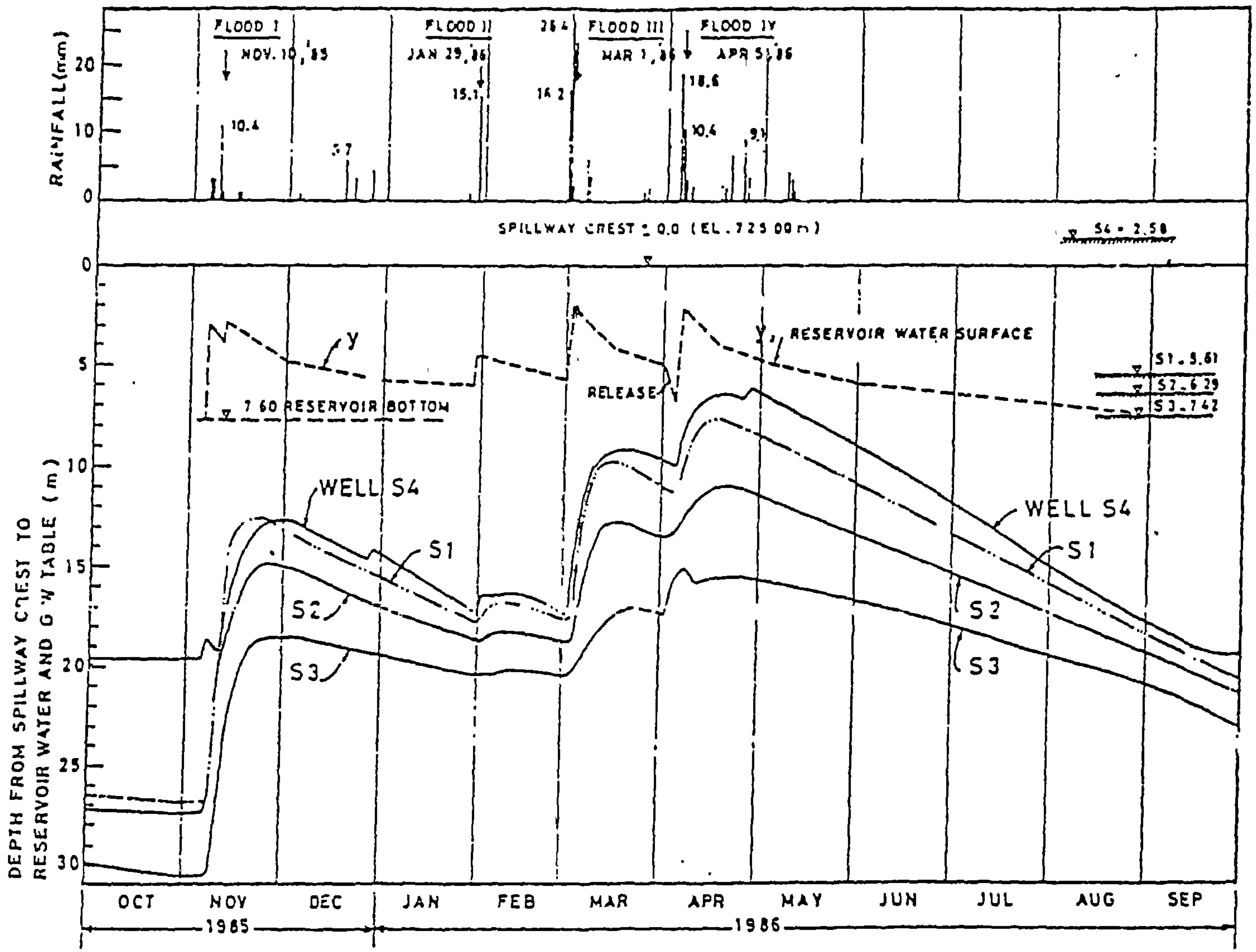


Figure (33) Weekly values of recharge volume, runoff value and rainfall depth in Al-Amalih dam in the central region of Saudi Arabia (After Al-Muttair, *et al.* 1989) were reported in the flood plain. Salinity in some of the wells decreased from 25,000 to 10,000 ppm (MAF 1980), and in others from 10,000 to 6,000 ppm. The contribution of surface runoff to groundwater recharge from some of the relatively large dams in the United Arab Emirates, such as those constructed on wadi Ham, is shown in Fig. (34). The magnitude of recharge depends on the volume of runoff. Higher recharge magnitudes were shown to occur near the dam, as reflected by observation well response, as shown in Fig.(34). In Oman, dam recharge schemes also include diversions to spread flood water over a large area. Small dams were also built in the United Arab Emirates, and groundwater responses similar to those in Oman were observed. No data are available for dams built in the remaining countries of the peninsula, however they have demonstrated different degrees of effectiveness in providing flood protection. Flood damage has been minimal, especially in areas where encroachment into the flood plain was limited. The only major flood-related damage occurred from an extreme 200 year flood in southwestern region of the peninsula in April-May, 1982. Bridges, roads, villages, farmlands and livestock, as well as lives were lost in Saudi Arabia, and a number of small dams failed in the western region of Yemen.

In some cases where dams have not served their intended purposes, problems were attributable to inadequate maintenance and operational procedures. There were also problems associated with high evaporation losses resulting from prolonged storage of water in reservoirs, high siltation rates with inadequate removal, and lack of proper operation and maintenance of controlled outlets. Infiltration rates from reservoirs reduced with time as a result of progressive deposition of silt and clay. Siltation within reservoirs is a major problem in many parts of the peninsula due to high sediment concentration. Sparse vegetative cover in combination with steep ground surface slopes, exposed rocks and high intensity rainfall, result in high concentrations of silt and clay being carried along by flood waters. Lack of regular water release, especially during periods when the reservoir's water level is low, contributes significantly to water losses through evaporation.

While dams generally serve their intended purpose of flood protection, they also provide local residents with a false sense of security. Downstream encroachment into the flood plain is increasing due to the absence of flood zoning regulations and enforcement. Significant water release or high magnitude flooding still poses a threat to farming communities and urban development. In addition, the absence of periodic water release has caused farmers to cultivate areas in the main wadi

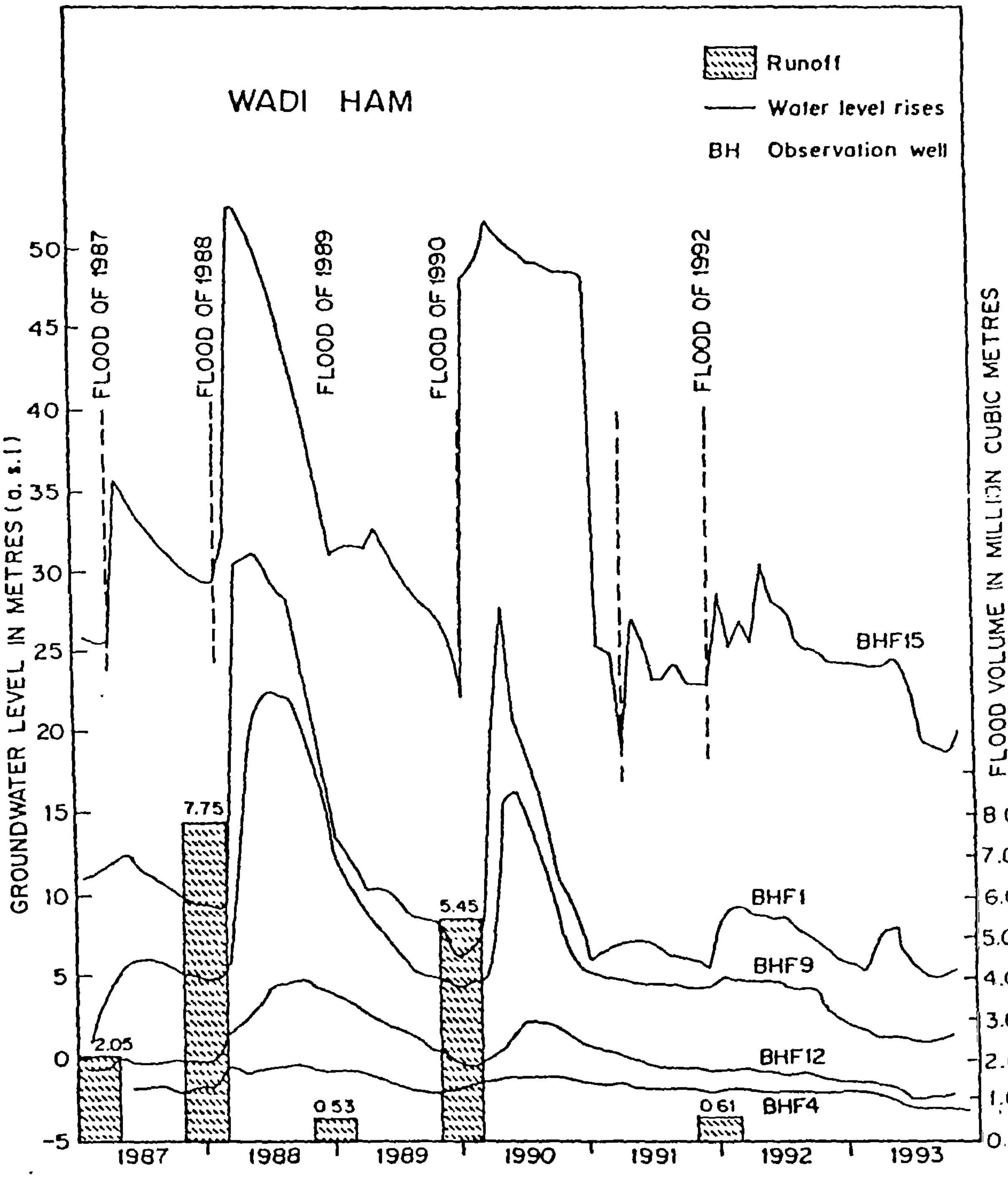


Figure (34) Runoff contribution to ground water recharge from Al-Ham dam in the United Arab Emirates (After Al-Asam 1994) channel and its flood plain. While it appears that most of the dams have served their intended purpose, implementation of efficient operation regulations would result in greater social and economic benefits. Also there is a need for follow up studies to evaluate performance of each of the dams. The concerned Ministry needs to enforce monitoring and evaluation of existing dams and carry out follow-up studies as part of the performance check.

Step terracing is used on the steep slopes of the calchment, while water spreading is carried out in the downstream portions of the catchment. Cultivation of the terraces depends solely on rainfall, while spreading basins receive their water either directly from rainfall or through diversion of flood water.

Terracing

Terracing is known to be an efficient method of water conservation. It also helps prevent soil erosion, and enables farmers to grow crops in hilly or mountainous regions. A number of different forms of terracing have evolved to serve specific purposes such as soil conservation and efficient use of water under various climatic and topographical conditions. Types of terracing systems practiced in arid and semi-arid regions such as the Arabian peninsula include weir terraces across narrow wadis, barrage terraces, linear dry field terraces, and staircase terraces.

Weir terraces are usually constructed along tributary wadis carrying small runoff volumes (Evenar et al, 1971). The tributary is usually terraced along its entire length by construction of a series of walls across the channel and spaced 10-15 meters apart and forming small agricultural plots. The narrow channel barrage terraces are constructed across deep-cut wadis with steep relief. Barrage terraces are usually built with local stone material. They may have deep accumulations of soil with high water storage potential. They range from simple ridges following the contour of gentle slopes to stone walls which support terraces on steep slopes. They are designed to trap rainfall and collect sheets wash flow from upper slopes. Weir and barrage terraces have been used in other areas of the peninsula, and linear dry field terraces have been widely used in Yemen and Saudi Arabia.

