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WATER CONSERVATION THROUGH LAND TREATMENT MEASURES

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ABSTRACT

The basic source of water on the earth is precipitation which may be in the form of rainfall or snowfall. Estimates have been made that the entire country received about 400 m ha.m of precipitation during a year. Out of this about 115m ha.m flow as surface runoff, 215 m ha m seeps into the ground and rest 70 m ha m gets lost to atmosphere in the form of evaporation from streams and land surface. The country has been facing severe drought conditions for last 2-3 years in succession due to deficiency of rainfall. Keeping in view the continuing nature of drought conditions it may be worthwhile to review all land treatment measures which help in conserving water. These treatment measures may be basically employed for increasing runoff from land surfaces in areas where less rainfall is received. These measures may include physical clearing of land surface, management of vegetation on upland watershed, use of mechanical measures etc.

In the present report a detailed review of all land treatment measures have been presented and effectiveness of all measures have been discussed based on available results. The viability of these techniques for conditions in the country would also be discussed. This will be helpful in planning overall strategy for water management.

1.0 INTRODUCTION

It is hardly necessary to state that water is one of the most important minerals and vital for all life. It has played an important role in the past and in the future it will play the central role in the well being and development of our society. This most precious resource is sometimes scarce sometimes plentiful and always very unevenly distributed both in space and time. In the present year many parts of country are suffering from severe drought due to abnormal rainfall. The variation of rainfall in India over space and time has created conditioned that about one third of the geographical area and 29% of the population of the country are affected by drought. The impact of drought is felt in the water supply for domestic and industrial uses, agricultural and fodder production and stream water quality because the occurrance of drought leads to low stream flows and consequent ground water. Therefore, in the scanty rainfall areas there is need to conserve water through land treatment to overcome the various problems caused by drought.

One method of greatly improving runoff efficiency and providing water of high quality is to artificially treat the surface of the soil. This increases the runoff which can then be stored until it is needed. A facility designed to catch rainwater using artificial means is called a water harvesting catchment. The term water harvesting refers to the deliberate collection of rainwater from a surface (catchment) and its storage to provide a supply of water. This process is distinct from the natural runoff of water into perennial rivers which is then controlled and stored in dams and reservoirs. There are many regions in the world where rainfall is heavy for some months of the year and light for the rest; rainwater and storm runoff, harvested in season and then stored, would help in alleviating the problem of water shortage during the dry season. Water harvesting was used as early as 3000 B.C. by a large indigenous civilization in the Negev Desert in the middle east in a region receiving less than 200 mm of rainfall annually.

Much efforts have been made recently to improve runoff and water harvesting techniques through various land use treatments. The present report is an attempt in the direction to review the status of various water harvesting techniques and studies conducted in India and elsewhere.

2.0 LAND TREATMENT MEASURES

The basic source of water is precipitation in the form of rainfall or snowfall. The country's average annual rainfall is about 119.4 cm which when considered over the geographical area of 328 m ha m amounts to 392 m ha m. This may be rounded off to 400 m ha m including snowfall which is not yet fully recorded. It is estimated that out of the average annual precipitation of 400 m ha m, about 70 m ha m, is lost to atmosphere. Of the remaining 330 m ha m, about 115 m ha m flows as surface runoff and the rest 215 m ha m soaks in to the ground (Fig.1). However, the problems posed by drought vary from area to area, depending on the amount of rainfall and its variability. It is generally assumed that the districts which receive less than 75 cm of rainfall per annum are liable to drought. As stated earlier, about 53.75% of annual precipitation gets infiltrated into the ground per annum, so there is need to increase surface runoff in scanty rainfall areas by reducing the infiltration capacity of soil through different land treatments, which can be served for agricultural, domestic and industrial purposes in the drought prone areas.

The various means of increasing the runoff from an area can be classified as follows:

1. clearing sloping surfaces of vegetation and loose

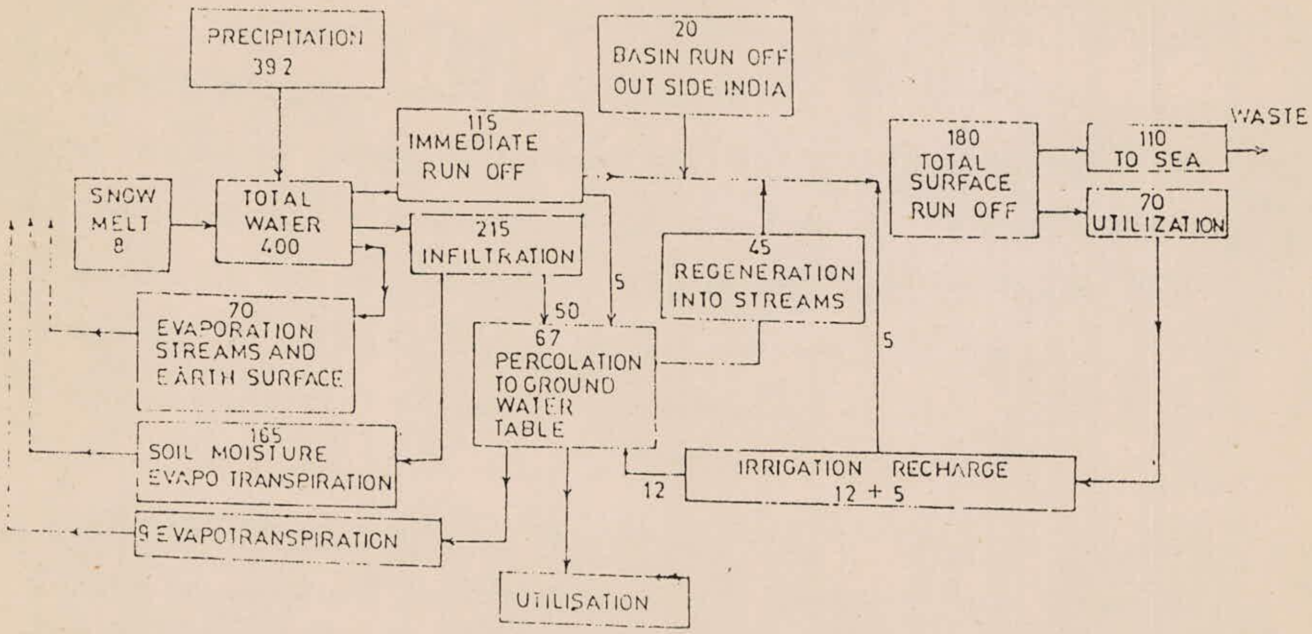


FIG. 1 — WATER RESOURCES OF INDIA (M. ha. m.)

materials.

