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INDIAN NATIONAL COMMITTEE ON HYDROLOGY
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No. : INCOH/SAR-3/95

CURRENT STATUS AND PROSPECTS OF RAIN-WATER HARVESTING

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INCOH SECRETARIAT
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PREAMBLE

It has been estimated that the total world population will increase from 4.5 billion in 1980 to about 6.5 billion by the year 2000, with the most rapid growth in the developing countries. By that time, the countries within the humid tropics and the other warm humid regions will represent almost one-third of the total world population. This proportion will continue to rise in the twenty-first century. The developing and under-developed countries thus quite clearly are the regions facing potentially serious water problems. Hence, it is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This call for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

Though serious efforts have been made all over the world to cover more and more area under irrigation but the scope for expansion of irrigation is limited due to certain constraints and a major portion of cultivated area will have to depend on rainfall for crop production. In recent years more and more emphasis has been laid on rainwater harvesting to increase and stabilize rainfed crop yields. Water deficiency periods occur not only in arid and semi-arid areas where rainfall is low but also in sub-humid and humid regions because of erratic rainfall distribution in time and space. Bits of experiences and information available on rainwater harvesting have been reviewed in this report to develop rainwater harvesting systems for location specific situations. Comprehensive review on techniques for rainwater inducement, direct rainwater conservation in situ, runoff water storage, seepage and evaporation control in tanks and utilization of stored water are given. It is possible to develop techno-economically viable systems for rainwater harvesting in different dryland/rainfed areas.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of Unesco and is the National Committee for International Hydrology Programme (IHP) of Unesco. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country to prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assitance of its Panel on Surface Water has identified this important topic for preparation of this state-of-art report and the report has been prepared by Dr. H.N. Verma of H.P. Krishi Vishvavidyalaya, Palampur and Dr. K.N. Tiwari of the Indian Institute of Technology, Kharagpur. The guidance, assistance and review provided by the Surface Water Panel are worth mentioning. The report has been compiled and finalised by Dr. K.K.S. Bhatia, Member-Secretary, Indian National Committee on Hydrology.

It is hoped that this state-of-art report would serve as a useful reference material to practicing engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilization of the water resources of the country.

(S.M. Seth)
Executive Member, INCOH
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Roorkee,
April 10, 1995.

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INTRODUCTION

Availability of water is a must for agricultural systems and assured irrigation is the principal requirement to stabilise and maintain agricultural production at a high level. With the prevailing monsoon type of rainfall, the arid and semi-arid regions suffer most for want of irrigation facilities. Even in high rainfall areas where irrigation facility does not exist, water deficiency periods do occur during critical crop growth stages causing low and uncertain yields. Though serious efforts have been made all over the world to cover more and more area under irrigation, a major portion of cultivated area still depends on rainfall. Inspite of all possible efforts the scope of irrigation expansion is limited due to various factors. At present only a small fraction of average annual rainfall is actually used for crop production in many rainfed areas. In such areas, efforts should be made to utilise maximum possible rain water by adopting water harvesting technology. Water harvesting was practised as early as 4500 B.C. in various parts of the world (Sastri et al., 1981). Water harvesting can be a soruce of water for variety of purposes in arid and semi-arid regions when common sources such as streams, springs or wells fail. In addition to supplying drinking water for people, live stock and wild life, water harvesting system can provide supplemental water for growing food and fibre crops. The term water harvesting was probably used first by Geddes (1963), who defined it as, "The collection and storage of any form of water, either runoff or creek flow for irrigation use". Myers (1974) modified this to "the practice of collecting water from an area treated, to increase runoff from rainfall and snow melt". Water harvesting is the practice of collecting water from an area treated to increase runoff from rainfall or snow melt for beneficial use (Boer et al., 1979). According to Tiwari (1984) water harvesting technology includes inducement of runoff from the land surface, collection and storage of runoff water in storage reservoirs or ponds, reducing the seepage and evaporation losses and use of the conserved water most efficiently to provide life saving irrigation to crops.

Now-a-days water harvesting has become a general term for collecting and storing of precipitation and runoff or creek flow, resulting from rainfall and snow melt, in soil profiles and resrevoirs (Verma, 1983). Previously rain water harvesting technologies were used for arid and semi-arid areas, but recently their use has been extended to sub-humid and humid regions too.

In rainfed areas, a small additional increment of harvesting water can dramatically increase crop yields and lower the and risk of crop failure. Some times, it can make a difference between a crop and no crop in drought years. Water harvesting can increase cropping intensity in such areas. It may also be used for fish production and for growing forage crops to relieve grazing pressure on range land. It is observed that providing a small source of irrigation water motivates farmers to adopt other improved inputs and crop management practices in rainfed areas (Verma et al. 1984).

The distribution of rainfed farming area of India in different climatic groups, where rain water harvesting is needed is as follows (Vimani et. al. 1980)

- arid tropics 19.3%
- dry semi-arid tropics 60%
- humid and sub-humid
  (mostly wet/dry semi-arid tropics) 20.7%

There are two types of rainfed area, (i) dryfarming areas of arid to semi-arid climat and (ii) wet farming areas of sub-humid to humid regions. In both the type of rainfed areas water stresses of varying degrees occur. The harvested rain water is mostly used for domestic use, cattle in dryfarming in arid and sub-arid tropics where as its use in humid and sub-humid areas is for cattle use and rainfed farming.

WATER HARVESTING SYSTEMS

The objectives and technologies of rainwater harvesting are highly location specific and an appropriate technology developed for a particular region cannot be used as such for other areas for physiographic, environmental, technical and socio-economic reasongs. The rainwater harvesting technologies are not based on annual rainfall only but on its variation in space and time too.

(A) Rain Water Harvesting For Domestic Use

It is common practice to harvest rain water from house roofs, hill and rock surfaces and even from especially surfaced area and store it in cisterns or tanks for domestic use. Cisterns are excavated in soil/rock and water proofed with a thin layer of cement plaster. Several innovations in cistern design have originated from traditional food/grain storage bins. Ghala tanks in Kenya are made by modifing a traditional granary basket or Ghala and lining with 2:1 sand cement mixture. Traditional water jars used for roof rain water collection in Thailand is also made with similar technique. Dogan people of Mali used mud-walled grains bins as water by adding wire reinforcement and plastering with cement (Watt, 1978). Roof rain water harvesting use is common in India pearticularly in Himalayan areas, Northern States, Lakshadweep, Rajasthan, Andaman Nicobar, Kerala and Tamil Nadu.

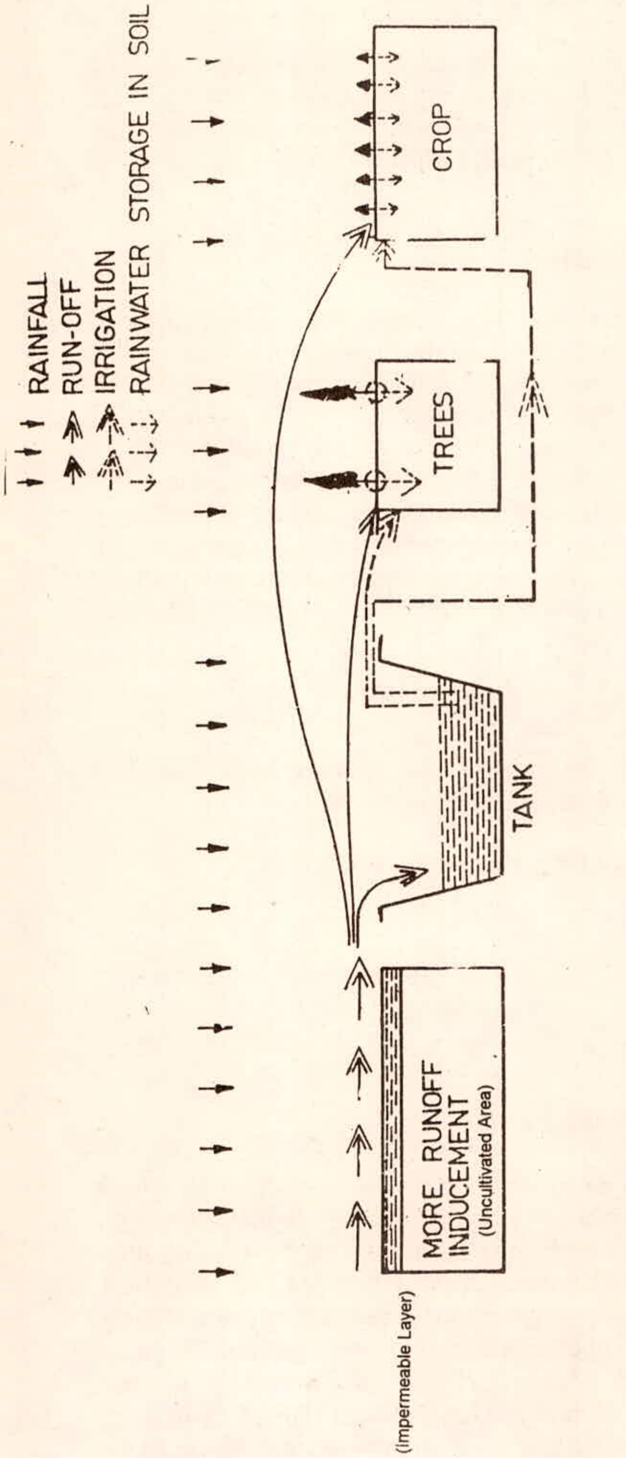
(B) RainWater Harvesting For Agriculture