Design features of the step terrace system consist of the construction of step terraces of varying widths (Finkel 1986). The width of the terraces is influenced by several factors including the degree of ground surface slope, soil depth and quality of water flow. The general rule is, the steeper the slope, the narrower the terrace. The depth of the soil to be excavated along the upper margin of the slope's surface also dictates the size of the terrace, steeper slopes with smaller soil cuts result in shallower soil depths. In areas with higher flow velocity, the terraces tend to be longer than in areas with slower flow. The surface of the steps may be level, but are usually sloped in the range of 5 to 10% so that runoff will be carried laterally. A level step surface will allow infiltration of a large portion of rainfall, while a sloped surface will promote runoff to drain to successively lower steps. The walls of the steps with sloped surfaces are usually twice the depth of soil excavation.

Terracing as means of rainfall utilization and soil conservation is still being used in the mountainous areas of southwestern Saudi Arabia, most parts of Yemen, and mountainous areas of Oman. Extensive terrace systems exist in these areas. Terraces are usually narrow on the steep slopes of the Sarat and Asir mountain ranges, especially in watersheds draining towards the Red Sea. The objective of terracing in these regions is to collect rainfall for farming and slow down the runoff process. Rain water collects in the terraces and soaks into the shallow soil. Walls at the edge of the terraces prevent runoff from flowing down to the next terrace except during intense rainfall events. The walls of the terraces are built of stones, while voids between the stones allow water to move down to successive terraces without eroding the soil. Water can also move from level to level near the sloping bedrock. Subsurface drainage is required in these areas to channel flow from one terraco to the next to relief the pressure of excessive subsurface water. The terraces also trap fine sediment. They are designed and constructed in a manner to allow the passage of runoff through sheet flow, which prevents damage to the terraces from runoff concentrating at certain points. This method is effective if terraces are constructed in the upper parts of the wadi. An example of typical terrace construction is shown in Fig. (35).

In Saudi Arabia, an elaborate terrace system is being used in the upstream catchments of wadi Bishah in the southwestern region. Size of the terraced area as of 1980 was estimated at 270 km2 and the average rainfall was estimated at 450 mm resulting in an estimated 120 mcm of harvested rainfall. More than 27,000 hectares of rained terracing located at an elevation of 1700 m or more are being farmed, and the terraces are cultivated twice a year. The number of terraces is estimated at 59,000 distributed in the areas of the Asir highlands. Rainfall in this region is adequate for most crop requirements, as well as for forested areas, estimated at 1.6 million hectares. Rainfed agriculture is practiced on the

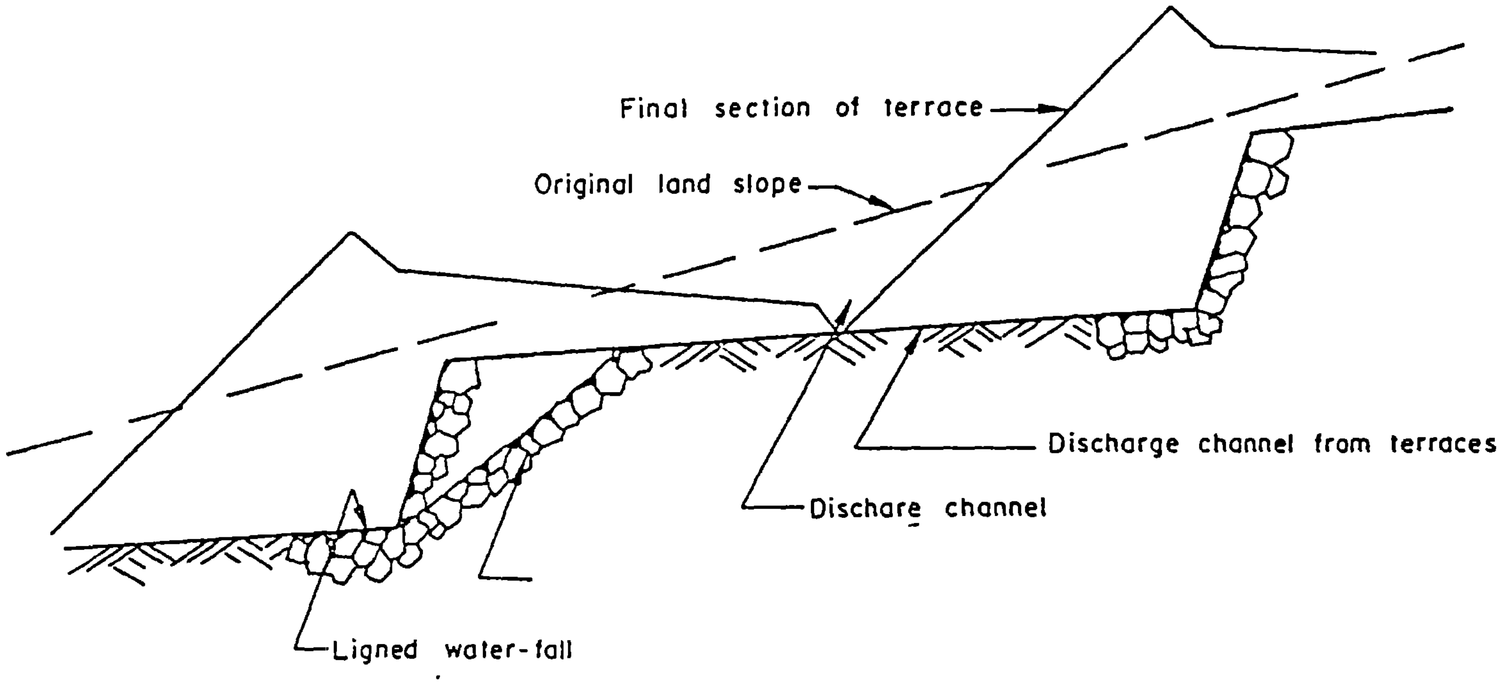


Fig. (35) Illustration of typical terrace construction.

terraces of the Asir highlands of Saudi Arabia and in most of the mountainous areas of Yemen. It has been estimated that rainfall harvesting techniques can be used in this area to meet domestic and livestock water demand.

Most areas of Oman receive small amounts of rainfall, far less than the amount needed for dry farming, except in the higher elevations of the Omani and Dhofar mountains in the north and south. Virtually all lands require irrigation water carried by Qantas or pumped from groundwater. In the foothills an estimated 6900 hectors of terraces are being irrigated from wadi base flow and aflajes (Speece and Cook, 1981). The terraces extend along the sides of the wadi course, and in some cases cross-channel terraces are constructed. The elevated terraces above the wadi bed can be irrigated by diversion of aflaj water upstream of the terraces. Channels and aqueducts which provide water to the terraces may sometimes extend for several kilometers.

Mountain terraces with areas estimated at 700 hectors are found primarily in Jabal Al-Akhdar in Oman. The terraces have been built up on the slopes in the upper areas of the catchments. Soil within the terraces is composed of natural accumulations behind the retaining walls or has been brought in by the farmers. Terraces at higher elevations are usually rairfed, while those at lower elevations receive watr through cascading runoff or water from aflajes.

Traditionally, agriculture in Yemen has depended on dry farming using either rainfall or spate irrigation. Rained agriculture is practiced on terraces in most of the highlands (Fig. 36), while spate irrigation is practiced along the wadi courses and coastal plains of Tihama. More than 1.5 million hectares are regularly cultivated. The country's particular topographic structure affects and modifies the climate on a regiona basis, especially rainfall distribution, and influences the availability of water for agriculture. The majority of Yemen consists of rugged terrain of igneous and metamorphic rock. Some areas receive rainfall in excess of 500 mm/yr. Extensive terracing is being practiced in the mountainous areas (Fig.36). The characteristics of areas where abundant rainfall is received are the same as those described for the southwestern region of Saudi Arabia, except that events occur more frequently and are of larger magnitudes.

In the mountains of Saudi Arabia, Yemen and Oman, terrace agriculture has been practiced successfully for centuries. Over the last ten

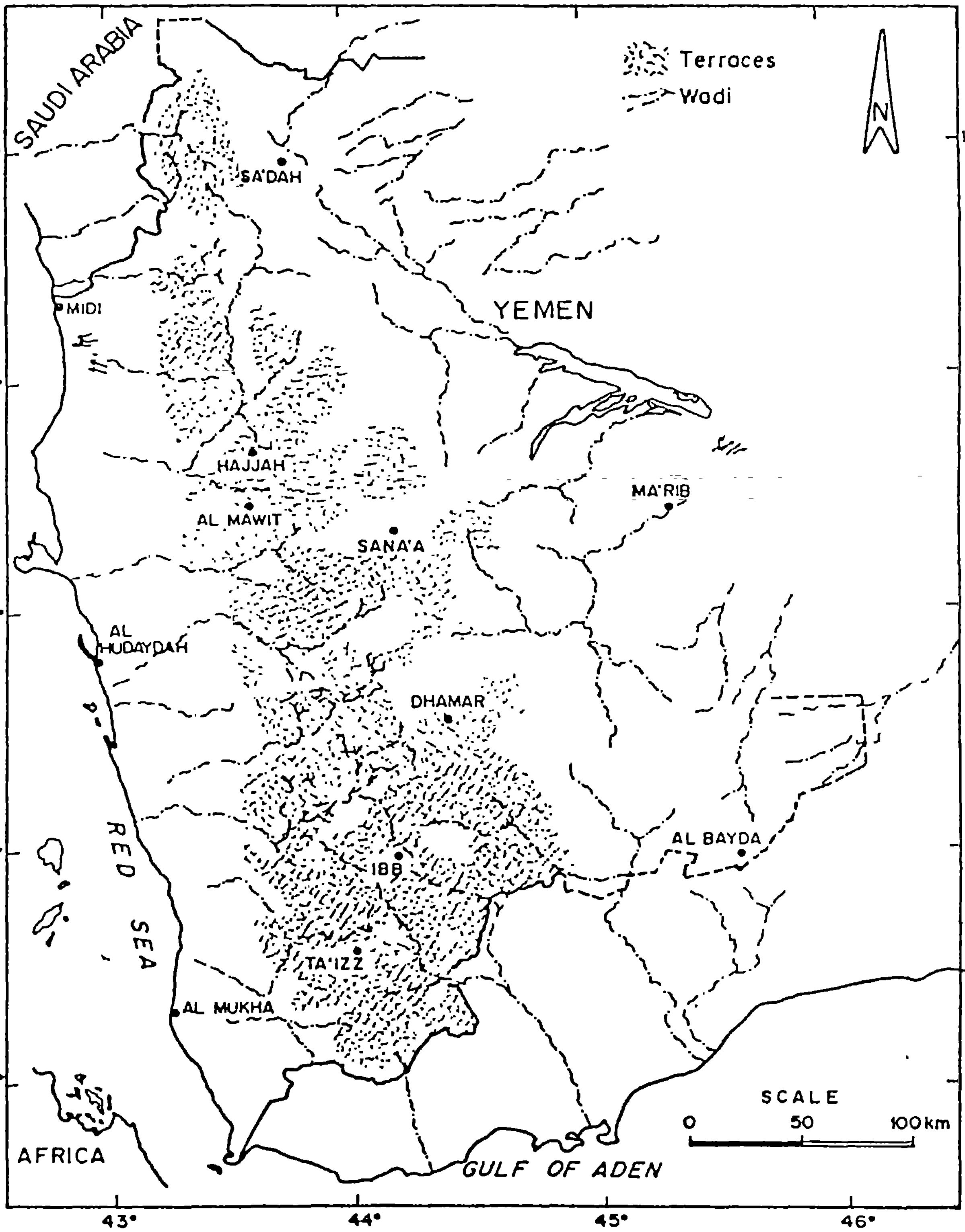


Fig. (36) Terraced areas in Yemen.

years, however, rained terracing has been declining due to lack of maintenance, migration of labor and emphasis on large scale agricultural development. Cultivation of terraces is known to be labor intensive, especially at high elevations. Farmers may have to travel long distances to maintain their terraces. Traditionally, the family unit was large enough to farm these areas and maintain the terraces. Unfortunately, migration of new generations to urban areas has decreased the local labor force and causes the use of terrace farming to be abandoned. In addition, seasonal shortages of labor make it difficult for this form of farming to remain commercially viable. Deterioration of terraces results of increased erosion and flooding because the structures control the movement of water and sediment. This, in turn, threatens the other agricultural systems downstream. Once the terraces are demolished they are generally never rebuilt.