2. vegetation management by changing ground cover;
3. mechanical treatment including smoothing and compacting the surface, contour terracing and micro-watersheds;
4. reducing soil permeability by the application of chemicals;
5. surface binding treatments to permeate and seal the surface;
6. covering the catchment with a rigid surface; and
7. covering the catchment with a flexible surface.

2.1 Surface Clearing

Land clearing has been in existence as a runoff inducement method for thousands of years due to its simplicity and requirement of very little efforts. Such practices were used in the Negev Desert of Israel in ancient times. All the runoff can be utilized by removing stories or obstruction material from the fairly impervious catchment e.g. rock catchment. Removal of obstruction can be expected to increase the velocity of runoff and also increases surface soil erosion, unless the natural surface is quite level. The erosion can be avoided by contouring the land which can be further compacted to achieve a greater efficiency in runoff collection. The surface treatments such as rock clearing (Evenari et al, 1971), smoothing and compacing (Frith, 1975) are usually done in combination (Anaya and Tovar, 1975; Fink and Ehrler, 1979).

2.2 Vegetation Management

Over years several countries have experienced rapid increase in demand of food, fibre and fodder. In an attempt to meet the requirement on an adhoc basis unscientific manipulation of land use of watershed has been the consequence. Besides other effects, the land use changes have major influence over hydrology of the basins. The land use changes alter mainly the volume of runoff as well as its time distribution. Also the hydrologic effects that appear to be important as far as land use changes are concerned can be listed as below:

a) increase or decrease in water yield

b) increase or decrease in peak flow

c) increase or decrease in low flow

d) change in surface water quality

f) increase or decrease in ground water flow

f) change in ground water quality.

One of the most important effects of land use treatments is increasing runoff volume.

Vegetation management can alter the water budget of the watershed by modifying the hydrologic processes involved therein. The vegetation manipulation essentially modify the hydrologic cycle which results in water yield alterations. The increased water yield may be caused in part, by changes in one or more of the following hydrologic factors as a result of vegetation management:

i) reduced interception losses,

ii) reduced evapotranspiration losses

iii) changes in the hydrologic properties of the soil's surface and forest floor, and

iv) more efficient conversion of a snowpack to stream flow.

Mostly experiments on vegetation manipulation have been done in USA to increase yield of water. According to experiments carried out since 1950s in Arizona, USA, possible vegetation management strategies include: conversion of areas immediately adjacent to stream channels to runoff-enhancing vegetation covers, cleaning the forest or shrub cover in uniform or irregular strip cuts, and thinning overstory densities. On the basis of above statement vegetation practices or treatments carried out in water yield improvement experiments can be broadly classified in to two categories:

a) Forest cutting or removal

b) Change in forest types or vegetative cover.

Forest cutting or removal of vegetation practices include clear cutting or partial cutting of vegetative cover.

i) Clearcutting: complete removal of the vegetative cover.

ii) Partial cutting: This may include partial cutting, selective thinning, thinning, strip cut, block cut with or without selective thinning.

Changes in forest types or vegetative covers include conversion of natural forest to tree plantation, or from one land use to another, i.e., forest land to grassland, grazing land, agricultural land etc.

2.3 Mechanical Measures:

Another way to conserve moisture is by employing mechanical measures which have great importance in arid and semiarid regions for crop production as well as for soil erosion control. These measures may help in either increasing infiltration, reducing evaporation or preventing unnecessary plant growth. In practice these can be accomplished by the following practices:

i) Contour farming

ii) Strip cropping

iii) Conservation tillage,

iv) Terracing, and

v) Microwatershed system

2.3.1 Contour farming:

Contour farming is the practice of performing field operations, such as ploughing, planting, cultivating, and harvesting approximately on the contour. The small ridges and plant stems in the contoured row hold water and thus prevent runoff. The ridges are most effective in row crops, but the water holding ability of the ridges supplemented by plant stems, makes contouring valuable for small grains also.

2.3.2 Strip cropping:

Strip cropping is the practice of growing alternate strips of close-growing and intertilled crops in the same field. Strip cropping is not a single practice but it is a combination of several good farming practices, particularly crop rotations, contour farming and cover cropping, and may also include conservation tillage operations, and stubble mulching. When strip cropping is combined with contour tillage or terracing, it effectively divides the length of the slope, checks the velocity of runoff, filters out soil from the runoff water and facilitates absorption of rain. The three general types of strip cropping shown in Figure (2) are:

1) Contour strip cropping
2) Field strip cropping
3) Buffer strip cropping

Contour strip cropping:

In contour strip cropping the crops are arranged in strips or bands on the contours at right angles to the natural slopes of the land. Generally the strips are cropped in a definite rotational sequence.

Field strip Cropping:

Field strip cropping consists of strips of uniform width running generally across the general slope and the practice is recommended only in areas where the topography is too irregular or undulating.

Buffer Strip Cropping:

Buffer strip cropping consists of strips of some grass or legume crop laid out between contour strips of crops in the regular rotation. They may be even or irregular in width and can be placed on critical slope areas of the field.

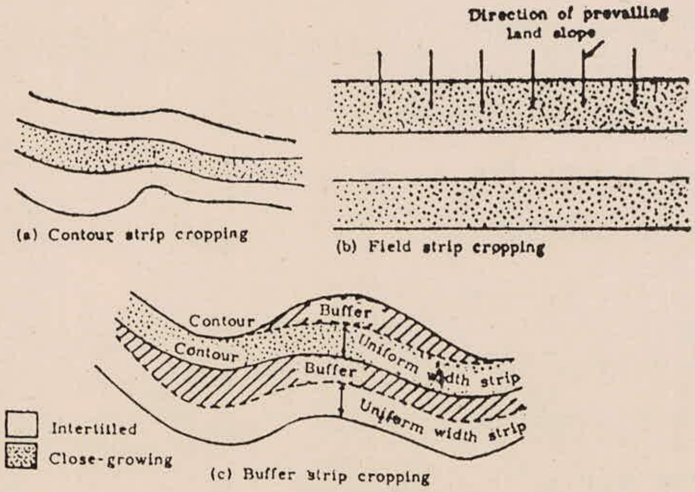


Fig. 2. Typical layout for different types of strip cropping.