The rainwater harvesting systems for agriculture (Fig.1) may have following components or phases depending upon location specific situations :

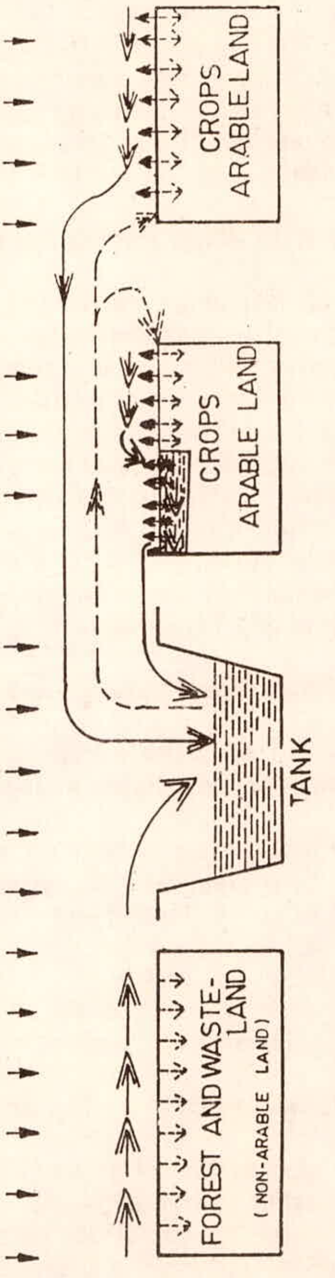
1. Inducement of more runoff on non-cropped area (only in arid areas).
2. Direct rainwater conservation in situ
3. Runoff collection and storage
    a. on soil surface
    b. in soil profiles
    c. in tanks/reservoirs.
4. Utilization of stored water

Inducement Of More Runoff On Non-Cropped Area

Modification of ground surface to induce runoff is the main aspect of rainwater harvesting in arid lands where rain falls infrequently and its quantity is insufficient for good crop growth. Under such conditions, runoff may be increased by treating non-cropped catchment and diverting to cropped area or storage reservoir for irrigation. Ancient people of Nagev cleared desert areas to expose soil for harvesting precipitation. Simple systems have been used for this type of precipitation harvesting about 500 years ago in USA and other parts of the World (Myers, 1974). It is possible to harvest precipitation in the areas having as low as 50 mm average annual rainfall by treating catchment. In Israel, usable runoff had been induced on a catchment even in a very dry



(a) FOR LOW RAINFALL AREAS.



(b) FOR MODERATE TO HIGH RAINFALL AREAS

Fig .1 Schematic Diagrams of Rainwater Harvesting Systems year having 24 mm of rain (Everani et al. 1971). In early attempts, natural materials like soil and rocks were used to induce runoff, but recently many artificial means for treating catchment have been developed. Reducing the infiltration rate into the soil surface and increasing hydraulic efficiency of the catchment are the main approachs to increasing runoff. Some methods of increasing runoff are discussed below which are mainly concerned with the water supplies for livestock and domestic pruposes. However, many of these techniques may be used for runoff agriculture.

By Infiltration Reduction

Land alteration

Clearing the land by removing vegetation reduces infiltration and increases runoff. This practice had been used in Nagev in olden age (Everani et al., 1971). When raindrops fall on cleared soil surfaces, they seal the surface and reduce infiltration. Land alteration sometimes creates soil erosion problems.

Soil compaction

The effect of soil compaction on infiltration rate varies with the texture and some other soil properties. Coarse sand and gravel may not reduce infiltration rate remarkably in absence of fine materials to block the pores. Higher clay percentage is good for compaction, but too much clay may cause cracking after compaction. Sandy loam raised runoff from 45 to 56 percent after compaction, and a well-structured clay loam actually reduced runoff from 28 to 20 percent after compaction, due to surface cracking (Hillel, 1967). Cluff et al. (1972) reported runoff increase from 22 to 58 percent after compaction of sandy loam plots. Compaction of soil is cheap and equipment for compaction is readily available. Tiwari et al. (1987) got 39 percent of rain as runoff by cleaning and compacting land surface.

Soil deflocculents and additives

Salts like NaCl can be used to increase runoff on clay-containing soils. The sodium salt causes breaking of clay into small particles sealing soil pores and cracks. Hillel (1967) obtained 70 to 80 percent runoff on sandy loam by spraying 0.2 L/m^2 of 41 percent NaCl annually for three years. However, there was increased soil erosion due to salt spray. Cluff et al (1972) also found more runoff and soil erosion on clay loam with 6700 kg/ha NaCl application. Some soil additives like bentonite block the pores of soil and reduce infiltration. Bentonite, a clay containing montmorillonite as the essential mineral, has ability to swell in water. Mickelson (1974) mixed 1.1. kg/m^2 bentonite into the top 5 cm of silt loam and found more runoff. Cement has been used as additive to reduce infiltration, but it was not very effective.

The results of runoff inducement efficiency of the plots treated with sodium salts, bentonite clay and mixture of both are reported by various investigators (Table 1). The quantity of sodium salts used for inducement has an effect on water quality. Based on the chemical analysis of harvested water i.e. pH, EC and S.A.R., it was found to be acceptable for irrigation (Tiwari et al. 1987).

Hydrophobic chemicals

Many hydrophobic chemicals, like soduim rosinate, sodium silanolate, dialkyle quanternery ammonium chloride, metalic soap, fatty amino acetate, silicone water repellants, wax and fuel oil, have been used to reduce infiltration. The quantity of compound to be applied and effect of these compounds on quality of water are not reported. The runoff production efficiency of plots treated with silcane and paraffin water repellent varied between 50-80 percent and 60-90 percent respectively (Frasier, 1974). Myers (1967) got 76 to 96 percent rain as runoff by treating land surface by hydrophobic compounds.

Table 1. Runoff inducement efficiency of surface treatments

Treatments and mode of application	Soil type	Slope percent	Runoff inducement efficiency (Runoff as percentage of rain)
A. Sodium carbonate			
1. Broadcasted	Clay loam	-	70
2. Applied in spray form 10 percent solution in water @4.5×10^{-3} kg/m^2	Clay loam	-	70
3. Sprayed @0.1 kgm^2	-	0.5 to 1	35-42
4. Broadcasted and liquid spray @8×10^{-2} kg/m^2	Sandy loam	2	71
B. Sodium chloride			
1. Broadcasted	Sandy loam with vegetation cover	-	10
2. Broadcasted and liquid spray @0.1 kg/m^2	Sandy loam	2	64
C. Mixture of Bentonite and sodium chloride			
1. Broadcasted and liquid spray @0.2 kg/m^2	Sandy loam	2	61

D. Bentonite clay			
1. Broadcasted	-	2	19
2. Bentonite 20 percent mixed with soil 2.25 thick.	-	0.5 to 1	13-18
3. Broadcasted and liquid spray @0.3 kg/m^2	Sandy loam	2	56

Sprayed asphalt coating

Asphalt has been widely used to treat catchment for runoff inducement in Australia and USA, Asphalt is a promising material for providing a low-cost impermeable catchment, if it is applied on surface by spraying. Myers and his associates made a detailed study on the use of different combinations of cut-back and emulsified asphalt sprays and concluded that a smooth and compacted soil base, plus a soil sterilant, a cut-back primer and emulsion seal coat, were needed for producing a satisfactory catchment (Myers 1967). The results of runoff inducement efficiency of asphalt and bituman treatments are given in Table.2.

Membranes

Very thin membranes, like aluminium foil, polyethylene, polyvinyl fluoride chlorinated polyethylene, acrylic and butyle rubber, have been tried (Hillel, 1967, Frasier and Myres, 1972). Their installation requires cleaning and smoothing the area, sterilizing the soil spraying with asphalt, laying the film and, finally, soft rolling. These membrances are easily damaged by animals, plants and movement of men. They are costly and require too much care. Plastic films have also been used for rainwater harvesting with 10-12 cm cover of gravel to hold them down against wind. In situ membrane have also been tried for precipitation harvesting. They are formed by laying a reinforcing mat coated with asphalt emulsion/asbestos fibre or asphalt-clay emulsion. At some places, thick vinyl and polyethylene sheets laid on soil surface have worked satisfactorily for 2-3 years. Nylon reinforced butyl rubber and as phalt-coated roofing felt have been treated in the USA and asphalt/coated fibreglass material has been tried in Australia. Experimental investigations on low density polyethene sheet (Myres, 1965, Cluff, 1974 and Tiwari et.al. 1987) indicated that runoff production efficiency ranged between 60 to 85 per cent. Runoff inducement by memberanes and plastic films is costly and not advisable in a crop production system. It may be suitable sometimes for drinking water supply or for livestock.