This loss of terrace farming on a regional scale has far-reaching implications. Losses in local agricultural production and related income result in migration of population to urban areas. Residents who remain depend heavily on food imported from surrounding areas. Expansion of irrigated farming resulting in further mining of groundwater resources depletes local water supply and results in salinity buildup. Loss of terraces can lead to the deterioration of sediment and water control to the point where downstream agricultural systems and communities are threatened. This is particularly true in the mountainous areas of Yemen.

Water Spreading

Water spreading, known as flood irrigation or spate irrigation, is the simplest type of water harvesting, where cultivated areas lie within and immediately adjacent to an ephemeral stream or wadi. In many areas of the Arabian Peninsula, direct use of flood water for irrigation or groundwater recharge is small compared to the amount of available surface runoff. Water spreading involves the use of small cultivated basins adjacent to the main wadi channel where flood water is diverted to meet crop water requirements. Excess water percolates into shallow groundwater alluvial aquifer. This method is used in Saudi Arabia, Yemen, Oman, and United Arab Emirates. In Qatar, water is collected in shallow depressions and injected into the underlying aquifers through wells. Flood irrigation is still being widely practiced in the downstream areas of major wadis in the southwestern region of Saudi Arabia, and in most regions of Yemen and Oman. Cultivation of flood plain is carried out through construction of small basins that are prepared ahead of the rainy season along the main wadi course. They may extend laterally for many kilometers as far as the flt terrain allows. Sources of water include either direct rainfall or flood water diversion. An example of the typical spreading system used in Yemen is shown in Fig. (37).

The main system of flood diversion is the construction of inexpensive earthen barrages, called weir terraces, built in succession across the wadi channel, or dike built into the tanque from the embankment. These structures raise flood water level within the channel, cusing it to collect in cultivated basins which are usually less than one meter high. They are generally constructed of sand and gravel. Diversion barrages are suited for narrow wadi channels in upstream catchments, while dikes are mainly used for wide wadi channels in the lower end of basins. Typical flood diversion irrigation structures are shown in Fig. (38). Depending on the magnitude and duration of flood flow, the upper basins fill first, followed by those located laterally adjacent to the wadi, according to established water allocation laws. Subsequent downstream basins are filled in progression of the stream flow, and water is distributed according to local customs. Barrages are frequently overlapped and in major floods they may be completely removed and the bed may be subject to scour. In extreme floods, diversion structures are usually breached, resulting in loss of irrigated area. Depending on the flood magnitude and duration, some of the diversion barriers and small dams may last throughout the flood season, or may require repair or replacement. Upstream structures are usually washed out or require repair due to high flow velocity and sediment load.

Diversion structures were originally built manually from local bank and bed material. Currently, bulldozers are used to construct the barriers. The embankment of the wadi is sometimes bolstered with rock walls. In some cases stonework intake structures are built. More recently, series of check dams have been used in conjunction with the diversion structures to increase agricultural area. This method is being used downstream of wadi Jizan dam in Saudi Arabia. Just upstream there is a check dam conveyance channel that runs parallel to the wadi channel and distributes the flow laterally into adjacent spreading basins. Cultivated basins serve as a spreading ground to enhance the infiltration process and aid in groundwater recharge. Most basins are usually characterized by soil of reasonably high hydraulic conductivity, fertility and holding capacity.

Artificial Recharge

Development activities in Qatar have resulted in mining of the groundwater is available from the regional Ras, Um Er Radhuma and

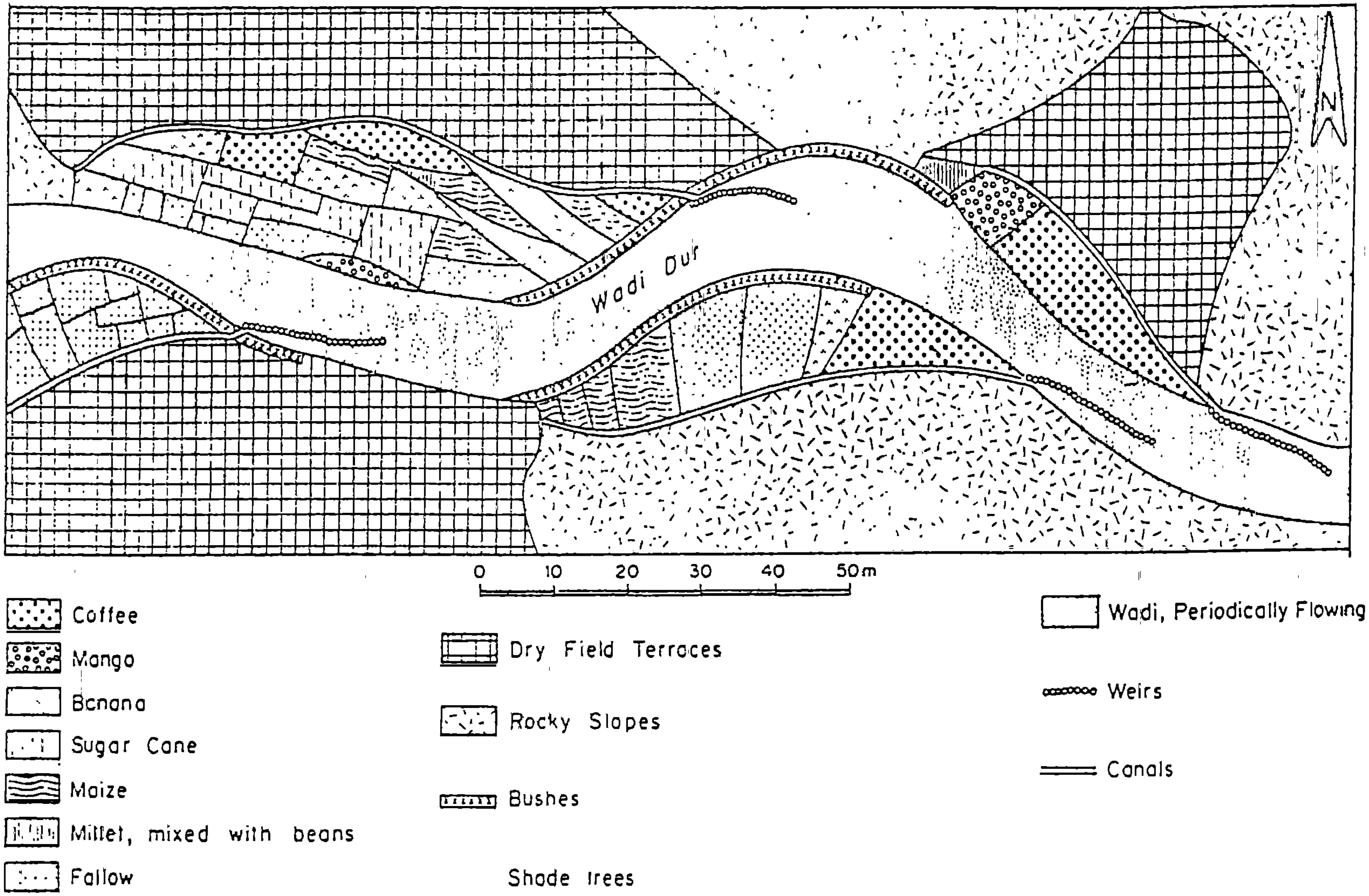
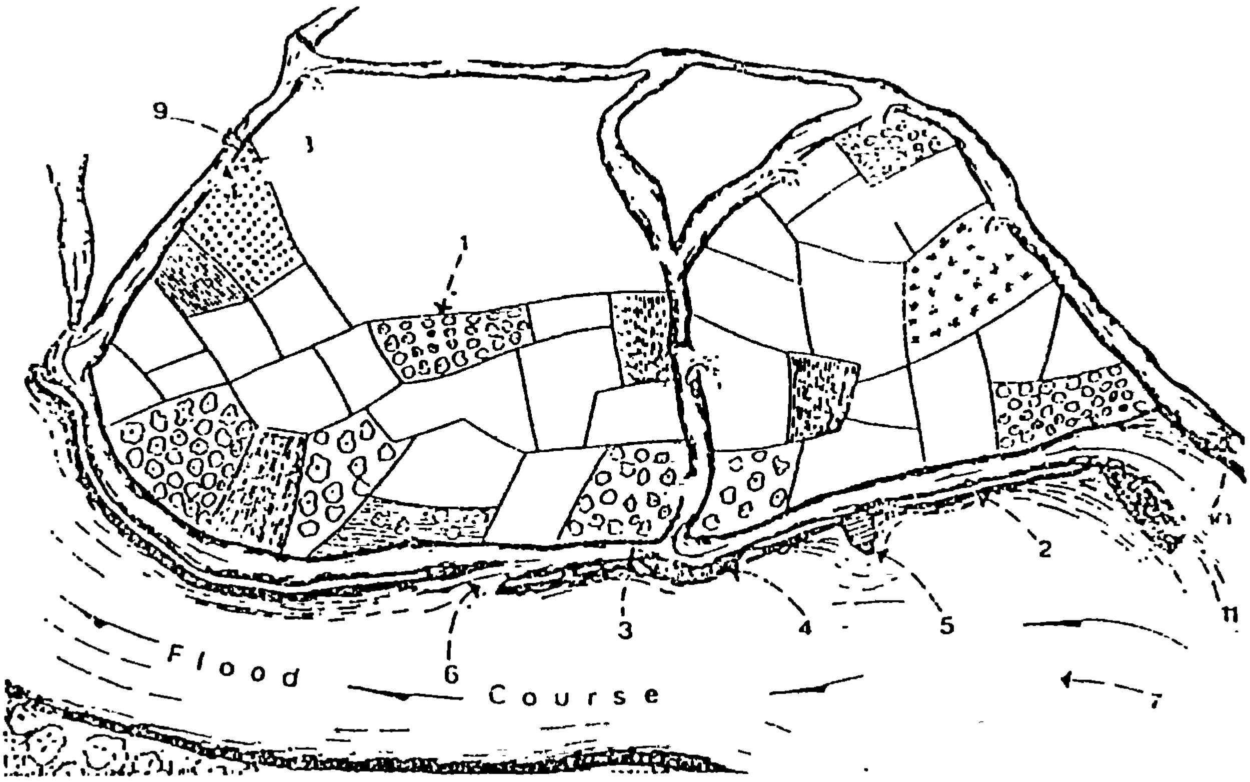
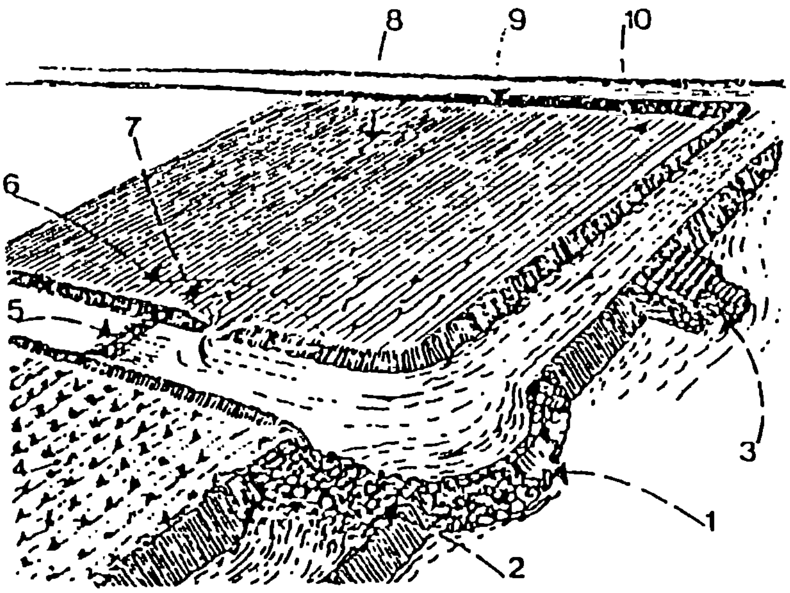