2.3.3 Conservation tillage: Tillage is the mechanical manipulation of the soil to provide soil conditions suited to the growth of crops, the control of weeds, and for the maintenance of infiltration capacity and aeration. Traditionally tillage has consisted of cutting loose, granulating, and inverting the plouth furrow slice, thus turning under the residues. While the essential basis for tillage is the preparation of a seedbed, the role of tillage has become more important as a water conservation measure. The conservation tillage operation can be classified into following classes:

(i) Mulch tillage: Mulch tillage or stubble mulching is a crop and soil management practice that utilises the residual mulches of the preceding crop by leaving a large percentage of this vegetation residue on or near the surface of the ground. Tillage that leaves the surface of the soil cloddy and mulched with crop residues is an effective accompanying measure with strip-cropping to minimise soil erosion and to conserve moisture. It is one of the most effective measures to conserve soil and moisture on land that is in fallow and to protect small grain and row crop land during periods of seed bed preparation for a succeeding crop. In extremely heavy mulches, particularly when they are perennial, or when soil moisture is relatively high, it is sometimes necessary to particularly invert or cut up the crop residue.

(ii) Listing and ridge planting: In low rainfall areas in which a large percent of the annual rainfall comes in short intense storms, and in regions where gently sloping fields permit the use of contouring alone as soil and water conservation practice, tillage is frequently carried out with listers.

2.3.4 Terracing

A terrace is an earthen embankment or ridge constructed across a slope to control the runoff and minimise soil erosion. The function of terraces is to decrease the length of the hill-side slope, thereby reducing sheet and rill erosion, preventing the formation of gullies, and retaining runoff in areas of inadequate precipitation. The two major types of terraces are:

i) bench terrace which reduces land slope,

ii) broad base ridge type terrace which removes or retains water on sloping land.

On the basis of primary function, broadbase terrace is classified as graded or level. Graded terrace has a constant or variable grade along its length and is used to convey the excess water at a safe velocity into a vegetated channel or outlet. A level terrace follows the absolute contour, in contrast to a graded terraces. Level terraces are recommended only in areas where the soil is sufficiently permeable and where conservation of moisture for crop use is particularly important. Level conservation terrace consists of an earthen embankment and a very broad flat channel that resembles a level bench. The relationship of this type terrace to the conventional level terrace, both in terms of cross section and in relative moisture storage pattern, is shown in Figure (3).

In the Southwestern United States current research is being carried out on contour terraces, (Figure 4 & 5), where they are constructed along a slope perpendicular to runoff flow. The terraces are separated by sloping collector areas which provide runoff for the narrow field strips below them. The main principle underlying this technique is the use of level, ridged fields to control erosion and to retain, spread and infiltrate storm runoff from the upslope collector areas.

In the Negev Desert Israel slopes are levelled over short widths at different elevations, with a low mud or stone wall separating terrace. Such terracing is found on hill slopes everywhere as well as in smaller wadis in the Negev (Evenari et al., 1971). The technique of terracing is also practised in South Yemen to collect dew and mist during the night time, besides rain water to provide substantial amounts of moisture (Aeron, 1978).

According to Kolarkar et al.(1980), the simplest method of water harvesting in the three types of areas including (i) low plain valley area in between the rocky areas as in Jaisalmer area, (ii) in the low bottom lands in the plains near hillocks as in Siwana area, and (iii) in the low lying valleys in regular ridge and valley pattern physiography as in Bap-Phalodi area, is to divert or slowly channelise the natural runoff flow water from these catchments to the farm lands by means of contour bunds/or

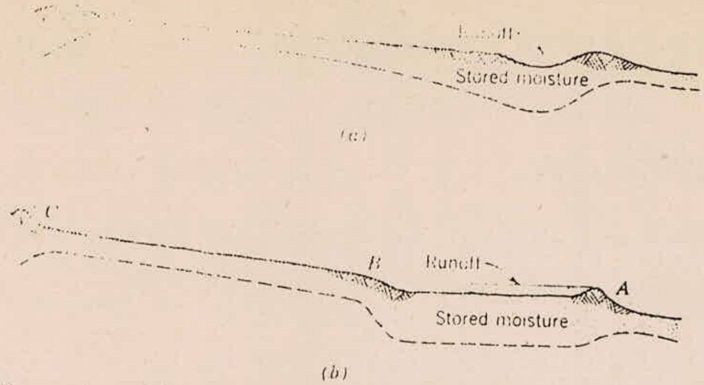


Fig. 3. Comparison of cross sections of (a) conventional level terrace and (b) conservation bench terrace showing available soil moisture stored. Ratio of storage area AB to runoff area BC may be varied to suit soil, cover, and topographic conditions. (After Hauser et al., 1962.)

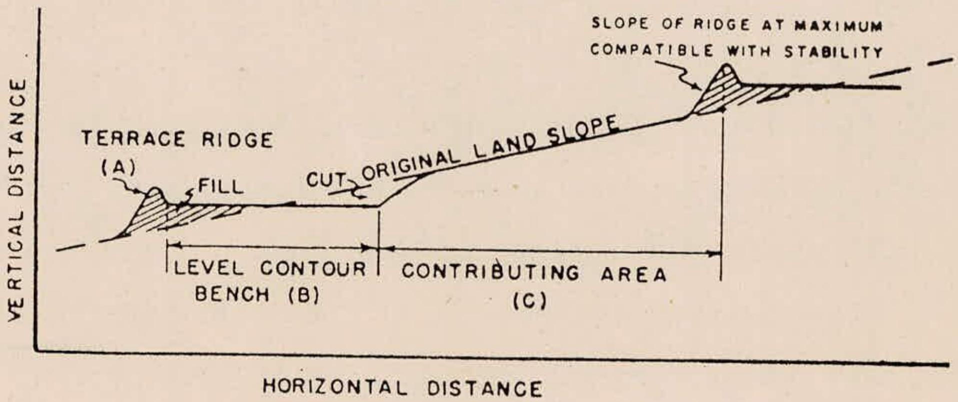


Figure 4 Cross section of a conservation bench terrace (Jones and Hauser, 1975)

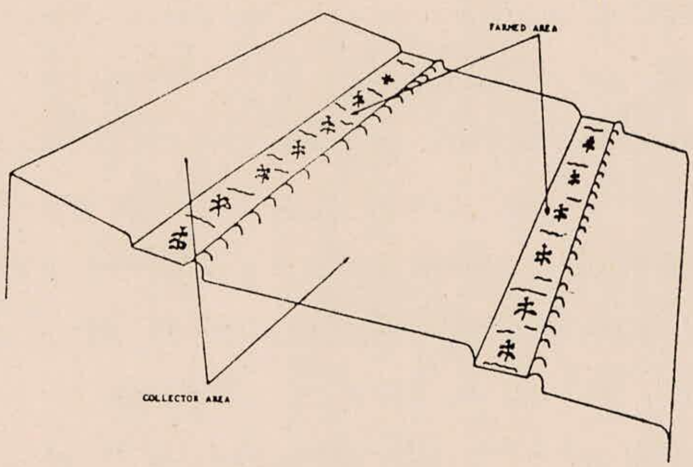


Figure 5 . Diagram of the desert strip farming concept (Morin and Matlock, 1975).

shallow trenches.