Table 2 : Runoff inducement efficiency of bitumen and asphalt treatment

Treatment	Expected life (years)	Runoff inducement efficiency (Runoff as percentage of rain)	Reference No.
Asphalt	5	60-90	15
Asphalt chip Coated plastic polyethene reinforced sheet	10-15	85-95	24
Asphalt fibre glass sheet	5-10	85-95	36
Asphalt roofing	-	52	68
Bitumen mixed with kerosene oil	6	77	108

Concrete and Iron sheet

Hundred per cent runoff harvesting efficiency can be achieved by covering the land surface by galvanised sheet coverings (Lauitzen, 1960 and Frasier, 1974). The rainwater harvesting catchments made of concrete and corrugated iron have been used in USA and Australia for higher efficiency and durability. These catchments are very costly and developing countries cannot afford them for crop production.

Improving Hydraulic Efficiency

Decreasing depression storage

The depression storage of a catchment can be reduced by removing stones or rocks, smoothing surface and increasing ground slopes. It is especially required where rainfall comes as frequent short-duration showers, rather than longer periods of rain.

Reducing wetted area during recession hydrograph

When rain ceases or the intensity falls below infiltration rate, the water losses are governed by the duration of recession and the speed of reduction of surface area of flow. By changing slope, runoff length, cross-section areas, shape and gradient of channel, the time of flow recession and wetted area can be altered.

Roaded catchment

The roaded catchment is formed by changing the configuration of catchment to enhance runoff. The soil is graded into series of parallel roads similar to flat ridges of earth, that drains into a channel separating them (Fig.2). This is a cheap method of catchment improvement. The concept of roaded catchment was developed by the Public Works Department of Western Australia, and in 1973, 23 catchments were installed, totaling 707 ha area, for country town water supply. This is widely practised in Western Australia where roads vary from 50 m to 300 m in length and 5m to 12m in width (crest to crest). The catchment area can vary upto about 10 ha. However, an asphalt-surfaced catchment is preferred because it provides a more reliable and clean water. Large roaded catchments have many problems.

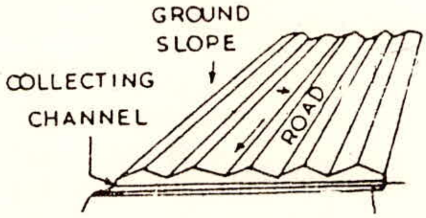


Fig. 2 Idealized Roaded Catchment Water Harvesting System

Flat batter tanks

In the areas where 2-5 metres of deep sand overlayig a clay sub-soil occur, excavated tanks can be built and clay taken out from the bottom can be spread and compacted to form an apron around the tank as a catchment. This type of rainwater harvesting tank has been constructed in Western Australia. The apron may be 30-40 metres wide, with a gradient of 0.5 to 1.0 percent toward excavation. This system has been found to be effective in the area having more than 400 mm rainfall. Circular apron catchments are better than rectangular catchments because of less erosion of soil.

Contour catchments

The contour catchment method was developed for steeper slopes in South Australia (Young, 1965), in which the hill sides are cleared, smoothed, compacted, and grade drains constructed across the slope to prevent erosion and guide flow. The shape and spacing of contour catchment grade banks are altered so that the catchment resembles a modified roaded catchment. Contour catchments have been found superior to roaded catchment on 5 percent ground slope.

The contour catchment method can also be used in flat or undulating desert area, where terraces can be built to shed runoff on to adjacent strips of cropped land. On flat land, an artificial slope for the catchment can be formed by mounding soils between strips. The catchment strips can be treated for more runoff inducement with above methods, or left. This method is also called desert strip farming and has been tried in Wedi Mashash (Israel) and (Arizona (More Water for Arid Lands, 1974).

Microcatchment

For growing single plant or plants in a small basin, micro-water catchment can be built around the plant or plants to harvest rainwater. This practice is also known as microcatchment farming. A micro-catchment is a very small watershed, varying from 100 m^2 to 300 m^2, designed to collect runoff for the consumptive use of single tree or plants. Each micro-catchment as shown in Fig.3, consists of a contribution area and an infiltration basin in which the tree grows. The objective of this system is to redistribute precipitation to small crop area where water is concentrated in the root zone and moving into deeper layers of soils, and consequently reducing evaporation loss of the added precipitation. On flat land, a round or rectangular batter can be formed around the cropped basin and the batter may be compacted or treated to reduce infiltration. On sloping land, the cropped basin should be at the lower end of microcatchment. The microcatchment methods have been used successfully in Nagev (Everani et al. 1971) and tried in Punjab (Paihar et al., 1970). Ehrler et al. (1978) used micro-catchment of 20 m^2 formed a basin of 2 m^2 to harvest runoff for Jujube plants and reported 281 and 722 mm runoff collection in the basin increasing seed yield from 0.5 to 8 and 0.5 to 23 gram/plant in compacted and water repellent treated micro-catchments, respectively. Oron et al. (1983) improved micro-catchments, inserting perforated verticle pipe near tree to improve water use efficiency which led to a conclusion that net income is higher than micro-catchment rainwater conservation system without inserting pipe. Fairbourn (1974) tried micro-watershed system to grow serghum in a low rainfall area and found the raio of 3:1 the contributing slope area to crop area, to be most suitable for getting maximum yield.

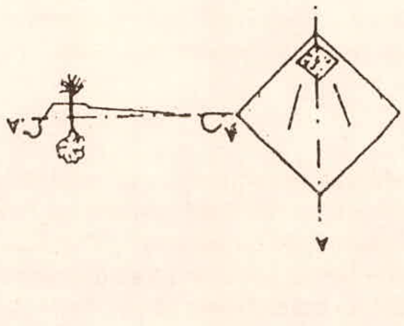


Fig.3 Plan and Cross - Section of a Micro-Catchment

Catchment treatment for inducing runoff has been used widely in Australia. Hollick (1974) found butyl rubber or plastic membrane and bitumen too expensive and treatment of soil unsuccessful. He analyzed capital and maintenance costs of different treatment and found roaded catchments to be cheapest.

DIRECT RAINWATER CONSERVATION IN SITU

Basic Soil Conservation Measurement for Land Development

Some of the well established basic soil conservation measures adopted for cropped land development in moderate to high rainfall areas also conserve rainwater in situ for raising rainfed crops. These measures include :

1. Terracing
2. Land levelling with shoulder bunds
3. Graded border strips
4. Contour bunding
5. Contour ditching

A lot of literature is available on above said soil and water conservation measures which are used in rainfed areas. As the main aim of these measures is to check soil erosion, detailed review and discussion on these measures are not included in this report.

Increasing Infiltration and Storage of Water in Soil Profile

In cropped rainfed areas, efforts should be made to retain as much rainwater as possible in root zone of soil profile. This may be achieved by adopting in-situ rainwater conservation measures which are based on the principles of increasing infiltration rate and water storage capacity of soil. The research information available in literature on in-situ rainwater conservation are reviewed and presented below.

Off season tillage

Off-season tillage (summer tillage) between harvest of **rabi** crop and the beginning of monsoon with local plough has been found beneficial for rainfed crops in many situations (Sharma et al., 1982). It facilitates absorption of first premonsoon rains and allows early field preparation. Off-season tillage was found to be useful in weed control and conservation of rainwater leading to increased sorghum yield (Venkateswarlu and Singh, 1982). Effectiveness of off-season tillage was more evident in years of sub-normal rainfall (Sharma et al. 1982).

Crop cover during rainy season

In many rainfed areas there is a practice to keep land fallow during rainy season to take up a post rainy season crop only. This is a controversial practice in dry farming system. Under certain conditions the practice of following does result in storage of moisture in the soil and this way a part of the rainfall can be made available to a crop grown in the fallowing season. In light soils like loamy sand and sand having low moisture holding capacity, growing only a post rainy season crop in residual moisture has been found beneficial than having two poor crops, one in rainy season and another in the post rainy season (Singh et al. 1983). On the other hand, in heavy soils like vertisols, **kharif** fallowing is done because of poor workability of soil. In such areas dry seeding and graded broad bed and furrow system were found to be very effective in having two crops, one in rainy season and the other in the post rainy season instead of only one crop (Kampen, 1980). However, there are many areas in which there is considerable doubt as to whether significant rainwater is conserved by a fallowing. The effects of fallowing are mainly due to increase in available nitrogen to plants and better weed control, rather than moisture conservation.

Conservation tillage or mulch tillage

Conservation tillage has been defined as a form of non-inversion tillage that retains protective amounts of crop residue on the surface. Such tillage practices have received considerable support due to their erosion control capabilities (Andraski et al., 1985). Conservation/mulch tillage is a common practice of rainwater conservation for rainfed crops in many countries where residual vegetative materials like leaves, stalk etc. are left on or near the surface as protective cover. Sub-surface tillage and minimum tillage are followed for sowing and other operations without disturbing stubble mulch. Conservation tillage decreases runoff, increases infiltration opportunity and reduces evaporation.

Contour farming

Contour cultivation is very simple and can easily be adopted on slopy lands by allowing all operations along the contour/graded bunds or across the slope. Contour farming has been found to be very effective in reducing soil erosion and runoff as compared to up and down hill cultivation in major soil groups of India viz., alluvial, black and deep laterite soil (Tejwani, 1980). Bhatia and Chaudhary (1977) reported reduction of soil loss and runoff by 28 and 61 percent respectively due to contour cultivation over up and down cultivation at Kanpur on 2.2 percent slope. Bonde (1985) reported substantial reduction in soil loss and runoff in maize (at Dehradun and Chandigarh) and in sorghum (at Bellary) by adopting contour cultivation in place of up and down cultivation.