Figure (37) Example of spate irrigation system in Yemen



1 AL-SAWM
2- SĀID AL-UBER
3- MA'QAM
4- GABW / JABW
5- KALB OR MASRAF
6- MA'DBAL OR MANSAM
7- AL-SAILAB
8- FUQR
9- LUG'AB / LU'JAB
10- LIGĀM / LIJĀM
11- MA'QAM OR SUDD



1- GABW
2- MAQAM OR SUDD
3- KALB OR MASRAF
4 MARKAB
5- LIG'AB / LYJ'AB
6- SADR
7- FUQR
8- MIRWAN
9- AL- SAWM
10- AL- SHAGIB

Fig.(38) Spate irrigation diversion methods used in Yemen

Dammam aquifers as shown in Fig.(39). Expansion of agricultural activities base on groundwater resources has resulted in an alarming water table level decline, which in turn has caused groundwater mixing and salt water intrusion. Qatar has implemented a number of measures to manage its limited water resources. One of these methods is a groundwater recharging well scheme where runoff is collected in depressions and drainage basins and a large number of vertical recharging wells in these depressions facilitate the infiltration of thin water. Shallow depressions, where runoff is usually collected, were formed by subsurface collapse of geological structures as a result of extensive solution and removal of anhydrides and calcium carbonates. These depressions range in size from a few hundred meters up to three kilometers (Bazaraa, 1988). They are covered by colluvial soils made of calcius, sandy and sandy-clay loam.

Artificial groundwater recharge schemes have been implemented to augment natural recharge which is estimated at 42 mcm. Recharge results directly from rainfall and runoff, deep percolation of excess irrigation water and exchange with water from the deep Um Er-Radhuma aquifers. Pilot studies of artificial recharge schemes using harvested runoff have been implemented in the northern part of Qatar.

Artificial groundwater projects in Qatar were initially implemented in 1987 through the use of five recharge wells. The system was eventually expanded to include 140 wells. During the period 1977-1988, monitoring of groundwater levels indicated that recharge volume had increased by 30%. Water level fluctuations shown in Fig.(40) indicate the response of the wells to rainfall runoff events. Eight hundred new recharge wells are planned for construction starting in 1994.

Future Outlook

Availability of relatively abundant rainfall in the mountainous areas of Saudi Arabia, Yemen and Oman makes water harvesting possible through storage reservoirs, terracing, and flow diversion techniques. In addition, soil characteristics in the mountainous areas, where terracing is practiced, are much better than in the coastal plains, and more suitable for water conservation programs. Any diversion/storage structures should be simply designed which does not require heavy construction machinery. Past experience suggests that storage facilities such as small size dams provide an effective means of managing rainfall water, especially in areas with high runoff coefficients. These small dams provide flood protection and groundwater recharge if properly maintained and efficiently operated. It is an expensive option qu to high cost of construction in mountainous

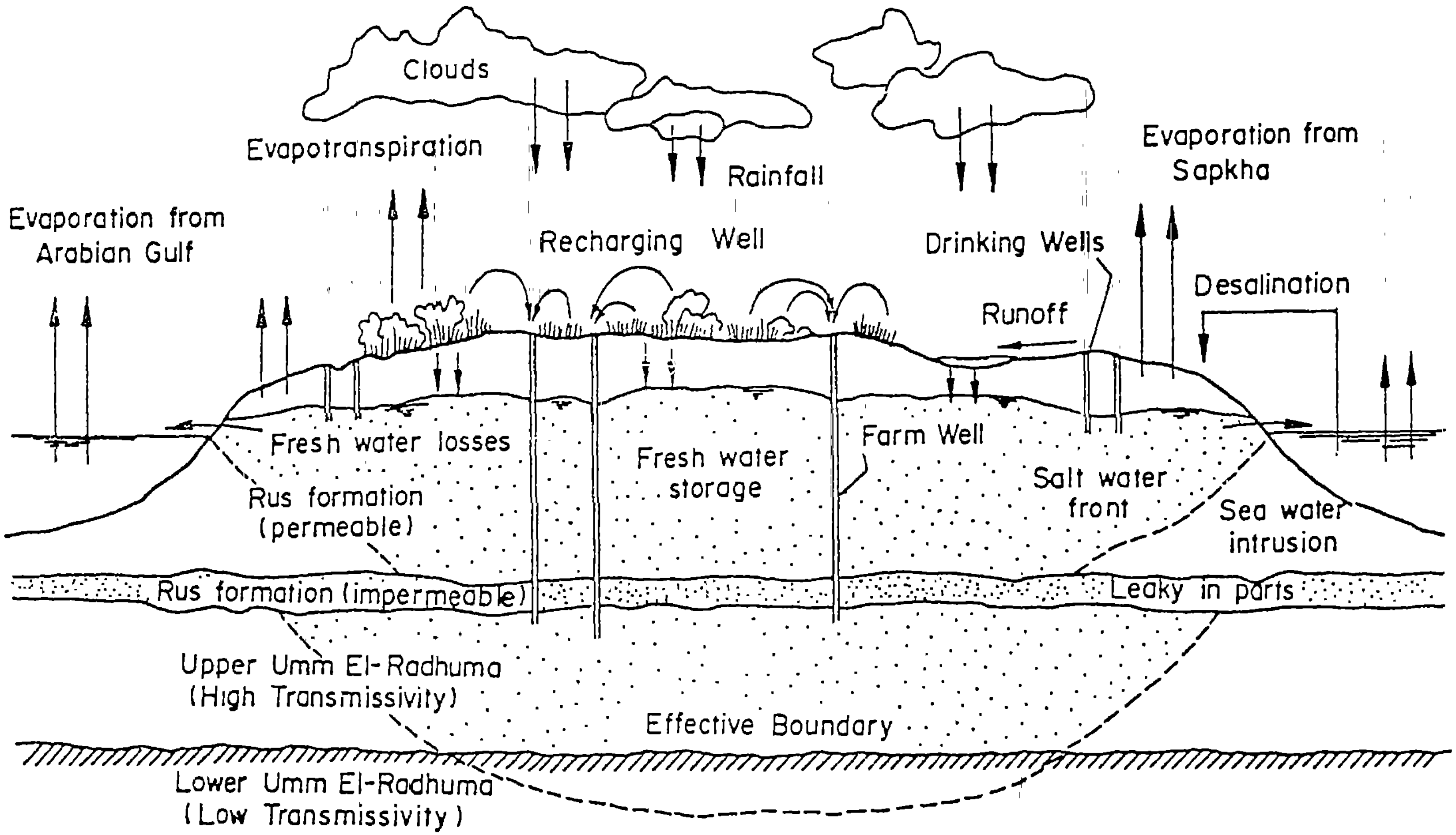


Figure (39) Schematic diagram of hydrological cycle in Qatar

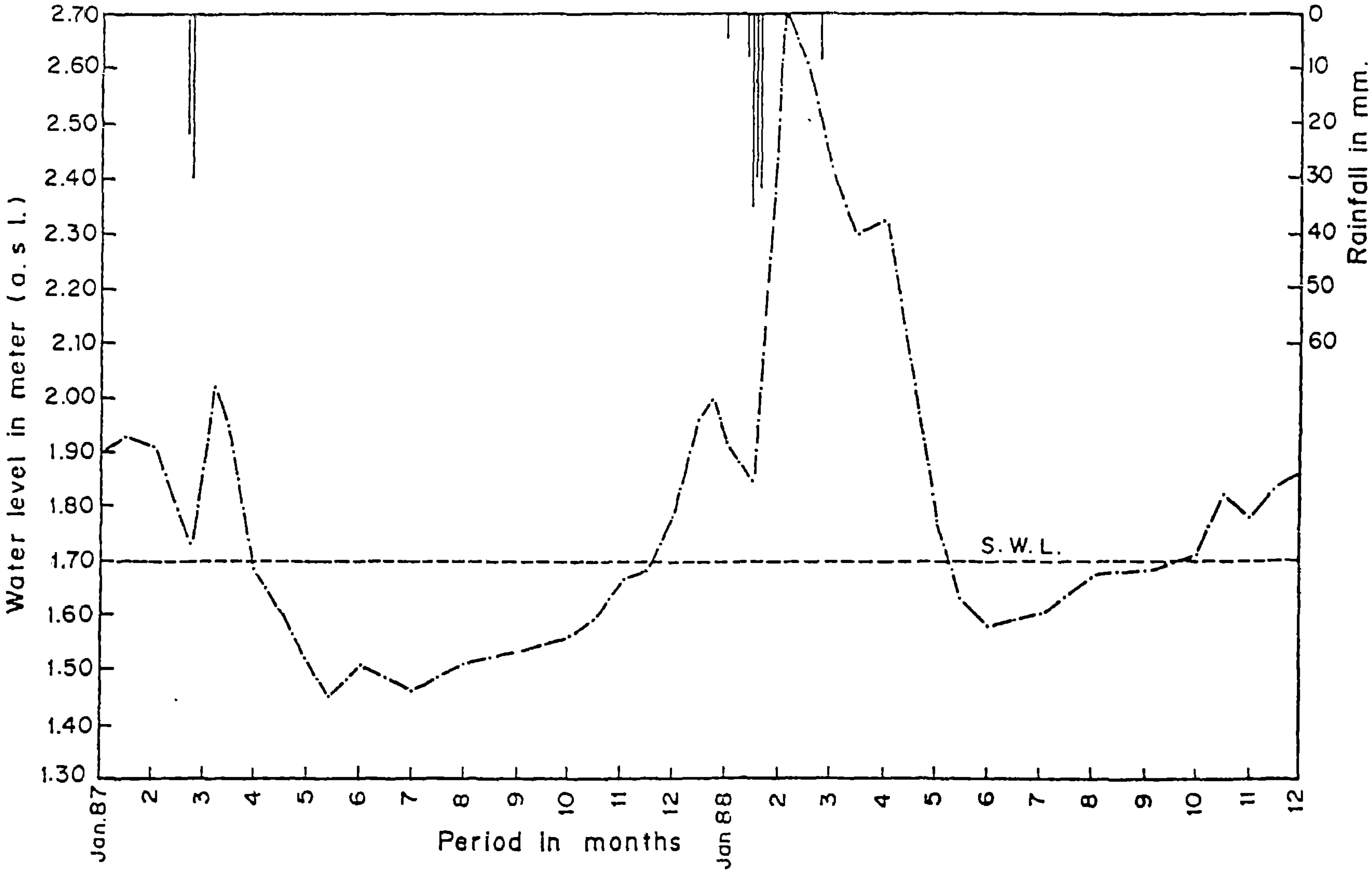


Figure (40) Well response to artificial recharge operations in Qatar regions, however a combination of storage facilities and terracing could provide efficient use of runoff and possibly extend the growing season.