In southern Tanzania and Zambia, water harvesting terrace system has been developed to allow for the conservation of excess water where the rainfall exceeds 500 mm. Here ditches are dug following contours and the soil is piled on the downhill side, creating wide shallow furrows which are so carefully levelled that they will retain excess runoff during the rainy season. This excess runoff slowly seeps into the soil.

2.3.5 Microwatershed system:

Microwatersheds operate on the same basic principle as other forms of land alteration where runoff from a collector area is concentrated, retained and infiltrated within a small ridged plot. In the case of microwatersheds, the collector area and infiltration plot serve only one individual tree or a very limited number of plants. The collector area of microwatersheds is devised to maximise runoff while infiltration is encouraged in the basin immediately surrounding the plant. Mulch is frequently used to decrease evaporation.

2.4 Chemical Treatment to Reduce Soil Permeability:

In order to increase runoff, some chemicals can be used to reduce the permeability of the soil. Colloidal dispersion and/or hydrophobic treatment of soil can reduce the soil permeability.

i) Colloidal Dispersion

Sodium salts, when mixed into the upper portion of the soil profile, tend to reduce the permeability of the soil by dispersing the clay fraction. The sodium salt promotes a breakdown of the soil aggregates and the dispersed clay particles migrate with the infiltrating water to a zone where they clog the soil pores and form an impermeable clay lens (Gal et.al, 1984). These salts may be referred to as dispersing agents and include, but are not limited to, sodium chloride, sodium carbonate, sodium silicate and sodium polyphosphate. The amount of salt to be applied depends on type of soil and clay percentage in soil. As a general rule, however, during catchment construction sufficient salt is applied in order to sterilize the soil to prevent weed growth. As reported by Cluff et.al.(1978), a rate of application of 11.4 metric tons/ha was recommended. The treatment of soil to reduce permeability by adding sodium salt is cheap but recent research has found that erosion of the soil is a severe problem with such treatment and that the salt tends to be washed away in a short period (Myers, 1967, Cooley et al. 1975).

For water harvesting applications, sodium salts can be applied to the soil by either (a) surface application as a dry material or water solution or (b) mixed into the soil during final stages of site preparation. Following a rainfall event or other suitable water application, the catchment surface may be compacted to achieve maximum soil density in the surface soil layers. The mixed soil-salt approach has been used on several water harvesting systems constructed for runoff farming applications with agronomic crops (Dutt, 1981, Dutt & McCreary, 1975; Fink and Ehrler, 1981).

Hydrophobic Treatment:

Water infiltrates into soil under the influence of gravitational and capillary forces. The capillary force causing water to move into a soil pore is directly proportional to the cosine of the contact angle between the soil and water surface. This force is maximum when the contact angle is zero, as is usually assumed for most natural soils, and decreases to zero as the contact angle increases from 0° to 90°. When the contact angle exceeds 90°, water will not move into a soil pore unless an external force is applied. Therefore, if by any means the contact angle between soil and water is increased, it will help in reducing infiltration of water. Infiltration may be completely stopped if the contact angle exceeds 90°. Such soils where contact angle exceeds 90° are called water repellent even though they do not actually repel water (Fletcher 1949). Myers and Frasier (1969) also investigated the possibility of increasing precipitation runoff by creating water repellent soils. Increasing precipitation runoff from soil requires only the soil surface to be water repellent. Naturally or accidently created hydrophobic agricultural soils have been reported by Jamison, 1946; Krammes and Debano, 1965; and Wander, 1949. Hydrophobic soils are normally undesirable for agricultural use and studies of these soils have been aimed at eliminating or counteracting the water repellency (Pelishek, 1963). All of the referenced work on soil stabilization by artificially induced water repellency has involved mechanical mixing of chemicals into the treated soil. Application of hydrophobic materials by spraying them on the soil surface should cost less than application by mechanical mixing.

2.5 Surface Binding Treatments:

Petroleum products which penetrate the surface, bind soil particles together and provide an impermeable surface, have been used in many situations for surface sealing. In this connection, studies have been carried out in USA, Israel and Mexico. Recent work in USA with Texas crude oil demonstrated that repellency disappeared within six months of spray application. Researchers, therefore suggest caution in the use of fuel oils as repellents, particularly in view of their rising cost (Fink and Frasier, 1975).

Another relatively cheap material for constructing water harvesting catchment areas is paraffin wax. Pulverized paraffin wax of a low melting point can be hand applied to a smoothed soil surface at a rate of approximately 0.54-1.08 Kg per square meter (Cooley et al 1976; Fink et al.1973). Paraffin can also be applied in the form of granules or flakes and allowed to melt and spread. Early experiments during the 1950s and 1960s demonstrated that the most effective methods consisted of a two layer spraying of catchments. Sites were first cleared, smoothed and sterilized. A cutback asphalt or bituman in solvent was then sprayed on the soil, penetrating and making a strong porous pavement. This pavement was then topped with a non-penetrating asphalt emulsion to seal pores and protect the base against deteriorating by photo oxidation. Several good and effective combinations of asphalt and other materials have also been developed. Wind damage to thin plastic and metal films (black polyethylene, polyvinyl fluoride, aluminium foil, chlorinated polyvinyl, and butyl, used as catchment covers can be reduced substantially by bonding the films to sprayed asphalt pavements, although subsequent problems remain with film durability and water quality (Myers, 1967). Other development includes placing layers of fibreglass or polypropylene matting on the soil surface and spraying them with asphalt then sealing them with roofing grade asphalt emulsion. Usually little surface preparation is required, and almost any soil is adequate. This method results in a very durable efficient catchment, with the matting providing the reinforcement and the asphalt providing the water proofing.

Graveled plastic catchments utilize inexpensive polyethylene cover with as 12.7 to 25.4 mm layer of gravel (Cluff, 1971). The gravel cover effectively protects the polyethylene and holds it to the ground. In as much as some precipitation is retained in the gravel cover, this method should not be used in climates where a substantial percentage of the rainfall occurs in less than 6.4 to 12.7 mm. A gravel extraction soil sifter has also been developed to screen gravel out of the soil, lay down the sheet plastic on top of the fine material, and cover the soil with the extracted gravel. This method is superior to asphalt catchments as it does not produce potentially toxic phenols.