Deep ploughing

Deep ploughing has been one of the research recommendations reported to increase infiltration and soil water storage (Patrick et al. 1959; Moolani and Hukkeri, 1965; Malik et al. 1973; Bhushan et al. 1977 and Verma et al. 1979). According to Willcocks (1984) medium textured soils need some loosening to enhance infiltration and allow effective root growth. In contrast, the vertisols do not impede root elonagtion but the control of weeks is the primary purpose of field preparation which can be done away with shallow tillage or with the use of herbicldes. In alphisols, deep tillage creates favourable conditions for water entry into soil profile. The steady state of infiltration and sorptivity was found to have increased with deep tillage. However, both, infiltration rate and cumulative infiltration decreased in the second year due to resettling of loosened soil (Acharya and Bhagat, 1984).

Hard pan immediately below tillage depth caused by tillage tool on medium and coarse textured soils restricts root peneration into sub-layers and works as a barrier for percolation to the sub-soil. Under such conditions chiseling or sub-soiling increases soil water storage by increasing infiltration (Campbell et al., 1974; Lindstrom et al., 1974 and Prihar et al., 1986).

Deep ploughing has been found very useful in increasing rainfed crop yields at Anantapur, Bangalore, Jhansi, Ranchi, Agra, Jodhpur, Hissar, Varanasi and Dehradun centres of AICRP for Dryland Agriculture (Sriram et al. 1982). Dryland research results at Bangalore show that response of deep tillage is more in deep rooted crops than shallow rooted crops. Venkatanadhachari et al (1979) found beneficial residual effect of deep ploughing up to 3 years and recommended deep tillage (25-30 cms) with tractor draw implements once in three years with early monsoon showers to break hard pan and allow more water storage. Deep tillage with mould board plough (25-30 cms) helped moisture storage and its effective utilization through deeper root penetration at Dehradun (Singh et al. 1981). Prihar et al. (1986) reported better response to deep tillage and chiselling in low rainfall years as compared to normal rainfall years in sandy loam soils.

Surface mulching

Surface mulching increases infiltration, reduces evaporation and lowers soil temperature. This results in significant increase in water availability to plant growth. Spreading of vegetative mulch at the rate of 3 to 6 tons/ha on surface is known to increase soil moisture storage and maintain higher moisture content especially in upper soil profile (Army et al. 1961 and Prihar et al 1979).

There are two main objectives of organic surface mulching. First is to reduce kinetic energy of raindrops so that splash is reduced leading to minimised surface sealing. Further, runoff is restricted as the mulch acts as barrier to flow. To achieve this purpose, mulching is done after germination of the crop in the beginning of the rainy season. Mulching has been found very effective in reducing runoff and soil loss in high rainfall regions having short intermittent dry spells (Lal, 1975 and Khybri et al. 1980). Green vegetation mulch applied during rainy season get decomposed and add to plant nutrients. In wheat, following mulched maize, the yields with zero and 40 kg nitrogen/ha were comparable to those with 40 and 80 kg nitrogen/ha respectively in absence of mulch saving 40 kg nitrogen/ha (Singh et al. 1983).

Organic mulch spreading before the recession of monsson in standing **kharif** crops maintains higher infiltration, increases soil water storage and reduces evaporation helping both rainy season and post rainy season crops (Mannering and Mayer, 1963; Singh et al. 1983 and Acharya and Bhagat, 1984). Gupta and Gupta (1983) reported increase of legume crop yield and reduction of soil temperature and content of weeds due to grass mulching during wet season in arid land.

Application of surface mulch at the rate of 4 to 6 T/ha in Nigeria was compared with conventional tillage and was found effective in increasing yield by 50, 25, 22, 21 and 5 percent in maize, sweet potato, cowpea, soyabean and pigeonpea, respectively (Bornemisza and Alvarado, 1975). It has also been found as effective as 10 to 15 years of bush-fallow in soil restoration in the traditional system of shifting cultivation. Mulch and deep tillage during **kharif** increased yield of maize individual and their combination gave maximum yield (Verma et al., 1979).

Gravel is also used as an effective mulching material (Corey and Kemper, 1968).

Vertical mulching

Incorporation of vegetative mulch in the soil in a band has also been found very useful in conserving rainwater (Lawes, 1961). In heavy soils having very low infiltrability, vertical mulching (putting crop residue in a band in narrow trenches across the slope extending above ground surface) is found very effective in conserving rainwater and enriching soil profile (Rama Mohan Rao et al., 1978). Vertical mulching increased sorghum yield significantly in the black soils of Bellary, Sholapur and Bijapur (Venkateswarlu and Singh, 1982). Fairbourn (1974) found vertical mulching beneficial in conserving rainwater in a microwatershed in low rainfall area. Vertical mulching of sorghum stubbles in 30 cm deep and 15 cm wide trenches extending 10 cms above surface is recommended for medium to deep clay soils at 4 to 5 meters distance across the slope (Rama Mohan Rao et al, 1978 and Krishnamutrhy et al. 1981). The effects of vertical mulching were found to last 4 years. It is more effective in dry years (Rama Mohan Rao et al., 1978).

Soil amendments and use of soil conditions

To increase water storage in soils, mixing of other soils, organic materials and chemicals to the soil are followed. Soils having impermeable layer at the surface can be mixed with porous soil, gypsum and organic materials to increase infiltration. Similarly very porous soil having low water holding capacity can be mixed with clayey soils or crushed brown coal (Gullen, 1973) to increase water holding capacity of the soil. The soil conditioners like bentonite and organic amendments like farm yard manure (FYM) and compost can increase the water retention capacity of light textured soils (Patel and Maliwal, 1982).

Increasing Infiltration Opportunity

All measures discussed so far increase infiltration/ intake of soil and its water holding capacity. After allowing cptimum infiltration, excess runoff produced on crop land can be stored on the surface upto certain depth depending upon the crop and infiltration characteristics to increase opportunity of infiltration excess rainwater into the soil. This method is also called intra-plot runoff conservation which is achieved by modifying the surface configuration of cropped area on bunded slopy land or graded land within a terrace. Intra-plot in-situ runoff conservation methods include tied ridging and inter-row water conservation methods like dead furrows, ridge and furrow system and bed and furrow systems.

Tied ridging

Tied ridging or basin listing (formation of small basin) has been used at many places and found to be very effective in conserving rainwater in soil profiles and in increasing crop yields (Clark and Hudspeth, 1976; Ahn, 1977 and Haney, 1978). The objective of basin listing is to hold rainfall in place where it falls until it infiltrates into the soil. This method facilitates the conservation of moisture when rainfall is low. When precipitation is very heavy, the excess water can be drained away by breaking the cross-ties when found necessary. In India, tied ridging has been found beneficial for moisture conservation and in increasing yield of cotton (Rao and Ramachandran, 1974). This rainwater conservation practice is in less use because of slowness of operations, difficulties in weed control, tillage and above all, its high cost.

Dead furrows

In some rainfed crop's cultivation, dead furrows are left in the sown field for rainwater conservation. Dead furrows at 2.5 to 3.6 meters interval were found effective in increasing soil moisture and yield of groundnut (Anonymous, 1979a).

Ridge and furrow system

Sowing rainfed crops with ridge and furrow system across the slope stores runoff in the furrows. Sowing maize on ridge and paddy in furrow has given much more total yield as compared to normal maize and normal paddy without making ridge and furrow at Dehradun (Vijayalakshmi et al. 1982). In Northern India rainfed farmers do 'halod' (ploughing in standing maize between rows after 20-25 days of sowing making furrow and ridge) to conserve rainwater in furrows (Singh et al. 1988). Similarly, crop yield of pearl millet was found to be higher under ridge and furrow system than that of flat sowing at Hissar sandy loam soil (Oswal et al 1984). On gentle slope and moderate to light soils, ridge and furrow system across the slope was found effective in reducing runoff by 52.2 and 44 percent and soil loss by 52 and 52.8 percent over flat lands for tobacco and cotton crops respectively giving higher yields (Anonymous, 1978) at Dehradun.

Bed and furrow system

The broad beds and furrows have been found to be suitable for managing the deep black soils in India where surface drainage during the monsoon period is a problem (Kampen, 1979). The beds function as minibuds and help in reducing the velocity of surface runoff and increase the infiltration opportunity. The excess runoff water is drained through furrows laid on 0.4 to 0.8 per cent grade. Bed and furrow system is found effective 10 improving general environment for crop growth in black soils. But this treatment does not prove its superiority in red and alluvial soils over flat sowing on grade with ridging later (Sharma et al. 1982). Moreover, bed and furrow system development is dependent upon a tool bar called 'Tropiculture' which costs Rs.4,000 plus additional Rs. 3,000 for a few implements to be attached to the tool bar (Bali, 1980).

The intra-plot runoff conservation measures discussed above, if properly adopted, may even eliminate contour/graded bunding on slopes upto 3 percent (Bonde, 1985).

Inter-plot Runoff Conservation Measures

Above discussed measures conserve rainwater when it falls within the plot through infiltration rate, infiltration opportunity and water sotrage capacity of soil ensuring even distribution of moisture in the plot. In inter-plot runoff conservation measures, runoff produced or induced by changing configuration in a part of field/plot is allowed to be concentrated in another part of the field/plot, which is treated to receive and conserve runoff in soil for crop production. The inter-plot runoff conservation measures require shaping of land into small plots or strips.