Increases in groundwater recharge volumes from surface runoff, especially in Saudi Arabia, Yemen and Oman, can provide additional water to be used whenever needed. Large volume of surface runoff lost to the sea from coastal drainage basins and evaporation from inland drainage basins can be saved and utilized for recharge purposes. There is a need to increase efficiency of recharging dams that have been built in different regions of the peninsula through better dam operation and removal of silt and clay deposits. Increases of aquifer recharge from surface runoff and water imported from neighboring countries can provide strategic reserves of potable water. Building of such reserves presents a standby source that can be used under emergency conditions. Such schemes in the United States and elsewhere indicate that, with appropriate dam design and operation, the same volume of water stored could be recovered whenever needed. A series of recharge dams or injection recharging well fields can utilize excess generated runoff. Imported water can also be used to build a series of water reserves in certain locations through recharge dams, spreading basins or ingestion wells.

Another suggested approach is the construction of a series of small dams across the wadi channel to alleviate the problem of salutation and increase the magnitude of groundwater recharge. Theoretical analysis (Sorman et al, 1990) suggests that a series of inflatable-dellatable rubber dams with heights ranging from two to three meters, be used as storage reservoirs, allowing more retention time and longer contact area thereby enhancing the infiltration-recharge processes. These rubber dams can help solve the salutation problems associated with traditional dams because they can be lowered during the initial flooding stage to allow silt deposited during a previous flood to pass. In addition, sediments carried as part of the bed load can be washed downstream with flood waters. Dams can then be inflated during the remaining period of hydrograph time base. Dams can be inflated using either air or water. They are popular in the United States and the Far East as they are easy to operate and require only minimal maintenance. Infiltration-recharge equations (Abdulrazzak and Morel-Seytoux, 1993 Morel-Seytoux et al., 1988) can be used to estimate increases in recharge rates resulting from the use of rubber dams. Analyses indicated (Sorman et al, 1990) that natural recharge can be enhanced by at least 35%, however pilot studies are needed to confirm these preliminary findings.

Future water management strategies call for an inventory of the existing terracing systems and their function in relation to hydrological characteristics in Arabian peninsula countries. Detailed technical evaluation of water storage and movement through the terracing system is needed to determine whether rehabilitation of existing terraces or reconstruction of deteriorated steps would be beneficial in enhancing water harvesting schemes. If so, appropriate maintenance procedures and agricultural practices that support efficient water use within the terrace systems should be developed and implemented. In addition, special attention should be given to the social and institutional aspects of the terrace systems and their possible economic contribution.

The socio-economic aspects of terrace agriculture should be considered in terms of capital investment, labor migration, personal income, human settlement, land tenure and environmental preservation. All elements should be used to develop quantitative models for terrace function and stability.

There is a need for detailed evaluation of the hydrological functions of terraces in relation to their stability and utilization. Runoff and soil moisture potential, infiltration rate, drainage, sediment accumulation and erosion of terraces all need to be examined. It is essential to understand the dynamics of water movement in relation to rainfall frequency, crop type and salt accumulation. In addition, it is important to determine whether upstream terracing or downstream water storage and spate irrigation, or a combination of the two, is most suitable to enhance water harvesting in a particular area.

Research efforts on rainfall-runoff water harvesting over the last decade have been focused on understanding and improving traditional systems as well as teting different types of materials having the potential to increase the runoff coefficient. Most water harvesting activities have dealt with catchment shaping, surface treatment and storage of water. Feasibility of these techniques depend on rainfall regime, construction costs and topography. They are usually suited for providing water for livestock, rural communities and development of small farms. Some of these techniques may further enhance the efficient utilization of rainfall and runoff water in certain areas of the peninsula.

Microcatchment shaping consists of constructing small semi-circular, triangular or square basins on steep slopes or in complex terrain. The basins size range from 16 to 1000 m2. The basins are constructed in long rows along the contour lines. Basins on each level are staggered in such a manner that those on the lower tiers can easily collect the overflow from the higher tiers. Semi circular catchments with radii ranging from four to 12 meters are used for improvement of grazing, while triangular and square basins are used for planting trees (Finkel, 1986). Microcatchments may be used in areas with rainfall averages between 150 and 200 mm. These basins are inexpensive to construct and maintain. Disadvantages include evaporation loss and low yield per unit due to low tree density.

Microcatchment techniques can be used in the lower elevations of southwestern Saudi Arabia and Yemen for fruit tree orchards and drought resistant plants, where rainfall amounts exceed 200 mm. They can also be used to replace destroyed terraces or those that require extensive reconstruction. Extensive areas of microcatchments can be established near the wadi foothills and irrigated by diverted flood flow and aflaj, in Yemen and Oman, respectively. Tree crops grown in the catchments will contribute towards better income compared to other crops. The feasibility of using microcatchments should be investigated through pilot studies in areas with seasonal rainfall in adequate amounts.

Surface treatment techniques are usually used to increase runoff efficiency of small watersheds. The methodology consists of various soil treatments or coverings to achieve greater efficiency. The techniques include vegetation removal, soil compassion and chemical surface treatments consisting of applications of paraffin wax, silicon, sodium salt, asphalt and oil. These methods can be used for small acatchments in mountains areas of the peninsula. Treatments are sometimes expensive to apply and may have adverse environmental effects. They provide only limited additional amounts of water for small farms and livestock.

Surface covering techniques consist of gravel cover, plastic sheeting, rubber sheeting, metal sheeting and asphalt roofing (Speece and Cook, 1981). Gravel cover and plastic sheeting seem to be the most successful and cost-effective. The limited amount of water resulting from use of these techniques could be used for livestock and very small mountainous villages in Saudi Arabia, Yemen and Oman.

Construction of small dams for storage purposes is another method of improving rainfall harvesting. Current dam programs should be continued with emphasis on <u>minimizing</u> reservoir surface area to reduce evaporation, and implementation of efficient operation and maintenance procedures. Evaporation can be kept to a minimum by using floating reflective covers on reservoirs with small surface areas, and increasing water depth. Dam site selection criteria should stress construction in locations with large depths and small surface areas, as well as availability of farm area. Cost-benefit analyses and environmental impact investigations should be a major component of all dam studies. Underground dams can also provide an effective means of water conservation.

It would be prudent if several catchments were selected as water harvesting pilot study areas. Based on the results from small study areas it could be determined if large scale water harvesting programs would be both feasible and practical in helping solve water shortage problems in these areas.

Another variable alternative for increasing rainfall amount is the modification of weather by cloud seeding. The potential benefits for some regions of Saudi Arabia, Yemen and Oman include frequent cultivation of terraces and spate irrigation basins, increased magnitude of groundwater recharge, additional water supply for rural communities, improvement in vegetative cover and hail suppression. The availability of additional runoff will encourage continuation of farming which in turn, will discourage urban migration and increase local incomes.

The presence of mountain ridges in the southwestern region of Saudi Arabia, Yemen and southern Oman, forces the moist air masses in these areas to lift up making weather modification a viable means of increasing the amount of rainfall. Recent cloud physics studies, including preliminary seeding trials in the Abha-Khamis Mushait area of southwestern Saudi Arabia, indicated that there is potential for increasing rainfall. Studies showed that air masses on the windy side of the mountains have a higher water content than on the inland side. A detailed study is planned for the area to evaluate the feasibility of a long tenn cloud seeding program.

The feasibility of weather modification programs in the mountainous areas of the peninsula should be given attention as a means of increasing rainfall amount. Social, economical and environmental aspects of such programs should also be considered.

7.2 The Central Region

The central region includes Egypt, Sudan, Djibouti and Somalia. It can be divided into two distinct sub-regions, separated by the Ethiopian plateau. The first encompasses Egypt and Sudan in the Nile valley and the second includes Djibuti and Somalia. The Ethiopian Plateau constitutes the main source of water for the two sub-regions through the Blue Nile and other Nile tributaries which flow northwestwards into Sudan and Shebelli and Juba rivers which flow southeastwards into Somalia. The Western and Nubian deserts separate the Mediterranean climate zone characterized by winter precipitation from the Sahelian zone characterized by summer rainfall. Precipitation, however, in the Mediterranean zone decreases, sharply southwards. In the northern coast, therefore rainfall falls at a distance of 12 Km. from the sea to about 60 % of the average at the sea shore (El-Gindy and El-Araby, 1993). In contrast to this narrow semi-arid belt rainfall in Sudan estimated at about 1000 BCM, extends northwards for a distance of about 1800 Km. It decreases from 1800 mm/yr in extreme south to 200 mm/yr in the Khartoum area. The climate of Djibouti and Somalia is semi-arid grading northwards into arid, thus in Mogadishu area annual rainfall ranges from 400 to 500 mm. It increases southwards to about 700 mm and decreases northwards to 100-300 (in Djibouti and northern Somalia).

In the past few decades, a vast area in northern Sudan and Somalia was affected by desertification as a result of the combined impacts of human activities and recurring droughts. A variety of rainfall management techniques have been applied among other measures to combat desertification and control land degradation. Some of these techniques together with improved traditional practices have had positive impacts and, therefore are considered effective means for conservation of natural resources and rehabilitation of degraded lands in areas. These techniques will be described next in some details.

Sudan

Construction of hafirs has started in the Sudan in 1946 by the Soil Conservation Section. The aim of such hafirs was to provide water in order to develop the lands for agriculture, pasture, and forestry.

The hafir is by definition (from the Arabic hufra) a small depression where water accumulates during the wet season. The volume of water thus stored is used for domestic purposes or to water the animals. The conventional hafirs are usually excavated in areas where soil conditions are favourable, being sufficiently impervious to cut down the seepage losses to minimum. Hafirs usually have the shape of an inverted frustum of a pyramid whose base is rectangular in section for practical purposes. However, other shapes are being also adopted such as semi-circular, circular, or square.

Hafirs are excavated in different capacities varying from 5,000-150,000 M3. Twin hafirs have been adopted for large capacities to facilitate cleaning and desilting during rectification, and to reduce the area exposed for evaporation by means of pumping from one hafir to the other as water level drops. A silt trap is installed at the inlet to reduce the amount of silt entering the hafir. Water usually enters the hafir through a single or multiple inlet pipeline of asbestos, concrete, or steel. It is drawn through another pipeline located at the opposite side which ends at a closed concrete or masonary well fitted with a simple hand pump feeding the distributing troughs from which water is drawn free of charge. In big water points (over 50,000 M3 capacity) near large settlements, small purification plants are constructed. Generally speaking, due attention is paid to provide water of sufficient quantity at low cost.

The selection of a hafir site is usually governed by the suitability of the site topographically, and geologically as well as by the water potentiality of the feeding source. Needs and land capabilities having been decided, the capacity of hafir is based on water availability at the site. This can be assessed by estimating surface flow of the feeding source or by adopting an adequate runoff coefficient. In both cases hydrological data concerning the duration and frequencies of floods are necessary. Where water supply is adequate, the main deciding factor for the capacity of a hafir is the water demands.

Hafirs vary in type according to the nature of catchment which may be classified as follows;

1. **Khor Catchment:** In this type, the hafir is fed from a natural water course. Water is conveyed to the hafir either by an excavated canal or by daming the water course to raise its water level. In the latter case, spillway has to be carefully designed to avoid any damage that might result due to under estimation of the maximum discharge of the water course.