A relatively new catchment construction method named Asphalt-Plastic-Asphalt-Chipcoated (APAC) utilizes or combination of asphalt emulsion and black poly-ethylene sheeting protectively covered with aggregate (Cluff, 1974; Frobel et al., 1976). Similarly, a meeting material of polypropylene, burlap or fibreglass can also be used in combination with asphalt and gravel chips to provide a strong, efficient catchment. In catchment construction, the asphalt emulsion is sprayed on the prepared subgrade at the rate of approximately 1.136 Lit per sq.m. (Cluff, 1974). Polyethylene sheeting or one of the matting material is then placed over the asphalt and a second coat or asphalt emulsion is applied over the reinforcement. This is immediately followed by an application of aggregate chips. The chips extend the life of the asphalt and inhibit the production of oxidation products which can significantly discolour the harvested water (Mayer et al., 1967).

Fibreglass Asphalt Chipcoated (FAC) method, developed by University of Arizona, USA consists incorporation of fibreglass matting into the APAC type treatment. Frobel et al. (1977) have tested the effectiveness of asphalt-rubber for catchment construction at University of Arizona.

Rigid surface rainwater catchments have been built independently to provide water for people and livestock first time in Australia. Kenyon (1929) compiled a paper on ironclad catchments in which he analysed demand patterns and precipitation records. He proposed a scheme with a 2,300 sq.meter catchment made of flat sheets of galvanized iron on a timber framework to prevent corrosion by contact with the ground. Similar schemes had already been constructed in the State of Victoria, feeding into concrete tanks (Kenyon, 1929). Sheppand (1962) used corrugated galvanised iron sheets for catchment construction. Runoff from catchment can be stored in reservoirs excavated in rock or made of concrete. On South Australia roof catchments of iron or timber substructure were constructed as early as 1885. They continue to be a practical and necessary solution to water supply problems in this area.

Evans et al. (1975) suggested that the highway catchments can also be considered as a potential source of harvested runoff for the purposes of livestock water, supplemental irrigation for forage or highway beautification. At present, much of this water is wasted. However, it is estimated that with the construction of relatively inexpensive diversion ditches and storage structures, significant amounts of runoff can be harvested. The concept of water harvesting from highway catchment is shown in Figure (6).

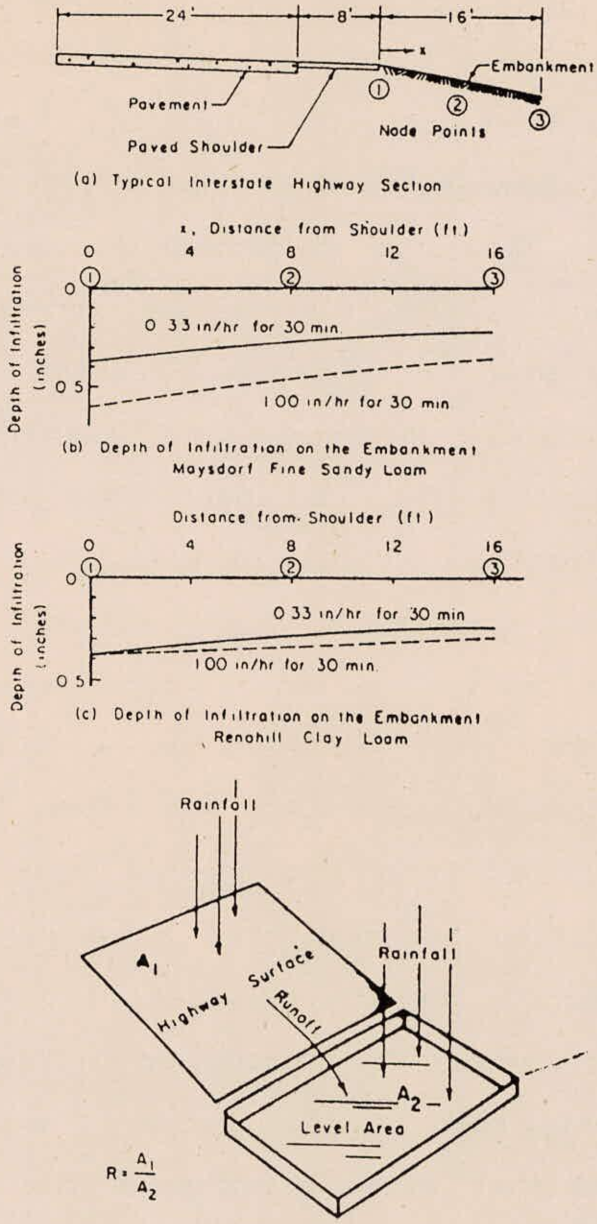


Figure 6 – Diagram of infiltration on highway embankments and of a highway water harvesting system (Evans *et al*, 1975)

2.7 Flexible Surface Coverings

Development and availability of variety of prefabricated product during the last decade, make it possible to quickly and effectively water proof virtually any area. A prefabricated fibre glass mat saturated with asphalt and produced in rolls has been used for canal linings at several places. However, earlier coverings were made of materials similar to those used for roofing. U.S.Bureau of Reclamation tested a variety of plastics for use as canal lining and based on the results of these tests, it is indicated that no plastic was suitable as an exposed lining but if covered by atleast one foot of material (to prevent exposure of the membrane to air and sun light), the newer plastics, particularly polyvinyl chloride and polyethylene, worked very well in reducing water losses.

Other interesting possibility is aluminium foil, which was laid in rolls on a hot-sprayed asphalt emulsion in Arizona. On particular catchment gave trouble when individuals walking on the sheet caused pebbles on the unsmoothed based to protrude and rip the aluminium (Myers, 1967). The asphalt bond eliminated problems due to wind. Aluminium is stable in air so it may be that this construction method would be satisfactory on a very smooth base. Since 1950s, artificial rubber sheeting probably has been the most widely used cover. Its advantages are its lower cost as compared to sheet metal or concrete, and the fact that it can be installed over moderately rough surfaces if sharp stones and shrubs are removed. The most robust of the flexible coverings currently available is butyl rubber.