Conservation Bench Terracing (CBT)

Conservation bench terracing involves runoff collection from an upper (contribution) catchment and diverting the runoff to the lower part of the catchment (receiving) area. The crop may be grown in receiving area only (arid region) or in both the contributing and receiving areas (semi-arid, sub-humid and humid areas). the crops requiring relatively less water or needing good drainage can be grown in the contributing area. In receiving areas, crops which can tolerate waterlogging, like paddy can be grown. In this method receiving area needs levlling and bunding to collect runoff. The consrevation bench terracing has been used widely on the Great Plains in USA to conserve and utilize runoff, increasing grain and fodder production (Cox, 1968; Hass and Willis, 1971; and Hauser, 1968). The results of research investigations at Dehradun (Bhushan, 1979 and Tejwani, 1980) indicate that yield of lower receiving plot as well as total crop yield (Paddy + maize) of both plots increases when maize is grown on contributing catchment and paddy in receiving plot. On the other hand, at Kota (Anonymous, 1979b) conservation bench terracing reduced total yield when paddy was taken in receiving area. But when sorghum was taken in both receiving and contributing areas the yield increased from 23.6 to 30.0 q/ha and 82.1 to 104.7 q/ha (4 years average) for grain and stalk, respectively (at contributing vs receiving area 1:2) due to CBT (Prakash and Verma, 1985).

The conservation bench terracing is also used in arid lands where contributing slopy catchment is uncultivated and sometimes treated to contribute more runoff to the rainfed crop grow in the lower level plots. Vijayalakshmi et al (1982) reported 1:1 ratio of contributing catchment and level cropped (pearl millet) area to get maximum advantage. Sharma et al (1982) found catchment and level area ratio of 2:1, 1.5:1 on and 0.87 : 1 most suitable to get higher yields of **jujube** slopes of 0.5, 5 and 10 percent, respectively. Jones and Hauser (1974) compared conservation bench terracing (3:1) and bench levelling and found both effective in increasing yield. Bench terracing gave over all more yield but was costlier than that of coservation bench terracing. Ordier and John (1975) also found conservation because terracing more profitable than bench terracing because of low levelling cost per unit area. Yadav (1976) compared inter-plot runoff collection system having 1:1 contribiting vs receiving area (with maize) with inter-row runoff collection method having ridge and furrow system. The grain yield in inter-row water conservation system was significantly higher and nearly double (21.4 q/ha) as compared to inter-plot runoff conservation system (11.1 q/ha).

RUN-OFF HARVESTING

Conceptually, runoff harvesting involves collection of excess natural run-off in soil or reservoirs. In cropped land, as much rainfall as possible should be retained in the soil on which it falls. Excess run-off should be directed to the other area having a crop which requires more water, or to the storage, for its recycling to replenish soil water at a later stage of crop growth. The streams carrying runoff water from unclutivated areas, hillsides or cropped land, may also be harvested for life-saving irrigation or aquifer recharging. The different methods of harvesting runoff for agricultural production are discussed below.

Stream Diversion for Water Spreading

Short-duration intense storms sometimies produce too much runoff which swiftly drains through gullies and creeks, creating flooding problems downstream. This water may be directed from its natural course and spread over cultivated area, range land and pasture. A water spreading system should be designed carefully with considerations of soil, slope, crop and drainage. The quality and quantity of sediments and gravel carried by water stream should also be considered while designing such system. Sometimes, ephemeral streams may be pumped to direct runoff to cropped land.

Drains on Rock

In some dryland areas, patches of rocks are found near cultivated area. In South Australia, granite outcrops are common in broad and plain ridges, where gutters are built around many outcrops to collect runoff from the rocky catchment (Burdass, 1974) for stock water supply. Runoff from rock catchment can easily and economically be collected in a cropped field or in a storage for later irrigation use.

Intercepting Sub-surface Flows

At many locations in submontane rolling topography, sub-surface soil water moves down slope and outflows as a spring above an impervious sub-soil or by rocks. This watrer can be collected in reservoirs for crop production. In the Indian submountainous northern part, many streams of this type exist and considerable amount of water can be harvested in dry seasons.

STORAGE OF HARVESTED WATER

Storage of harvested water is vital and should be used in conjunction with water harvesting systems. It is very important to provide an efficient storage for rain\runoff water to make it available at the peak time of demand. An efficient storage retains the supply without excessive losses until it has served the intended purpose for which it has been designed. In case of runoff storage, quality of water should be checked for suitability for irrigation.

In agricultural water harvesting systems, there are two types of water storage reservoirs. The first is soil reservoir, where water is stored in the pores of soil. There may be two kinds of soil storage-surface layer soil storage for runoff farming and, second, underground reservoir (aquifer) from which water can be pumped. The second type of storage is made by escavating or constructing a dam or wall. These reservoirs are used for supplemental/life-saving irrigation crops.

Soil Reservoirs

Surface soil profiles

Rain/runoff-water stored in the upper profile of soil depends on the water-holding capacity of soil which varies according to its composition of sand, silt, clay and organic matter. It increases with the fineness of soil texture, which also influences the availability of water to the plants. Water harvesting in this system is mainly for plant growth and thus available waterholding capacity of soil is very important for designing the system. Water losses through deep percolation, evaporation from the surface, and transpiration through undesirable weeds, should also be taken into account. The soil reservoirs should be filled up to filled capacity for their efficient utilization overfilling may result in deep percolation drainage and waterlogging. The approximate available waterholding capacity of different soild is given by Woodward (1986) as follows :

very heavy texture	17% of depth
heavy texture	19% of depth
medium texture	17% of depth
light texture	11% of depth
very light texture	7% of depth

Underground reservoirs

After filling soil and ground surface reservoirs in rainfed areas, excess runoff percolates down to recharge ground-water. Unconsolidated sand or gravel generally are the most important waterbearing materials in aquifers because they have high porosity and permeability. Water stored in aquifers may be pumped during the critical need of crop for irrigation. It is beyond the scope of this report to discuss aquifers and groundwater recharge in detail because it (this report) is mainly concerned with dryland agriculture and not irrigated agriculture.

Surface Reservoirs

These are water bodies created by dam or embankment constructed across a water course or by excavating a hole near a stream or at the lower end of a catchment. Very small tanks, either prefabricated or built in - situ for domestic or live-stock water supply are outside the scope of this paper. Agricultural crop production systems require relatively more water than live-stock, and dams or excavated tanks are usually cheaper than prefabriccated tanks.

Surface reservoirs for life-saving irrigation may also be used wholly or partially for live-stock water supply, field or orchard spraying, fish production, fire protection, recreation, and other multi-purpose uses.

Surface reservoirs may be classified according to topography, hydrology and economics (Burton, 1960). Storages may have their own catchment or may be filled by pumping, by gravity through diverting runoff from an adjacent catchment, or by a combination of both. Economics of stored water depend mainly on the ratio of storage to excavated volume, which varies from 1 to 10. Depending upon the topography, the following types of reservoirs may be constructed for water supply to crops.

Hill side storage

These storages are made on steep slopes to collect runoff from hillsides. The side of the hill acts as one well of reservoir. The other three wells (in the case of rectangular reservoir on uniform slope) or a curved wall (where contours are curved) are constructed from excavated material. The storage excavation ration may be above one on mild slopes, it may be less then one because water may only be stored in the burrow pits. Ratio of storage\excavation for hillside storages can rise to a ratio of 3 (Imre, 1974).

Gully dams

Dams on streams or rivers can provide a storage of water for irrigation, electricity generation, industrial and drinking water supply. Mostly large dams are constructed for multi-purpose use and are out of the scope of this paper. Only small dams on ephemeral or perennial streams which can be constructed on small gullies for limited water supply to rainfed crops are discussed here. Gully dam storages are generally economical in comparison with other surface resrevoirs, because their storage vs earthwork ratio are high, varying from 5 to 10. Verma (1992) found cost per unit capacity varying from Rs. 5.6 to Rs. 12.3 per cubic meter capacity in Shivaliks of norther India. As these reservoirs are for huge water supply, individual farmers having small holdings (like Indian rainfed farmers) cannot afford them. However, they could be constructed on a group of community basis in such areas. In other countries, like Australia, where farmers have large holdings, they are able to construct gully dams on their farms if topography and other factors permit.

Excavated reservoirs

Excavated reservoirs are generally constructed in relatively flat regions. They are also called tanks or ponds and store water within constructed walls. Gully dam storage or hillside storage sites are not available on flat land and thus excavated tanks are the only alternative for storing harvested water. The excavated tank/pond is generally fed by runoff in rainfed areas and be located in a natural waterway or to one side of waterway if there is possibility of diverting runoff into it. In cropped watersheds/catchments, the idea of storing excess runoff in excavated tanks for its later used as supplemental irrigation pre-supposes that available active storage in root zone has been fully utilised. Excavated reservoir should be constructed at sites having relatively impervious soils, thereby avoiding excess seepage. previous layers of clay or silty clay are very suitable for the tank. If possible, the reservoir depth should be limited to the availability of such layer. Sites having porous soils with sand and gravel in the sub-soil should be avoided, as artificial sealing of surface would be required to check seepage.