2. **Jebel Catchment:** The hafir in this type is fed by direct surface runoff from small hills and plinths, where no reliable water course exists at the site. The concept of such type is based on the fact that surface runoff in hills and plinths is considerably higher, and losses are relatively small. Water is collected through a drain canal or system of canals which in turn deliver water to a collecting canal ending at the hafir. Silting problems are more noticeable in such types of catchments which call for frequent desilting. However, it is still considered one of the best and most efficient methods to provide water where there are hills in rural areas. Topographic conditions may call for construction of drops to reduce the steepness of canals or to provide spillway to take care of any excess flow as to runoff coefficient is based on experience.

3. **Self Catchment Hafir;** In this type, the catchment is either from natural depression where water accumulates during the wet season or from areas with mild slopes, which calls for an artificial drainage system.

Provision of water in sandy areas where conventional hafirs are difficult to make takes a different shape. Storing rain water in tebeldi trees (Baobab) is one method. These trees of 1.0 - 3.0 m diameter are hollowed and filled with water annually during rains. A tree can store 3.0-10 M3 of water. These methods are temporary, however; and do not provide drinking water for the whole year.

The United Nation Special Fund Project in Northern Kordofan Province investigated the drinking water problem in the crisis area. According to their recommendation, wells, boreholes, hafirs and large reservoirs will in many places provide the best solution where natural conditions are favourable. But beyond the limits of these solutions, small polyethelene village tank with its own small catchment is used to collect and store the rain water.

Egypt

In the Nile Delta and Nile Valley of Egypt conventional irrigation delivers the entire plant-water needs because rainfall is very scarce. In remote areas along the Mediterranean sea coast and in Sinai peninsula some supplemental irrigation activities have been practiced at intermittent periods depending on limited seasonal rainfall. In this section a brief review of ancient and recent water harvesting techniques is presented.

a. Sinai Peninsula

The watershed of wadi El-Arish in North Sinai has an areal extent of about 21,000 Km2 with average annual rainfall intensity of 75 mm. Flash floods occur after heavy rainfall for short time duration. Earth dams are constructed across streams for flood control and groundwater recharge. The strip of land extended between El-Arish and Rafah cities have an average rainfall exceeding 100 mm/year. Although such amount of water is not sufficient for agro-production, it is considered the main source of water for fruit trees. During dry seasons groundwater stored in the neighboring sand dunes is abstracted for supplementary irrigation. Seepage pits which are cut-off trench-like basins are dug out in the sand dunes across the seepage flow to the sea, locally known as Al-Mawassi. Pits are excavated in the sand to a depth of 1.5-2.0 m till it hits the fresh groundwater body floating over the intruded sea water wedge at the coastal zone.

Fresh water then accumulates slowly inside the pit by seepage. the collected water is pumped out at low rates to avoid salt water upconing. This water is used for supplemental irrigation by lifting into an elevated tank directly feeding a drip irrigation network or to be stored until transferred to a nearby farm by mobile tanks.

Another technique adopted for water harvesting in Sinai is known as al-Harrabat (Escapes). A limited number of these escapes are spread over different locations of Sinai. They could be considered as artificially constructed micro-catchments with surface area ranging between few and hundreds of square meters. The surface area of the catchment is lined with smooth plain concrete having an appropriate slope towards a covered underground reservoir. The rainfall is collected inside the reservoir and stored for future use. Small escapes 50 m3 capacity are found in Kontella, Temed, Ras Al-Nakab and other places, while the largest one is 650 m3 capacity at Al-Joabany.

Severe flash floods occur in southern Sinai because of the steep slopes of the watersheds. some sort of terracing techniques is practiced by constructing small earth dams 50-75 cm high across wide reaches of the stream. Water of flash floods is partly retained upstream the dam along with the suspended sediments and bed load. Saturated terrace-shaped areas are formed after floods which are usually suitable for water melon farming.

b. The Mediterranean Sea Coast

Small amounts of rainfall annually recharge the permeable sand dunes along the Mediterranean sea coast. At El-Qasr area and at other parts along the coast, sand dunes have been developed for water harvesting using collecting galleries. Manholes or vertical shafts are dug at 25-30 meter intervals to a depth of about 1 meter below the water table. The shafts are connected by underground tunnels, which are about 1 meter wide and 2 meters high and extend 0.5 to 1 meter blow the water table .

Normally the galleries are constructed perpendicular to the direction of groundwater flow to increase the amount of water intercepted per meter of gallery length. Some of the galleries, however, meander around the dunes without planned alignment. Pumping stations are installed along a gallery in selected manholes.

The coastal dunes in El-Qasr area were first exploited as a source of water supply by the Romans about 2.000 years ago but, with the departure of the Romans, the dunes were neglected as a source of water. In 1931 a section of an old Roman gallery collapsed. Subsequent exploration revealed the alignment of the ancient gallery and reclamation began in 1932. By 1936 the "Old Roman Gellery" had been cleaned and restored for a length of 2260 m. During World War II, 1600 m of the gallery were open, but in recent years further galleries has occurred.

A second gallery, designated by the Egyptians as the "New Roman Gellery" to distinguish it from the "Old Roman Gellery" was discovered in the late 1930's and was used regularly during World War II. A new 1200 m Roman gallery was opened in 1935. The gallery is presently known as the Roman Gallery. In 1966 its total length was a little more than 1000 m. In 1966 the gallery was pumped about five hours daily in winter and 10-12 hours daily in summer.

The government constructed another gallery with original length of 950 m, but during World War II the British army prolonged it to 2250 m. The gallery suffered from the war and was completely collapsed in 1951. Collecting galleries are still in use for water harvesting. It is estimated that the water pumpage amounts to about 35 m3 of water per meter length of gallery per year.

On the other hand, there are many wells equipped with cylinder pumps powered by wind mills in service in the interdunal plain for water harvesting scattered near the southern edge of the coastal dunes. The wells are generally 1 to 1.5 m in diameter and are cased or lined with stone or reinforced concrete rings through the loose unconsolidated material overlying the bedrock. Many of the wells have one or more openings in the casing at ground level to allow surface-water runoff to enter the wells. The openings, in effect, make the well a recharge well during periods of runoff; however, they also contribute to the rapid filling of the well with sediment.

The wells are commonly less than 10 m deep with water levels generally less than 5 m below the surface. Some wells have horizontal shafts driven from the central, vertical opening to increase the infiltration area and storage reservoir, in effect, making them small collecting galleries.

Water is lifted from some wells by a bucket and a rope. They are sometimes lined with stone for a short distance below the surface but are often only a dug hole having a diameter tapering from 3 to 4 m at the top to a meter or less at the water table.

The estimated pumpage is 0.5 - 5.0 m3/day and 2.0 m3/day for wells with windmills and buckets, respectively.

7.3 Western Region

The western part of the Arab World comprises Libya, Tunisia, Algeria, Morocco and Mauritania and can be divided into two main geographic provinces; the Atlas mountains province and the Saharan province. The climate of the western region is subject to Mediterranean influence in the north and northeast, Atlantic influence in the west and north west, and continental-Saharan influences towards the south. The southern part of Mauritania is however, subject to inter tropical influences and is marked by a wet summer. Precipitation falls from June to October.

The Maghreb climate is characterized, as in the case in the entire Arab region, by high rainfall variability which results in a variable hydrologic regime at the annual and inter-annual level.

Mean annual precipitation ranges from 1500 to 2000 mm in the high Atlas mountains. It decreases gradually southwards to about 100 mm in the pre-Saharan zone. An extensive semi-arid zone encompasses the high plateaus, the Saharan Atlas and the foothill zone. Precipitation in the central Sahara approaches zero. Mauritania experiences a different precipitation region. Average annual precipitation along the Senegal River is about 600 m. It decreases northeastward rather sharply to 200 mm. The greater part of the country receives less than 100 mm.

Availability of water resources in the Maghreb countries is shown in Table (10) (Jellai and Jebali, 1993). A comparison of the per capita availability in 1990 and 2025 reveals an impending, chronic water shortages in the region. The uneven distribution of renewable water resources has already created serious problems with regard to rural and urban water supplies. The Mediterranean and Atlantic coastal catchments which represent 12% of the total area of the region produce about 80% of the renewable water resources (Jellali and Jebali, 1993). The remaining part occurs in vast semi-arid region which includes parts of the Anti Atlas, the Saharan Atlas, the high plateaus, the foothills and the Mediterranean coastal zones in Tunisia and Libya. The Sahara is underlain by large groundwater basins which contain huge reserves of non-renewable water resources. Mauritania has a single water source, the Senegal river, which is shared with Guinea, Mali and Senegal.

Several traditional water systems have been developed in the past in the Maghreb region. These include canats (Khettaras) in the Sahara,

Countries (1)	Population (10⁶ inhab)		Total Precipitation (10⁹ m³) (4)	Total flow (10⁹ m³)			Ratio (10³ m³/inhab)	
	1990 (2)	2025 (3)		Surface water (5)	Ground water (6)	Total (7)	1990 (8)	2025 (9)
MAURITANIA	2.02	5.12	-	7.00	0.40	7.40	3.66	1.44
MOROCCO	25.06	45.65	150	22.50	7.50	30.00	1.19	0.65
ALGERIA	24.96	51.95	65	12.40	6.70	19.00	0.76	0.36
TUNISIA	8.18	13.53	33	2.70	1.80	4.50	0.55	0.36
LIBYA	4.55	12.84	-	0.20	3.53	3.83	0.84	0.30

Table(10): Water resources in the Maghreb countries cisterns in Morocco and Libya, Jessours in south Tunisia and spate irrigation systems in the semi-arid mountain and foothill zones of Morocco, Algeria and Tunisia.

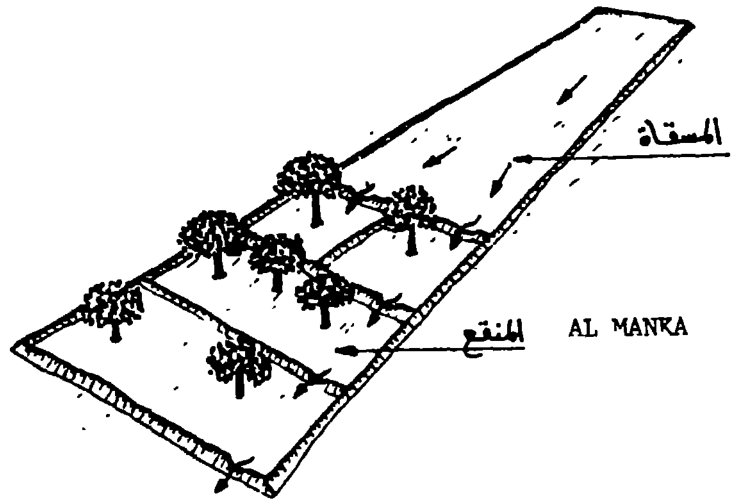
Modern hydraulic structures were first introduced during the 1920s. During the 1960s the tendency has been to develop large dams for irrigation purposes. Massive water resources development efforts were employed during the droughts of the 1980s. The present approach is to give more attention to small hydraulic structures, water harvesting techniques and artificial recharge.

Assessment of traditional water systems reveals that several techniques are compatible with the hydrologic regime of dry environment, and being well adapted to socio-economic conditions of the region. They could play an important role in several parts of the region, particularly in populated areas where stream flow is ephemeral and groundwater is unfit for human and agricultural uses.

The main traditional water systems in the region comprise the "Meskats", "Jessours" and the "Mgouds". These systems exist in the majority of the Arab Maghreb countries, especially in northwest Libya, Morocco and Tunisia. In Tunisia, the Meskat systems irrigate 300,000 ha and the Jessours cover some 400,000 ha (Tobbi, 1993).