3.0 EFFECTIVENESS OF VARIOUS CONSERVATION METHODS

Application of any developed technology or results obtained from various field/experimental studies on real field situation depends upon the effectiveness of method among various available methods. Therefore, the selection of any land treatment for conservation of water/moisture depends upon its effectiveness, applicability to particular physiographic and meteorological conditions and economic viability. A brief review of various studies conducted in India or elsewhere, has been presented in previous section and an attempt to review the effectiveness of various methods of water conservation through land treatment measures has been done as below:

3.1 Surface Clearing

In case of surface cleaning method, the catchment is cleared off stones, and other obstructing materials to increase the surface runoff. The surface clearing measures have been attempted in Israel and USA for increasing runoff. The runoff efficiency of catchments is difficult to generalise because it depends on such factors as antecedent soil moisture, storm intensity, storm duration, catchment size, and years after treatment (Fink et.al., 1979; Frasier, 1975). For smoothed catchments, runoff efficiencies ranging from 20-35% have been reported (Fink et al., 1980; Frasier, 1980). The main effect of surface treatment is that it reduces surface storage.

3.2 Vegetation Management

The clearing and removal of forest vegetation can modify soil surface conditions to change the hydrologic properties of the soils due to compaction of surface by logging equipment. Such compaction could reduce the infiltration and thereby increase the amount of overland flow. The changes in forest floor layer may also take place due to vegetation manipulation, which resulted in changes in water regime of catchment. Various studies on change in forest covers or clearcutting have been conducted in India and elsewhere. The effectiveness of these studies described below:

The results of studies conducted on experimental watersheds in areas of mixed conifer, ponderosa pine and chaparral, showed that if a vegetation management programme were implemented in Arizona's 15 major drainage regions, total water yield under normal rainfall conditions would increase by approximately 600,000 to 1,200,000 acre- feet a year (Folliott and Thorud, 1975).

a) Forest cutting or removal

Almost every well designed experiments has shown increased water yield as a response to forest cutting and in general the increase is proportional to the amount of canopy removed. In assessing the results from 94 catchments (Bosch and Hewlett, 1982), concluded no experiments in deliberately reducing vegetative cover caused reduction in yield. Moreover, they even suggest some predictive generalizations as follows:

- Coniferous and eucalypt cover types have approximately a 40 mm increase in water yield per 10 percent reduction in cover.

-Deciduous hardwood have approximately a 25 mm increase in yield per 10 percent reduction in cover.

They also suggest that the increase due to cutting are greatest in high rainfall areas but that the effect is shorter due to more rapid regrowth. The results of selected experimental watershed studies to analyse the influence of clear cutting forest vegetation on water yields are summarised and presented in the Table (1).

In Taiwan, Hamilton and King (1983) reported paired catchment results showing similar kinds of increases following clearcutting and skyline logging, with first year stream flow exceeding the expected value by 292 mm (48 percent), with greatest increases (108 percent) occurring in the dry season. On some watershed experiments in Japan under winter snow patterns, Nakano (1967) found only minor increases in annual flow in some small mountain drainage, though on others, increases from 8 to 24 percent were obtained. However, in subsequent analysis and modelling for five catchments, Nakano (1971) reported increases of 10,30,33,43 and 46 percent. Rao and Raj (1986) have reported that the increase in water yield due to forest removal gets reduced by 2/3rd after five years of regrowth

TABLE 1: Water Yield Increases due to Clearcutting

Sl. No.	Watershed	Location	Forest type	Area (ha.)	Annual preci-pitation (mm)	Normal Water Yield (mm)	Annual increase in water yield (first year) (mm)	Annual increase in water yield (first year) (%)	Remarks
1.	Wagon Wheel Gap	Colorado USA	Douglas fir & Englmann Spruce	80	536	165	28	20	Average of 5 years
2.	H.J.Andrew(HJAI)	Oregon, USA	Douglas fir Western Hemlock	96	2388	1376	380	34	
3.	Beaver Greek 12	Arizona,USA	Ponderossa-Pine	182	635	153	-	30	
4.	Coweeta Watershed	North Caro-lina,USA	Mixed deci-duous hardwood	16	1778	792	370	18.7	
5.	Fernow Experim-ental Forest Watershed	West Virginia, USA	Mix decidous hardwood	23.6	1473	584	130	26	
6.	Hubbard Brook Experimental Forest Watershed-2	-	-do-	15.6	1524	685.8	342.9	50	
7.	-	Colorado,USA	Aspen conifer	-	-	157.0	34	20%	
8.	Kimakiya	Kenya	High Montane & bamboo forest	-	-	-	-	50%	

Source : Sikka, A.K. and V.K.Lohani, (1986), RN-36, NIH.

and gets vanished after about 10 years.

Complete deforestation generally increases the annual yield by between 20 and 40% of normal, but maximum increases rarely exceed 400 mm/yr (Anderson, Hoover, and Reinhart, 1976). Based on the results of various studies they concluded the following points:

a) forest removal increase total water yield,

b) yield increases are greater when a greater fraction of the catchment is deforested,

c) maximum increases occur during the first year after cutting

d) cutting effects decrease logarithmically with time, and

e) the effects persist longer when the initial effect is greater.

Partial cuts results in smaller increases in yield, but the shorter cutting cycle for a watershed, which could result from partial cutting, would mean more frequent occurrences of increased yields. Results from catchment studies in New Zealand give some specifics on this aspect of water yield. In a 2,600 mm rainfall regime at Maimai, 100 percent clear-felling gave a 650 mm increases annual yield, and 75 percent clearfelling gave a 540 mm increase (Pearce 1980, Pearce et al., 1980). In H.J.Andrews experiment in Oregon, USA a treatment involving 30% cut in Douglas fir and Western Hemlock type of forests resulted in 10% increase in water yield. Tsuka-moto (1975) studied the impact of removing forest litter on streamflow and reported