Excavated tanks should be steep and deep as possible within the limitations workability and pumping conditions, so as to reduce the containment area, thus minimizing seepage and evaporation losses. These reservoirs are usually excavated using a bulldozer for economy. Verma (1991) found initial cost of excavated lined tanks as Rs.13.0, Rs.7.9 and Rs.6.4 for 1000, 10000 and 100000 mm^3 capacity. The benefit cost ratio of such fouks varied from 1.6 to 4.5 in Nothern India (Verma, 1988). Excavation of reservoirs in lowland areas or in depressions reduces earthworks. The tanks located at favourable locations may have storage vs excavation ratios ranging from 5 to 20 (Singh, 1983). On flat land it is difficult to store water above the ground and make use of the embankment for storage. Generally, storage/excavation ratios remain close to 1:1. The embankment of the reservoir can be utilized for storage by pumping water into the storage level. This solution depends on the relation between the cost of excavation and pumping.

Helweg and Sharma (1983) suggested construction of elevation inlet tank by intercepting runoff at higher elevation in the catchment and diverting it through elevated earthen channel to the tank below. In this case water is partly stored in the excavated portion and partly above ground level. It increases the storage to excavation ratio reducing cost of construction.

Helweg and Sharma (1983) developed a nonlinear optimization model to design capacity of tanks for semi-arid tropics of India. The model is based on ideal conditions like most economic shape of an inverted truncated cone with circular cross section and trapozoidal dyke, annual amount of irrigation water application, elevated inlet and minimization of total cost of excavation.

Palmer et al. (1982a) developed a simulation model combining a watershed runoff model and acorn grain model to determine the tank size necessary to ensure the availability of water for irrigation. They obtained probability curves of yield as a function of reservoir size for the simulation period. They have also presented a procedure for determining the optimum reservoir size, based on economics for water supply for supplemental irrigation. The procedure can also be used to evaluate risk of supplemental irrigation investment (Palmer et al., 1982b). For tank design a more dependable yield, smaller and occuring more frequently than the average should be selected (Harold and Victor, 1964). Many researchers have recommended 95 to 90 percent reliability for domestic and live sotck water supply and 80 to 60 percent reliability in case of irrigation water supply. Similar guidelines were also used in Southern India for farm pond design (Jaya kumar, 1975). Verma and Sarma (1990) suggested 40 to 80 per cent as appropriate probability level of lowest assured seasonal runoff for tank design for cropped catchment varying from 1 to 100 ha. In cropped watersheds of northern India, invested truncated pyramid shaped tanks lined with polyethylene (200 micron) at bottom and brick-cement (7.5 cm) on sides (slope 1:1) were found suitable (Verma and Saran, 1990 and Verma 1988).

Ring tank

These tanks are constructed on flat land and water is stored above ground surface. A circular embankment is made by excavating from within the perimeter. Some-times, the central portion of a ring tank is excavated for use in the embankment and a portion of the water is stored below ground level, too. These tanks are constructed by radially pushing earth by bulldozers, using scrapers.

When wall material of the ring tank is taken from the outside of the tank for its construction, it is called "Turkey Nest Tank". Nearly all stored water from turkey nest tank can be recovered by gravity. Ring tanks are filled by pumping.

Depression storage

Runoff water may also be stored in natural depressions with slight modifications. Natural depression storages are generally shallow and have large surface areas. A portion of these depressions can be excavated to concentration the stored runoff, thus reducing evaporation losses. Arland (1975) has found that economical storge can be obtained by construction dikes through the PLAYAS (depression) to form a reservoir and diverting all runoff into the reservoir by terraces.

SEEPAGE CONTROL IN TANKS

Seepage is one of the main losses from storage reservoirs, especially in the regions where soil is too permeable. Proper site investigation at the planning stage is essential to select a site having a relatively impermeable soil. However, the need for water and other factors relating to site selection may be so important to justify the selection of a permeable site. Seepage increases with the wetted area of a reservoir and special consideration during design should be given to minimize the wetted (containment) area per unit of storge capacity.This may be achieved by steepening the sides of batters and increasing the depth in relation to the surface area.

Seepage losses in reservoirs can be decreased by reducing the permeability of the containment to a tolerable limit. The tolerable seepage limit depends on many factors, like storage period, water requirement and economic analysis of available water. Sealing of reservoirs is essential to reduce seepage losses.

Many sealing methods and materials for seepage control have been recommended and recent technology has produced many inexpensive waterproof materials, but selection of a particular method or material for seepage control at particular location requires complete analysis of tolerable seepage, cost of sealing and maintenance, and availability, effectiveness and life of lining or sealing material. A good lining should have long effective life and should be install and maintain. Some of the seepage control methods are described below:

Reducing Wetted Area

Seepage loss increases with the wetted area of tanks and special consideration during desing should be given to minimize wetted area per unit of storage volume. This can be achieved by increasing depth and increasing the side slopes of the tanks.

Cluff (1977) has suggested compartumentalized tank in which the tank is divided into two or more sections and as the sections are emptied the water is pumped out of one section into the remaining sections to reduce seepage and evaporation losses by reducing wetted area. Under Indian condition sit is not viable because of high cost of withdrawal of tank water within a short period.

Self Sealing by Silting

Seepage losses in a tank automatically reduce with passage of time. Very fine clay and silt are washed away with runoff and get deposited after silting on wetted surface sealing the pores. Studies at Dehradun and Rajkot (Vijayalakshim et. al. 1982) reveal that seepage from a newly dug tank get stabilized to a very low rate in a period of 8 years due to silting. Silting also reduces seepage rate in brick lined tank (Verma et.al. 1984a).

Puddling

Trampling by animals in tank induces puddled conditions which reduces seepage loss. It is a common practice in case of village tanks of India.

Compaction

Simple compaction on tank wetted surface can reduce seepage in well graded soils. After clearing tank bottom a thin layer of impervious soil should be spread and after pulverizing to 20cm depth it should be compacted seal should be increased with the tank depth.

Particle Size Selection

Seepage loss from a permeable tank can also be reduced substantially by mixing large aggregates into the soil (Victor, 1978). By adding large aggregate, the amount of other sealing materials may be reduced. In the case of clay lining its amount may be reduced by half by adding larger aggregate.

Natural Clay soil Lining

Clay soil lining is generally the most economical in controlling seepage losses especially in large tanks. This type of lining is adopted only where bands of clay deposits are available near tanks. Pond surface having coarse grained soil may be sealed by putting a blanket cover of clay soil. A tank with 3m depth should be sealed with at least 25cm thick clay blanket. A gravel cover of 30 to 40cm should be placed over the blanket to protect it from cracking. Side slopes of the tank should be flatter enough to prevent the blanket from sliding under gravity.

Bentonite Lining

Similarly, seepage loss in a well graded coarse soil may be reduced by mixing bentonite in the surface soil of tank. Actually bentonite can absorb several times more water and swell 8 to 15 times its volume. The main advantage of bentonite lining is low cost and simplicity of ihstallation while its disadvantage is its short life. Bentonite loses its effectiveness and durability due to fluctuation resulting from wetting and drying of reservoir and removal of surface layer by erosion and seepage. Detailed studies on bentonite for seepage in tank are carried out in Western United States. About 5 kg of bentonite per m^2 is required (Bowman, 1967; Shen, 1959 and Rollins et.al. 1970))

Alkali Soil Lining

Preliminary investigation in small tanks revealed that it was practicable to reduce seepage loss effectively by plastering the tank with alkli soil of 5cm thickness (Venkatanadhachari et.al, 1979). Alkali soil has also been used for tank lining at Ahantpur (Vijayalakshmi, et.al, 1982).

Soil Deflocculents

Soil deflocculents like sodium carbonate, sodium chloride, tetrasodium polyphosphate and sodium tripolyphosphate can be used for reducingpermeability of tank surfaces. Sodium choride and sodium polyphosphate failed within 6 and 18 months, respectively, but sodium carbonate was more durable (Seginato and Myers, 1965 Reginato et.al, 1973). Reginato et.al, (1973) suggested that for successful sodium carbonate treatment at least 3cm of soil should be put over the pervious material and the clay content of soil should be at least 15 per cent and cation exchange capacity should be greater than 15 mill- equivalent per gram. Following equation for determining the amount of sodium carbonate required for sealing was proposed:

$Na_2\,CO_3$ = 0.0428 D.A. (0.15 CEC-ES)

where

$Na_2\,CO_3$ = Sodium carbonate, gm
D. = Depth of soil treated, cm
A = Area to be treated, m_2
CEC = Cation exchange capacity, meg/100g
ES = Exchangeable sodium, meg/100g.

Graveland and Olynk (1973) found that increasing the $Na_2\,CO_3$ application further decreased hydraulic conductivity and they modified above formula increasig coefficient of CEC from 0.15 to 0.25. Sodium carbonate has been found very effective and cheap for seepage control in tank (Nicholaichuk, 1978) and Vijayalakshmi et.al. 1982). Eventually, calcium and magnesium replace the sodium applied through $Na_2\,Co_3$ and seepage may start to increase after 2 or 3 years.