The Miskat System is one of the ancient methods employed in harvesting rainwater that dates back to prehistoric times. They are used in the Arab Maghreb specially in Tunisia, Morocoo and the north west of Libya in Nafousa mountain. At present, the state of these Miskats have been deteriorated because of the intensive agricultural development that took place since the middle of the century. The Miskat (Fig. 41) is simply a piece of flat land with a mild slope (3 to 6%) with few or no drainage channels. The land is prepared for rain water harvesting and then water is directed to another piece of land of half its area and located directly below; which is called the collector where crops are planted. Fruit trees such as olives, figs, stone trees and agronomic crops are planted. The surface area of the Miskat ranges between 1.5 and 5.0 hectares.

The Miskat secures water deficit resulting from the difference between water consumptive use of the crop in the basin (Manka') and the available annual rainfall. The deficit is covered by harvesting water during the period of rainfall occurring over an area called Miskat. This water is later diverted to the basins where it is stored in the soil and used by the



MISKAT AND ITS COMPONENTS

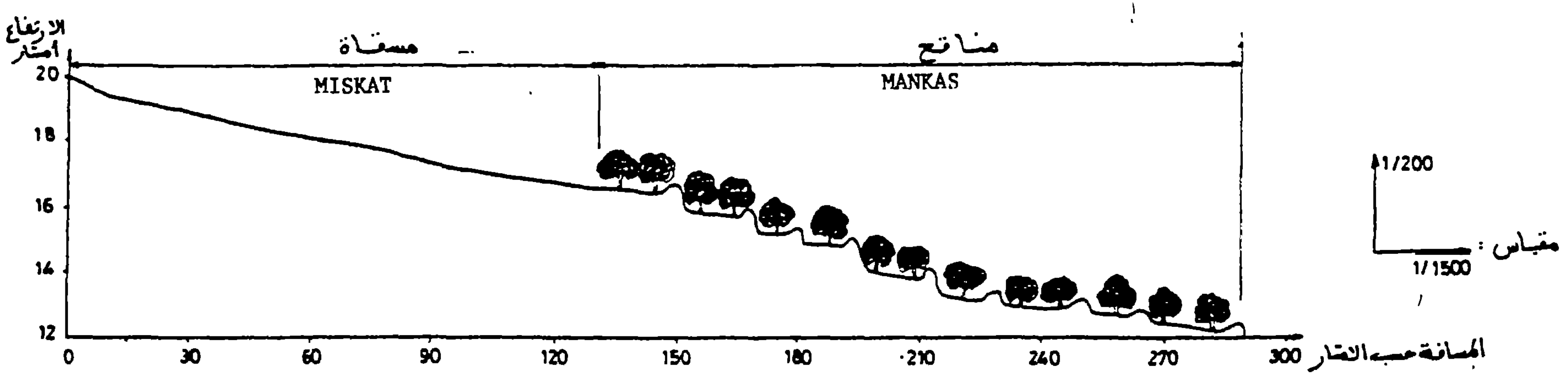


Fig.(41)- Longitudinal Section (a)-(b) in a Miskat in Ji'dan Basin in Shat Mariam (Tunisia).

Source: ACSAD-UNESCO/ROSTAS, 1986

trees and legumes. The ratio of areas between the Miskat and Manka' (K) is expressed as follows (ACSAD-UNESCO,1986);

$$K = \frac{N - T}{S \times T}$$

where:

K	=	the ratio of the Miskat area to the Manka' area.
T	=	the average annual rainfall in mm.
N	=	the crop water consumptive use = evaporation + transpiration in mm.
S	=	Surface flow coefficient.

From a study conducted in Shat Mariam coastal of region in Tunisia, it was found that K = 1.9, i.e. the area of the Miskat is almost twice that of the Manka'. This value is inversely proportional to the surface flow coefficient.

The economic returns of Miskat are appropriate. This fact is specially true when care is given to the system to protect it against failure or reduction of the Miskat area if more land is planted.

The **Miskat** plays an important role in balancing the environment and limiting soil erosion, consequently protecting planted areas in the coastal and low plains against flood damages.

The **Mgoud** is a water spreading technique that involves the diversion of a part of wadi flow for spate irrigation. The structures used consist of earthen bands 8-1 M high and about 1 m wide, while their length may reach 500 m.

The **Jessours** are traditional works well suited to the climate of south Tunisia. They are constructed usually in the upper reaches of wadi systems. They date back to times of the Greeks and Romans when such systems flourished and were employed in the hilly or mountainous terrain bordering the Mediterranean.

In Morocco surface water constitutes the principal component of the country's water resources estimated at 30 BCM/yr. Of this amount 20 BCM/yr is surface runoff, whereas some 10 BCM/yr infiltrates into underground or is shared temporality in the soil. Usable resources are estimated as 16 BCM of surface runoff and 6 BCM of groundwater. About 7.5 BCM of surface and 3.5 BCM of groundwater are currently used (Tayaa and Bazza, 1993). 34 large dams and 35 small dams have been constructed in the past decades.

Although the cost of development of remaining water resources is high, efforts are being made to develop these resources since they constitute about 50% of the total potential. Future plans include construction of large and small dams and development of water harvesting practices.

Water harvesting works constitute the principal hydraulic structures in the southern and eastern parts of the Atlas mountain range and they are constructed for agricultural and domestic purposes. Water is drawn from the hydrologic cycle at various locations. Storage devices include cisterns, detention basins and storage ponds. Shallow groundwater fed by interflow is harvested by canat systems (Khettaras) or sub-surface dams. "Matfias" are reservoirs dug in the soil or limestone and lined with impervious material such as a mixture of sand and quick lime. Shape and dimension are generally dependent on the lithology of terrain and construction procedures. Catchments are usually several hectares. Their ground surface is not altered or treated but commonly small earth ditches are managed to concentrate and direct runoff into the storage tank. During severe drought of the 1980s more attention was given to development of Matfias and to rainwater management practices to alleviate water supply shortages in rural areas. By 1990 the number of Matfias was estimated at 360 000. About 1.400.000 inhabitants, still use Matfias for their water supplies (Tayaa and Bazza, 1993).

R'dirs is an open rainwater storage pond used mainly for animal watering. Spate irrigation is common in arid areas, especially in the south and southeast of Morocco, where several wadis originate the Atlas mountain flow into the desert forehand. Development of their seasonal flow takes place in the piedmont zone at the foot of mountain system. Three types of floodwater harvesting systems can be recognized;

a. **Lateral diversion;** a system usually used in streams with relatively steep slopes. Diversion of parts of flood water from ephemeral wadis takes place through several off-takes.

b. **Earth Dyke diversion;** used generally in wadis with relatively low gradient. The dikes are constructed with gravel and sands excavated from wadi beds.

c. **Small retention dams;** used usually in the Saharan zone. They consist of low earth or loose rock dams, designed to store flood water for crop cultivation, in river bed upstream and for groundwater recharge. They are practiced in wide wadis with low gradient.

In 1984 Morocco embarked on a major program to construct small scale dams-reservoirs (Barrage collinaire), and to develop surface runoff in wadi systems, for irrigation animal watering groundwater recharge, and water supply purposes. The program also includes the construction of several types of terraces in sloping lands, for soil and water conservation. These included contour earth terraces, and infiltration ditches. Terraces have been designed to catch and hold the runoff they receive or let it overflow without destructing the structure.

8. NATIONAL PLANS AND STRATEGIES

Planning

Management of water resources entails the development and implemention of long-term water plans. The water plans should be comprehensive and flexible in order to accommodate social and economic changes, and to promote the allocation of water on a competitive basis.

The objectives of agricultural policies should be carefully defined since this sector is responsible for the majority of water consumption. Conservation programs which include water harvesting should be a major component in any comprehensive water management plan.

Development of water resources in wadi systems could be planned at the national or basin level. At the national level major hydrologic zones could be defined on the basis of technical criteria such as topography (mainly slope), geomorphology, soils and rainfall. The selection of an appropriate water harvesting technique, or a package of water conservation and water harvesting techniques, is tributary to physical and socio-economic layout.

Distribution of traditional water harvesting techniques in Tunisia demonstrates such concept. A similar approach could certainly be applied for the design of a national plan for extensive use of modern techniques. Appropriate techniques could be improved traditional techniques or modern techniques which have been tested and proved to be a viable technique under given natural and socio-economic conditions.

Greater effort and investment have been directed in the past to construction of large and small dams, whereas little attention has been given to development of water harvesting systems. There is even a lack of information about the status of existing traditional water systems. Assessment of such practices is required . The assessment completed and published in 1986 could be complemented and supplemented by in depth studies of selected promosing techniques. There is, however, a growing awareness and recognition of the importance of rainfall water management systems, and of the need to expand the use of these systems.

Many of arid and semi-arid areas in the Arab region are experiencing shortages of water. Under earlier historic conditions and population size. The limited water resources could meet the needs of the population in these regions. The rapid growth of population and socio-economic development seems to be overwhelming the technological capability to supply it, and furthermore the cost of supplying water to water-short areas is increasing. Under such conditions water harvesting could alleviate existing and potential water supply problems in the region. A major area of need is, however, the integration of rainfall water management programmes in the national as well as the regional water resources development most plans.

Selection of Site and System

Some of the systems constructed in various parts of the world have been outstanding success whereas others were complete failures. In drought-affected areas few projects succeeded in combining technical efficiency with low cost and acceptability to farmers. Both technical aspects of water harvesting and the socio-economic aspects should be taken into account for identifying potential areas and selecting the appropriate technique. Each site and water use are unique and each system must be fitted to local conditions and needs.

Any water harvesting system can be developed and cultivated as a single family enterprise or as a large communal undertaking. For small scale water harvesting systems, individual basis is often the most successful approach. Microcatchment design is easily installed and manipulated on a family scale. For a communal water harvesting project to be viable local users must posses a high degree of commitment to the project. Such commitment is usually represented or demonstrated in the form of labour. When water harvesting schemes are planned, other alternatives must be considered and compared with water harvesting in cost and risk. The comparison must take into account initial costs in addition to costs of operation and maintenance and operation. For agricultural water harvesting costs must include also seed, tillage and fertilizer items (Fraiser, 1993).

The basic technical selection criteria for water harvesting techniques comprise climate, topography, vegetation and agricultural practices. The ground surface slope is a limiting factor. Soils should not be saline or sodic and need to be deep and posses inherit fertility.

Understanding the social aspects of a local community is important in designing the appropriate system. There is strong inter- connection between the physical system and social structure of the users. Beneficiaries should participate in all stages of the project planning, implementation, maintenance and operation.

For an appropriate design of a water harvesting system it is recommended to determine the ratio between the catchment and the cultivated area. Estimation of this ratio could only result in an efficient and effective system if basic and reliable data are available. Crop water requirements should be assessed, and rainfall-runoff relationship need to be analyzed. Since rainfall is highly variable in semi-arid zones, it is necessary to modify the original design in the light of local experience (Crichley and Siegert, 1991). All possible available data should be collected and analyzed for the determination of relevant parameters. Certain data on hydrology, soils and vegetation could be obtained from satellite images. If such data are combined with digitized topographic maps and other relevant parameters, GIS becomes an important tool for analysis.