4% increase in the annual discharge. In Arizona, USA, experiments with Ponderosa Pine forests involving 33% strip cutting and 33% clearcut in irregular strips resulted in 16 and 22% increase in water yield respectively in Beaver Creek watersheds. When the treatment was changed to 50% clearcut in irregular strips including thinning between strips (65% basal area overall), the water yield was reported to increase by 103%. In Coweeta watershed in North Carolina, USA, a treatment involving 22% selection cutting of mixed deciduous hardwood resulted in 8.1% increase in water yield. In tropical humidqueens-and also, no dramatic increases in yield were observed following logging (Gilmour et al., 1982),. while statistically significant increases inmonthly totals were obtained following clearing of pastures(293mm) no significant increase occurred from unconstrained logging. In Kamabuti, Japan the overstory clearing of coniferous and deciduous forests resulted in 5% increase in water yield. Water yield was reported to increase by 56% when one-third of pine forests were removed at Jonkershock in South Africa. In Arizona, clearing one-third of the Ponderosa pine forests overstorey increased water yield by approximately 3 ha-m/ha annually and an addtional clearing of another one third of the forest overstorey increased water yield by approximately 6 ha-m/ha annually. Temperate zone research indicates first year increases in streamflow in proportion to the degree of canopy removal (Douglass and Swank, 1975). This effect was confirmed by a study in the Philippines involving different degrees of thinning of Benquet pine (Veracion and Lopez, 1975). Therefore, annual cutting or lopping on a sustainable basis should result in somewhat increased annual water yield. A paired catchment study on steep slopes at Mbeya, Kenya in which one watershed was approximately 50 percent cultivated, gave large increase in water yield (Edwards and Blaukie, 1981). Low and Goh (1972), reported an annual increase of 10 percent in water yield in a largely cleaned catchment over that from three forested catchments. The results of a study carried out by FRI in two experimental watersheds (6.5 ha under Shorea robusta coppice, deciduous moist forest) at Rajpur gave runoff as 42% of rainfall as observed by Subba Rao et al., (1973). A treatment of 20% thinning was imposed subsequently in one of the watersheds which showed that the peak rate of the flow increased by 8.6% in the first year which later on subsided in subsequent years. The changes in the volume of fortnightly runoff due to thinning were found to be non-significant (Subba Rao et al.,1984). A case study of small watersheds has shown that reafforestation by Eucalyptus in Dehradun could reduce peak flow by 77% while burning, cutting of trees and over grazing increased peak discharge from various small watersheds at Chandigarh by 69, 34 and 32% respectively. Contour trenching and afforestation, reduced the peak flow by 73% while continuation of closure, afforestation and gully control works reduced peak flow by 63% (Das and Singh, 1979). Studies on experimental runoff plots at Nurpur (H.P.) also showed increase runoff from regularly grazed areas as compared to the areas under shrub and grass cover (Sinha, 1975; cited from Lal and Subba Rao, 1981). Shastri et al (1984) reported that in Doon valley when a natural forest watershed open to grassing is deforested and cultivated, volume and peak rate of runoff were higher by 15% and 72% respectively.

The clearcutting practices involves removal of all vegetation and thus increasing chances of erosion and sedimentation besides water yield. Where as, partial cutting practices seems to have more potential for management of forested watershed for obtaining optimal yields of water without the problems of increasing erosion and sedimentation.

b) Change in forest type of vegetative cover

Effects on water yield due to changes in forest types or vegetative covers have been studied by many workers. Australian experience has indicated little or no change in yield, mainly from conversion of native eucalypt forest to Pinus radiator. Results from conversion of 11 catchments ranging in size from 4 to 300 ha indicated no differences between species (Bell and Gatenby, 1969). Boughton (1970) reported that when native eucalypt forest is cleared to establish an exotic pine plantation, there is likely to be an increase in the amount of water yield while pine forest is immature and has not established its full root depth, and this difference should disappear as the trees mature. Wicht (1949) also reported same statement about South Africa. In New Zealand, conversion of indigenous evergreen forest to radiate pine resulted in only slight difference. At Coweeta in the southeastern United States, replacement of mixed deciduous, broadleaved forest with Pinus strobus produced mark differences. In the most carefully controlled experiment, Swank and Douglass (1974) found that when two catchments in North Carolina were completely converted from mixed hardwood to white pine, annual water yields decreased rapidly, after 15 years the pine cover yielded 200 mm/yr less than the original hardwood cover. Banks and Kromhout (1963) showed that in the Jonkershoek catchments of South Africa there were decrease in stream flow beginning the fourth year after planting and continuing to about the twelth years, when it remained relatively constant but at a lower level than prior to reforestation. In these experiments, natural Sclerophyll Scrub was replaced with Pinus radiata. Similar results were obtained in the Transvaal in afforesting grassland with Eucalyptus grandis and Pinus patula (Van Lill et al., 1980). At Dehradun in India, Mathur et al., (1976) reported yield decreases of 28 percent following following afforestation with eucalypts. Studies done in Kimakia, Kenya indicated that replacement of high mountain and bamboo forests by pine trees increased water yield by 50 percent (Bosch and Hewlett, 1982). The experimental studies conducted at Kota (1979-82) on small watersheds (0.4 - 1.45 ha) showed that runoff was maximum from agricultural watersheds (15.1%) followed by trees (A. nilotica) + grasses (D.annulatum)(6,8%) and grasses alone (1.9%) as reported in Annual Report (1982) of CSWCRTI, Dehradun. Sharda et al. (1982) observed reduction in runoff as percentage of rainfall from 32.02 (1969) to 23.45 (1970) and 17.65 to 6.88 under grass cover alone (cenchrus cilliaris) and Shisham (Dalbergia Sisso) with grass cover respectively. Pathak et al. (1984), reported that the overland flow was maximum (1.24% of rainfall) for pine - mixed broad leaved forest and minimum (0.38% of rainfall) for mixed Oak, Tilong - dominated forest with average value of 0.68% of incident rainfall.

Cochrane (1969) reported results of studies done in Fiji and observed that under normal forest bankful discharge was not achieved while the forests got changed to grass, a 300 fold increase in discharge occurred within two hours from commencement of heavy rain. In converting a tropical forest catchment to pasture in Queensland, Australia, water yield was increased by an average of 10.2 percent during the first two years (Queensland Department of Forestry, 1977). However, in conversion experiments at Coweeta in the United States, showed that streamflow yield increases varied directly with biomass production of grass (Hibbert, 1969). Results reported under Arizona watershed programme by Ffolliott et al (1986) indicate that by converting forest overstories to grass cover, an annual water yield increase from 67 to nearly 95 mm, values representing 84.11 percent of the annual streamflows before the conversions, was observed. Studies on the amount of runoff under different vegetative covers e.g. shola, bluegum, wattle, broom and grasses carried out on 0.02 ha plots on 16% slope indicate highest runoff amounting to 1.27 of total precipitation from wattle and shola covers where as in bluegum runoff is recorded to be 1.08% of total rainfall (Anon., 1982). Low and Goh (1972) and Toebes and Goh (1975) reported that annual water yield increases by 10 percent when low land rain forest converted to oil palm and rubber plantations.

On the basis of all available research work it may be concluded that there is an increase in water yield when forests are converted to grassland. This occurs not only in the conversion process when trees are cut, but continues after the grass has become the vegetative cover of the area.

As summary of studies conducted throughout the world indicates that runoff can be increased by vegetation management in areas with an annual precipitation in excess of 280 mm (Cooley et al., 1975). Runoff efficiency with this method is low and may vary greatly with storm, season or year. The method is usually applied in combination with surface treatments (Hillel, 1967, Rands et al.1979). The main effect of vegetation management is that is reduces the infiltration capacity.