Gleization

Gleization is a new method used for reducing seepage in tank. It involves the use of origanic matter like straw and manure. Under anaerobic conditions, the metabolic activities of certain anaerobes affect a chemical reduction Process in soil which results in increased plasticity and dispersity and a decrease in permeability (Nicholaichuk, 1978). After a series of tests conducted in laboratory as well as in field, Nicholaichuk (1978) found that a combination of gleization and sodium carbonate resulted in an immediate seal upon treatment and neither sodium carbonate nor bentonite impeded the microbiological gleization process. In India also, storage tanks lined with wheat straw or cow dung mixes with soil has shown good results in controlling seepage (Vijayalakshmi, 1982).

Chemical Sealants

U.S. Bureau of Reclamation (1963) studied many chemicals iincluding resins, silicones, lingins, scrylomides and cationic asphalt emulsion but none was found very effective in seepage control. Willson (1964) tested cationic asphalt emulsion, petrolium emulsion and resinous polymers and found that these are short lived and affected by wetting and drying and erosion.

Asphalt Lining

Asphalt is a very common lining material which has been used in various ways for tank lining throughout the world. Geir and Morrizon (1979) used asphalt impregnated jute for tank lining and found it costly and inferior to polyethylene. Rauz et.al, (1970) used 4.2 kg/m_2 soft asphalt for tank lining and found it effective for only 3 years. There were severe fractures on loam and fine sandy loam soil as compared to dunesand soils. Froebel et.al, (1978) found mixture of asphalt cement with crumbrubber very effective for seepage control. In India asphalt lining has been found effective in controlling seepage (Shah et.al, 1978; Vijayalakshmi et.al, 1982; and Dwivedi and Sarkar, 1983), but it loses its effectiveness after few year when applied on surface.

Enzymes

Some enzymes are also tested for seepage control in tanks. Bayer and Cluff (1971) mixed organic enzyme with lubricants as aids in compaction of tank surface and found reduction in seepage rate.

Soil-Cement

Soil-cement lining has been widely used for tank lining. In well graded sandy soils, 7-12 per cent cement by volume should be mixed on the top 7.5 to 15cm layer of soil to check seepage in tank (Kraatz, 1977). Proper compaction, watering and curing is essential for setting and avoiding cracking. Soil-cement (10:l) has been found very effective in controlling seepage in tanks (Havanagi, 1982). The permeability of almost all soil-cement is an inverse function of cement content, i.e., an increase in cement will decrease permeability.

Lime and flyash have also been tried to control tank seepage and have been found effective (Dwivedi and Sarkar, 1983).

Membranes

Sealing membranes (thin films) may be used for lining tanks either exposed or burried under a protective earth layer. Exposed membrane requires special protection to resist erosion, mechanical damage and weathering and, thus, it is costlier. It is some time difficult to stabilize the membrane on side sloped of tanks. The side slopes should be flatter than 3:1 or steps should be asphalt, butyle rubber and plastics have been successfully used for seepage control (Mickelson, 1070; Kraatz, 1977 and Nicholaichuk, 1978).

Currently polyethylene sheet lining is widely used for tank lining. If carefully placed and covered it can give 100 per cent sealing and long expected life (50 years) (Mccracken, 1969). The main disadvantage is the susceptibility to puncture (Vijayalakhmi and Vittal, 1984). Polyethylene sheet lining has been successfully used in tanks and found very cheap (Rao et.al, 1980 and Verma et.al, 1981).

Hard Surface Lining

Concrete, brick, tiles and stones are used for hard exposed lining of tanks. These are most effective and stable lining having long life but are too costly. Brick, tiles and stones are used with cement mortar for lining. These lining materials are selected according to its availability in the region. Bricks and tiles are prous and some times sealing effect is produced by mortar used for its lining. Bricks are porous than stones and it may be treated before lining to seal its proes or a cement plaster (1:3) of 1 cm thickness may be applied. Stone slabs are available in many parts of our country at cheaper rate which can be used for tank lining.

Various lining materials have been tried at different centres of All India Coordinated Research Project for Dryland Agriculture for seepage control in tanks. The effective sealants are given in Table 3.

Table 3. Some effective sealants for tank seepage control

Research centre	Material used	Seepage as percentage of control
Bangalore	Clay + Na Cl + Na_2 Co_3 (20:5:1)	19
	Soil-cement (5:1)	30
	Soil-cement (10:1)	42
Dantiwada	Plastic overlaid by brick work	9
	Lime Mortar (1:6) with asphalit lining	11
	Cement-sand (1:6)	19
Hyderabad	Plastic sheet overlaid by brick work.	0
	Brick lining overlaid by cement plastering	0
	Asphalt	13
Ludhiana	Bottom - polyethylene	2
	Sides - brick lining	6
Rajkot	Soil + cow dung + straw (7:2:1)	11
	Soil compaction to high bulk density	43
Ranchi	Coaltar	44
	Clay	56
Varanasi	Black polyethylene	4
	Soil-cement (10:1)	24

Source : Vijaylakshmi et. at. (1982)

EVAPORATION CONTROL IN TANKS

In many rainfed areas high evaporation loss from the tank surface is the main problem in rainwater management system. The tanks should be designed for minimum possible surface are to avoid evaporation losses. This may be achieved by increasing tank depth. Compartmentalized tank method suggested by Cluff (1977) as discussed earlier also reduces evaporation losses but it is not feasible practically as well as economically under Indian conditions. There is a little possibility of providing a wind breaker by raising embankment and growing trees around the tank.

For reducing available solar energy for evaporation and transportation of vapour floating sheet covers of plastic membranes, polystyrene and foam rubber; floating blocks of asphalt-concrete, foamed wax, and wax, and circular material like plastic spheres, white silica sand, chopped polystyrene foam, pertito are, hydrophobic calcium carbonate etc. are tried on tank water surface but none has been economically feasible especially under Indian conditions due to high cost.

Many monolecular films of organic chemicals like octadecanol and hexadecanol have also been tried to reduce evaporation from tank surface. These are of low cost and easy to apply but are not effective. These films can reduce evaporation only by 20 percent (Cooley, 1974).

UTILIZATION OF STORED WATER

The scarce amount of harvested water in tanks may be used for drinking water supply or for industries agriculture. In this report water supply to agriculture has been focussed . The stored water can be used for fish farming, tree plantation, intensive irrigation to small area and extensive supplemental irrigation to rainfed crops. Despite good control of seepage losses, water losses from tanks are significant and after the end of monsoon the volume of water goes on decreasing with passage of time and the unit cost of water, thus, increases with time. Stored water in a tank is a developed resource and is, therefore, more expensive than the natural resource. Hence, there is a need to utilize it judiciously and efficiently.

There is a controversy as to whether the benefit from crop returns is increased by limited supplemental irrigation over large area with small quantity much below the water requirement or by intensive irrigations according to the optimum water demand over a small area. The former approach allows drought insurance to more area or more farmers and maximum returns of water applied, but this costs more on lengthy water conveyance and application systems, which are to be used for a very small period in a year (Zimmerman, 1956). Thus, for a particular area it becomes essential to know whether a fixed amount of irrigation water is utilised more efficiently by the full irrigation to a small area or by the limited supplemental irrigation to larger area that could otherwise be under rainfed farming. Maximising yield per unit area through intensive irrigation is economically justified where water is readily available and irrigation cost is low, but when water supplies become more limited or irrigation cost is high, the objective of irrigation shall be to maximize yields per unit of available water (Stegmen et.al, 1980). The harvested water may be judiciously used for crop life-saving (protective) /supplemental irrigation to increase and stabilize crop yield and to increase cropping intensity. The used harvested water should be managed in such a way that stored soil-water and applied water are used by the crop with the highest efficiency.

The yield response to depth of total irrigation water is a diminishing return function and at some level further application of water cannot be justified economically (Stegmen et.al, 1980).

Correct timing for supplemental irrigation requires knowledge of crop response to applied water at different growth stages. During some particular stages the plants are more sensitive to moisture stress than at others and these moisture-sensitive (critical) periods different with crop and varieties. In some cases these critical periods may also differ under different climatic and soil conditions for the same crops. These critical moisture-sensitive periods for various crops have been described in detail by Hukkeri and Pandey (1977) and by Hiler and Howell (1983). Application of water stored in a tank as supplemental irrigation at these critical stages is more productive than when applied at other stages because moisture stress during these periods will considerably reduce crop yield which cannot be recovered by subsequent application of water of later stages.

The results of an experiment at INRISAT, Hyderabad show that 5 cm supplemental irrigation in Alfisol applied to sorghum (at grain-filling stage) and maize (at pre-tasseling stage) increased yields of both the crops by more than 100 percent. However, pear lmillet showed an increased of 17-59 per cent and sunflower 27-32 per cent (Anonymous, 1976). The reason for small yield increase in the case of sunflower and pearl millet may be because of irrigation at non-moisture sensitive stages, whereas more increase in yield of sorghum and maize are due to timely irrigation at critical stages. Verma and Sarma (1989) suggested identification of critical dry spells at crtical stages of crop growth for planning a supplemental irrigation.

Crop water use efficiency (WUE) under field conditions increases, especially in grain crops, with the decrease in soil water supply until it is above a minimum critical level because plants actively try to economise water loss in the range from the minimum critical to optimum moisture level (Hukkeri and Pandy, 1977). However, total production per unit area decreases as the available soil water comes down below optimum level. Shmuely (1973) has also suggested the application of less than the desired amount of water to growing crops to increase water use efficiency.