Data Management

The foundation for efficient water management strategies is the collection of reliable information on water resources, including availability, variability, rationality and quality. Both historical and real time data are required for various purposes ranging from assessment of surface and groundwater resources and monitoring, to flood and drought forecasting. The existing hydrological and meteorological networks must be expanded and updated in order to provide an adequate data base. An important focus is the expansion of groundwater monitoring systems which provide constant data on both the quantity and quality of groundwater reserves as well as pollution levels. Emphasis should also be placed on utilization of advanced hydrological and meteorological technology such as electronic sensors, electric data storage devices, telemetry, remote sensing, and geographical information systems. In addition, use of secure and appropriate computer facilities and models should be encouraged in order to enhance the quality of data processing as well as assisting information dissemination. Arrangements should be made for telemetry and data transmission through satellites or telephone lines which will insure timely and continuous data collection.

Training of Personnel

Training is an important phase of professional water resource development and management. Training programs should include on-the job training, seminars, workshops, refresher courses and degree programs. Emphasis should be placed on the formulation of efficient training programs for new recruits, and education for established professionals to keep them abreast of new developments, techniques, management procedures and technology. Existing educational programs in hydrology and water resources in Arab World should be utilized for training courses, workshops, degree programs and higher studies. There are many universities, particularly, that offer technical programs in hydrology and water resource management.

Institutional Arrangements

Weakness in institutional cooperation is one of the major constraints in the development and management of water resources. Optimal communications and cooperation can be achieved through comprehensive legislation which defines the responsiblities of each organization. Such legislation should include provisions for project coordination on a local, regional, national and international level. Mechanisms for the exchange and dissemination of information between responsible organizations both within and among countries, should be outlined and reinforced with up-to-date technical support.

Research and Development

Application of research results should be accomplished through coordination between researchers and governmental agencies. Governmental and private agencies dealing with water resources should be encouraged to make use of local expertise rather than depending on expensive foreign consultation. Dissemination of information and documentation, particularly when required by researchers, should be encouraged and supported by governmental agencies. This will contribute towards the development and support of local research facilities and aid them in strengthening their capabilities even further. In turn, such institutions will be able to provide knowledgeable staff, train students and provide adequate facilities for tackling difficult water resource problems which lay ahead.

Environmental Impact Assessment

Water development projects in general and water harvesting schemes in particular like any other type of resource development, have both positive and negative impacts. Both human activities and natural phenomena maight cause environmental deterioration, but it is usually human activities that contribute to the maximum damage. Environmental impact assessment methodologies can be used to identify adverse influences of human activities. These methodologies are equally applicable to new development actions as to improvement and modification of existing projects. As a planning tool, environmental impact assessment can assisst planners in anticipating future impacts of alternative development activities with the aim of selecting optimum alternative which minimize adverses effects on the environment. However, since most water resources development projects were implemented in the past decades without adequate environmental impact assessment, and little follow up was given in monitoring the effects of development works after their constructions, it is imperative that the impacts of these projects are montared. Lessons drawn from the past can be used to improve the planning and implementation of future projects.

9. CONCLUSIONS

1. Rainfall water management encompasses a wide variety of techniques which can be grouped into four categories;

   a. Precipitation enhancement
   b. Evaporation reduction
   c. Water harvesting
   d. Water conservation in soils.
   e. Artificial recharge of groundwater

   The latter two categories have a wide application in different climatic zones, for the conservation, preservation and protection of land and groundwater. The former three categories are of relevance to dry regions and together with water conservation and artificial recharge techniques form a package of remedial action to the highly vulnerable and drought prone Semi-arid regions.

2. Although there is a keen interest in precipitation enhancement in arid regions experience indicates that positive results may only be obtained in mountain ranges which receive high or moderate rainfall. Prospects of increasing precipitation in the semi-arid lowlands do not seem to be promising. The viability of this technique needs further research.

3. There is a growing recognition of the importance of water harvesting techniques for the development of arid and semi-arid lands. Several modern techniques have evolved from traditional techniques. However both improved traditional methods and new techniques need to be further developed, refined, and adapted to changing needs and socio-economic conditions.

   Due to their high cost, modern water harvesting techniques as means for the provision of water supplies should be compared with other alternative sources

4. Both technical and socio-economic aspects of rainwater harvesting systems should be taken into account for planning water harvesting projects. This entails a participatory, bottom-up approach.

5. Increasing water demand necessitates use of existing water resources efficiently while exploring new means of increasing the water supply through rainfall - runoff management. Emphasis in the past has

concentrated on the utilization of groundwater, especially in areas where rainfall and runoff are not utilized. This focus must now be shifted towards efficient management of rainfall and runoff.

6. Rehabilitation and maintenance of existing terracing systems, is a major need in the Arab region, especially in areas such as Yemen and west Bank where degradation of these systems is taking place. Detailed studies should be made to investigate the status of traditional terraces and to explore means for their rehabilitation and improvement. Artificial recharge schemes which utilize rainfall and runoff must be included in government programs as a mean of achieving efficient water management, and the importance of terracing and flood diversion techniques should be emphasized. Artifical recharge operations have been applied in alluvial aquifers as well as along outcrop areas of some deep aquifers to augment infiltration to underlying aquifers.

10. PRIORITY AREAS FOR FUTURE ACTION

A wide number of actions have been proposed to meet areas of greatest concern and to address common water problems, to be carried out by national water institution, regional and international organizations. Principal actions include;

- Development of data collection systems in wadis, in arid and semi-arid zones.

- Upgrading the knowledge base on the hydrology and hydrogeology of semi-arid zones.

- Establishment of a regional network with well selected focal points and focal persons perhaps related to national IHP committees.

- Establishing a clearing house on rainfall water management techniques including related climatic topographic and hydrological characteristics of catchments.

- Definition of appropriate wadi development concepts for various climatic topographical and other conditions.

- Exchange of information and know how on microcatchment water harvesting techniques among various sub-regions.

- Assessment of environmental impacts of planned rainfall water management schemes and monitoring of impacts of implemented projects.

- Preparation of a state-of-the-art report on current involvement on rainfall water management in the region and similar regions abroad.

- Evaluation of these methods and selection of promising ones for further investigation; development through pilot schemes in few selected locations in Arab States.

- Preparation of a series of monographs and handbooks outlining the methods of design of each of the selected technique and distribution of this information widely in the Arab region.

- Rainfall water management techniques; follow-up and evaluation of these methods.

- Evaluation of related traditional methods and study of feasibility of rehabilitating, adapting, improving or designing systems based on this great inheritantce.

- Stressing the importance of data and information on climatic parameters (specially rainfall...)

- Promotion of research on evaporation, soil conservation, erosion and studies on the use of historical information related to Nile flow and other data to forecast trends in rainfall and flow pattern in the region.

- Promote research on the definition and forecasting of drought and floods in arid and semi arid zones.

- Basic study on how much could be obtained through RWM techniques from lost rain and how much it costs and what would be the cost and consequences of alternative methods for the augmentation of water resources.

11. RECOMMENDATIONS

1. Although a wide variety of rainfall water management techniques have been implemented in the Arab region, little attention have been given to evaluation and monitoring .

   It is recommended to:

   a. Establish or strengthen feedback mechanisms at the national level in order to adjust and improve running projects and draw lessons for developing and improving the design of future projects.

   b. Conduct a general survey and prepare an inventory of rainfall management techniques, selecting promising techniques for undertaking in-depth studies and distributing the results in the Arab region.

2. Microcatchment techniques, which are easily implemented, utilized and maintained at the family scale, seem to be a preferred approach. There is, therefore a need for a wider diffusion of know-how and information on these simple techniques.

   It is recommended:

   Developing manuals on existing "Water Harvesting" techniques based on experiences gained in the Arab region. These should include spate irrigation techniques, traditional water systems and other methods pertaining to rainfall water management. This activity could be emplemented by ROSTAS in co-operation with FAO and ACSAD.

3. Spate irrigation, which is practiced in major wadis in the semi-arid belt of the Arab region has the potential of increasing water supplies and consequently contributing to water and food security. The unique experience of Yemen regarding the application of improved traditional and new methods should be transferred to other countries. Most countries are confronted with similar problems and constraints and there are so many similar

characteristics that investigation of few systems can establish common principles .

It is recommended to:

Select experimental wadi basins and conduct in-depth studies regarding the evolutions and variabiliy of techniques practiced in these basins. These case studies should include assessment of the positive and negative impacts of spate irrigation techniques. Findings and conclusions should be diffused in the Arab region as widely as possible.

4. Wadi hydrology and hydrogeology are interrelated. An integrated development of spate and aquifers could therefore accomplish the best results.

It is recommended to promote such an integrated approach by utilizing techniques such as artificial recharge and applying appropriate water harvesting techniques.

A regional program based on deepening the knowledge base and building the capabilities of countries should be launched. The proposed programme should promote the use of modern techniques. Such as modeling, remote sensing and GIS for the collection and analysis of basic data and the selection of appropriate sites and techniques. The conjunctive use of wadi flow and wadi aquifer need to be encouraged.

5. Harvested water may be shared in the soil profile, ponds or underground in arid and semi-arid zones, underground storage of water have several advantages over surface storage systems, since high evaporation losses are eliminated, and siltation which is a serious problem in surface water reservoirs does not exist. Furthermore, environmental impacts of underground storage are usually much less than those resulting from storage in surface reservoirs;

It is therefore recommended that;

Groundwater recharge activities are promoted in the Arab countries and integrated into comprehensive water resources development plans. Emphasis should be placed on conjunctive use

of surface and groundwater especially in ephemeral wadis, and using artificial recharge as a tool to attain this objective.

A regional program on artificial recharge should be developed to enhance research activities, exchange of know-how and strengthen national capacities in assessing planning and implementing artifical recharge projects.

A comparative study should be conducted for the viability of various artifical recharge methods under various hydrologic conditions and the potential for their use to deal with areas of concern such as water supply, salt-water intrusion, aquifer depletion and environmental protection.

6. Urban stream runoff is not utilized effectively in the Arab region, and often aggravates urban water problems such as the rise of water table under urban centres.

   It is recommend that studies be conducted on quantitative and qualitative aspects of urban storm water and on the feasibility of harvesting and utilizing storm water runoff for industrial and irrigation purposes.

7. Rainfall water development and management projects, like other types of resources development may have negative impacts. Little follow-up efforts have, so far, been given to monitoring the impacts of such projects. Environment impact methodologies which have been developed as a planning tool, by anticipating future impacts of alternative development activities, have not been given the attention they merit, for mitigation of adverse effects of water development projects.

   It is recommended that a monitoring system be established to assess the impacts of rainfall water management systems and environmental impact assessment be undertaken at the planning stage to identify and assess potential implications of future projects and ensure that the results are incorporated into the planning process.

   Monitoring should be carried out for the majority of existing water harvesting projects which have not received adequate

environmental attention during their planning and construction stages .

8. Efficient and effective rainfall water management must be promoted at the local, national and regional scale. Precipitation- runoff processes vary within minutes, whereas groundwater flow may take months or years in small basin and semi-humid zone and thousands of years in large basins in arid saharan zones. It is therefore essential to transpose information among different spatial and temporal scales.

It is recommend that ;

At the local level, detailed studies of rainfall-runoff, and other characteristics of catchments, be carried out in order to select appropriate techniques, and define parameters and principles for the management of rainfall, and runoff. It is essential that emphasis be placed on microcatchment techniques used at the level of individual families or small communities.

At the national level, several major areas or zones should be defined on the basis of selected criteria for planning water harvesting activities, a package of appropriate techniques could then be proposed for each hydro-climatic zone. The final selection of sites and techniques would be based on technical criteria taking into consideration socio-economic conditions.

At the regional level the potential for rainfall water management should be assessed in order to assist in elaborating regional strategies such as food security and rural development. Hydrologic-runoff and thematic maps should be prepared by using GIS as a tool for synthesizing information, and CD/ROM for diffusion of acquired knowledge and know-how on application of viable rainfall water management techniques at various scales.

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