In areas where water supply is inadequate in relation to area, limited supplemental irrigation is often practiced with a view to obtain less than maximum yield per unit of available water. The major advantage of the limited supplemental irrigation is the increase of total farm yield and WUE by reducing the area allocated for complete rainfed farming (Stemen et al. 1980).

Stewart et al.(1981) designed and tested a limited irrigation - dryland (LTD) farming sytem utilising seasonal rainfall and limited amount of irrigation water. The unique system has flexible adjustment of the amount of land irrigated allowing more land to be irrigated during wet years with a limited amount of irrigation water than during a dry year and it uses furrow irrigation without causing runoff from the field.

There is a very high pay off to the tune of 2 q/ha/cm from supplemental irrigation (Venkateswarlu, 1982). A 5 cm irrigation given at critical stages of wheat, barley, sorghum and rice at 10 different stations of the coun try increased yield from 15.3 to 23.8 q/ha with efficiency of water use 20.9 kg/ha/mm. The results of multi-location trials carried out at different locations in India on one supplemental irrigation to rainfed crops are presented in Table 4. It is seen from the table that in the northern part of India, wheat has maximum response to supplemental irrigation which varies from place to place.

Verma (1987) reviewed available literatures on supplemental irrigation to wheat and maize. Majority of research workers has suggested 5 to 6 cm supplemental irrigation to wheat at early stress especially at presowing stage (in case of deficient sending zone moisture) or at CSRI stage of wheat.

Table 4 : Effect of one supplemental Irrigation (5 cm) on yield of rainfed crops

Crop	Station	No.of trials	Yield g/ha		W.U.E. kg/ha/cm
			Without irrigation	With irrigation	
Wheat	Dehradun	4	21.4	35.5	282
Wheat	Jodhpur	4	19.8	36.0	324
Wheat	Ludhiana	4	19.2	41.1	431
Wheat	Agra	2	21.9	27.4	110
Wheat	Rawa	4	5.7	18.8	262
Barley	Varanasi	2	26.0	33.6	148
Barley	Ranchi	-	5.5	11.7	124
Sorghum	Bijapur	5	16.5	23.6	148
Sorghum	Bellary	4	4.3	13.7	182
Sorghum	Solapur	5	9.8	18.2	168
Sorghum	Hedrabad	2	13.9	19.2	106
Sorghum	Kovilpatti	3	27.8	28.9	22
Upland rice	Rawa	4	16.2	27.8	232
Bidi tobacco	Anand	4	12.1	18.1	120
Finger millet	Bangalore	-	16.2	23.2	140
Pearl millet	Jodhpur	4	16.6	19.00	48
Pigeonpes	Jhansi	-	0.5	3.3	56
Sunflower	Bellary	-	1.3	2.9	32
Rape seed	Randhi	-	2.5	5.4	58
Chillies	Bangalore	-	2.1	4.5	48
Bidi tabacoo	Vasad	2	14.6	17.5	58
Safflower	Vasad	1	15.6	20.2	92
Mustard	Vasad	1	16.5	20.4	74
Gram	Vasad	1	10.8	16.3	110
Cowpea	Vasad	1	20.4	20.8	7.6

Source: Singh R.P. (1983)

In case of maize, tasseling-silking stage has been found most critical for a a supplemental irrigation. In northern India an irrigation of 5 cm. at presowing or at CRI stage increased rainfed wheat grain yield by 7.7 g/ha (Verma, 1981). According to Gajri et al. (1981) a supplemental irrigation to rainfed wheat increased grain yield by 30 to 81 per cent (Table 5).

Table 5 : Maximum response of rainfed wheat to one irrigation

Station	No. of trials	Average additional yield in response to one supplemental irrigation, q/ha	Percent increase over control
Ludhiana (Punjab)	16	11.0	54
Dehradun (U.P.)	6	14.7	81
Ranchi (Bihar)	2	2.4	30
Garhshankar (Punjab)	7	7.8	31

Source : Gajri et al. (1981)

INTEGRATED WATERSHED DEVELOPMENT AND MANAGEMENT APPROACH FOR RAINWATER HARVESTING

Watershed is a natural unit of land for managing water particularly surface water. It is an area from which runoff flows past a single point into a stream, a river, a lake or an ocean. A watershed is really a catchment area or drainage basin enclosed by a ridge line or divide line. Watersheds of small streams are sub-watersheds of the watershed of larger stream. Land, water and vegetation are the most important natural resources in a watershed for the existance of its inhabitants (human and animals). Rainfed watersheds are subjected to excessive soil erosion, fertility depletion and deforestation and ultimately land degradation resulting poor yields of food, fooder, fuel and timber due to improper use and management of the natural resources. An integrated approach is required to develop and manage a watershed in scientific ways to increase its productivity and meet the demands of the increasing population with ultimate aims of improving economic conditions of the inhabitants and conserve all the resources for future.

Rain water harvesting is a vital and basic component of watershed development and is a pre-requisite for management of other resources of the watershed like soil, vegetation, crop, animal and human resources. It should get top priority as it is the foundation for the sustainable agriculture in the watershed. Planning, design and execution of rain water harvesting works in a watershed should strictly follow following watershed principles.

1. A systematic execution of rain water harvesting should be taken up from highest ridge to the lowest valley line in each sub-watersheds.

2. Land should be utilised according to its capability

3. Maximum possible rain water should be conserved where it falls.

4. Lands should be provided with adequate vegetal cover on the soil during the rainy season.

5. Excess rain water should be diverted to storage tanks with safe velocity.

6. Check dams at suitable intervals should be constructed to avoid gully formation and to control soil erosion and recharge ground water.

7. The multi-disciplinary programmes should give maximum productivity per unit area, per unit time and per unit of rain water.

8. Cropping intensity should be increased through rain water management and land equivalent ratio should be increased adopting intercropping and sequence cropping.

9. Marginal lands should be safely used through alternate land use systems.

10. Sustainability of complex eco-system of the man-animal-plant-land-water should be ensured.

11. Total income of the inhabitants should be stabilised at higher level reducing risks during aberrant weather conditions.

12. Infrastructural facilities with regard to education, communication, transport, storage and marketing should be improved.

The objectives of rain water harvesting in a watershed area may be to:

1. prevent further damage of lands
2. develop lands already damaged
3. control productivity of lands
4. use maximum rain water for optimum production of crop/fodder/fuel/timber
5. check sedimentation of storage optimum production streams.
6. supply good quality water
7. check flood hazards down stream
8. recharge ground water.

The criteria for the determination of rain water harvesting priority area and priority of works should be based on curative, preventive and exploitative measures depending upon the sevarity and frequency of damage and productive potential of the land resources in the watershed. A large watershed may need different types of rain water harvesting techniques in different types of sub-watersheds depending upon the priority. For determining priority area of rain water harvesting in a watershed, factors like peoples participation, aesthetic value, accessibility and sentimental value attached to watershed should also be considered.

Rain water harvesting and its management in rainfed watershed having integrated land use systems is a multi-disciplinary and multi-departmental programme. It involves agencies dealing with agriculture, forest, animal husbandry, fisheries, soil conservation, road, dams, irrigation, drainage and buildings. In addition to this, the cooperation of agencies dealing with communication, marketing, banking, cooperatives, panchayats and social and voluntary organisations are also needed. Peoples participation is a must for successful implementation of watershed development and management programme. The rainwater harvesting and its management works should be designed and demonstrated to the watershed farmers in such a way that all farmers take interest in the development and maintenance of works. Presently various watershed management programmes are going on in these areas under central government, state government, institutions and other agencies.

Hydrologic responses of a watershed can be controlled and regulated employing rain water management technologies to fulfill aims and objectives of the watershed management programme. For successful implementation of watershed development and management programme, the multi-disciplinary team of workers should be headed by hydrologist/soil and water engineer at the initial developmental stage and after completion of major rain water management works. The team should be headed by agriculturist/forester/horticulturist at the management and maintenance stage according to priority area.

The watershed development and management works at the Operational Research Project Sukhmajri near Chandigarh have been an eye opener for taking up rainfed watershed management works on large scale. Grewal et al. (1988) have reported that rian water harvesting from a small hilly forest watershed of 1.52 ha by constructing a 6.5 m high earthen dam to store 9300 m^3 water has increased rainfed crop yields many-fold by supplemental irrigations. The harvesting stored water is conveyed to 2 ha rainfed area through a pipeline by gravity. Th rain water harvesting and management works have encouraged farmers to adopt other improved farming practices and social fencing of sub-watersheds. There are many successful stories of watershed management where rain water harvesting has been a key factor.

SUGGESTIONS FOR FURTHER WORK

It is possible to develop specific techno-economically viable plans for rain water harvesting on watershed basis. Rain water harvesting technologies are available in piece-meal. There is an urgent need to develop location specific packages for rain water harvesting and its recycling systems to fit in the watershed development and management programmes for optimum utilization of watershed resources and sustainable growth of agriculture, maintaining good ecosystem. Rain water harvesting has been totally ignored in irrigated areas. Lowering of water table and increasing cost of lifting water have been forcing scientists and farmers of some irrigated areas to contemplate for adopting rain water harvesting. Research investigation are, thus, also needed for conjunctive use of direct rain water through water harvesting techniques and transported surface and ground water available for irrigation.

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