3.3 Mechanical Measures

Mechanical measures include contour farming, strip cropping, conservation tillage, terracing and microwater shed. Application of mechanical measures results in increase in moisture conservation, crop yield and reduction in soil erosion losses. The results of studies conducted in India and other parts of the world are described in the following section.

In the use of contouring practice on steeper slopes or under conditions of high rainfall intensity and soil erodibility, there is an increased chances of gully erosion because of breakage of rows. Breakovers cause cummulative damage as the volume of water increases with each succeeding row. The effectiveness of contouring is also impared by changes in infiltration capacity of the soil owing to surface sealing. Depression storage is reduced after tillage operations cease and settlement takes place. Studies by Harrold (1947) showed that contour cultivation together with good sod waterways reduced watershed runoff 75 to 80 percent at the beginning of the season. This reduction dropped to as low as 20 percent at the end of the year, leaving an annual average reduction in runoff, due to contouring of 66 percent. In Octacamund, Raghunath et al. (1967) conducted experiment on experimental plots of 25% slopes to find out runoff under different agronomic and engineering practices. They reported runoff as a percentage of annual rainfall for up and down cultivation of potato (4.0) simple contour cultivation (2.3) and non paddy benches (1.1).

In strip cropping, rotations that provide strips of close growing perennial grasses and legumes alternating with grain and intertilled crops are the most effective Their effectiveness in reducing runoff is illustrated in Table (2) in which a 4 year rotation is compared with continuous cotton.

Table : 2 Runoff on Class III Land with 7 percent slope at Watkinsville, Georgia

Rotation	Runoff
First Year Fescue	104
Second Year FEscue	15
Corn	48
Cotton	99
Rotation average	66
Continuous Cotton	254

Source: USDA - ARS, Agr: Inf. Bull.269 (1963).

Field tests conducted during the early 1970 in the Attenbury Watershed in Arizona, an area which normally receives about 140 mm of rainfall in the summer months, demonstrated that significant harvests of short season grain Sorghum (a crop requiring 570 mm of rainfall to mature) were achieved by means of contour strip technique. Investigators found that over a period of three years which experienced widely different amounts and patterns of rainfall, sorghum yields ranged from 0 to 4,400 Kg per hectare. Whereas the average yield of sorghum under irrigation condition are 4,500 Kg per hectare.

Studies in Indiana utilizing artificial rainfall, showed that minimum tillage significantly influenced infiltration rates and erosion losses. Tests two to three weeks after corn planting and with three different antecedent moisture levels showed that of 132 mm of water applied, infiltration totaled 56 mm for the conventional treatment and 84 mm for the minimum tillage treatment. Thus, runoff was 76 mm and 48 mm respectively (Meyer, 1961).

The effectiveness of listing as a conservationmeasure has been shown in many studies. Iowa reports that on an erosive loses soil, over a 5 years period, contour listing of corn cut soil loss to about on-ninth that of uphill and downhill planting, water losses were reduced 61 mm. The effectiveness of all subsoiling and deep tillage is highly dependent upon the specific soil characteristics of treated areas, moisture conditions, crop management practices, secondary tillage operations and also on time of treatment.

By controlling the velocity and changing its direction the terracing increases the time of concentration and this substantially moderates both peak and volume runoff. At Dehradun (Gupta et al.1969) and in DVC (Teotia et al., 1964) broad and narrow based terraces reduced runoff considerably. Sastri et al.,(1984) reported that by constructing field bunds in the deforested watershed the peak rate and volume of runoff are reduced by 86% and 62% respectively of the corresponding values when it was natural forest watershed and the corresponding reduction in the soil loss was 94% when another comparable natural forest watershed is provided with brushwood check dams at appropriate locations, although no appreciable reduction in peak rate of runoff was observed, soil loss reduced by54%

In ©Octamand bench terracing was observed to reduce runoff by 50 percent of that from field under potato cultivated up and down the slope. It did reduce the effect of rains and runoff in causing soil loss and provides good moisture conditions through out the year (Das et al., 1967). Studies on suitable length of bench terraces on 25 percent slope has been done with terrace length of 91.5 m; 122.0 m and 152.5 m (Das et al., 1967). On the basis of analysis of fortnightly moisture data, it was concluded that on benches longer than 91.5 m, farther ends were significantly drier than those near to the cross disposal drains. On this consideration it is desirable to have bench terraces less than 100 m in length in Nilgiris.

Consequent to larger area and longer infiltration opportunity total absorption over larger area is more in terraced fields. The highest retention of rainwater was on the areas treated with contour bunding in DVC whereas the least retention was on the unterraced lands (Teotia et al., 1964 cited in Das, 1970). During all the weeks, the benches offered excellent soil environment in the Nilgiris for plant growth as moisture level remained close to moisture equivalent and the uniformity co-efficient for distribution were about 85 per cent, (Das, et al.1967) The benches used about 6.1 per cent (82 cm) of incident rainfall as compared to 29 per cent by the deteriorated and compacted grassland (Das, et al.1970). It was further shown that the water balance on rainfall disposition studies based on soil moisture storage, i.e. retention or available water (plant) storage, problem of drought and flood could be better understood in relation to physical and climatic attributes. Therefore, more appropriate Land Management Systems can be identified for implementation as a deterrent to such natural calamities (Das 1982).

In the runoff plots studies on 8% slope at Dehradun in silt loam alluvial soil maize planted on contour showed 41.2% runoff as percent of rainfall and soil loss of 19.3 /ha whereas when the same crop was grown up and down the slope the runoff was found 54.1% of rainfall and soil loss 28.3t/ha respectively (Ann: 1975).

Studies in the selected 5 watersheds of Tungbhadra catchment treated with appropriate soil conservation measures such as contour bunding, check dams, water harvesting structures, conservation farming etc. indicated that there was reduction in runoff volume by 35% (Ramsesha et al, 1983).

The peak runoff rate and runoff volume for identical storm before treatment and after treatment were compared for a watershed of area 22.5 km^2 in the catchment of Mahi-Ka-Dana (Rajasthan). The result indicated that there was reduction in peak runoff rate and runoff volume by 85% and 84% respectively when watershed was treated with bunding, terracing check dams, pasture developments, afforestation, water harvesting structures etc. (Singh et al. 1988).

A study of small watersheds of area 92.5 km^2 treated with soil & water conservation measures comprising of bunding, terracing, afforestation in forest and wastelands, water harvesting structures etc. in an integrated manner in Damodar Barakar catchment revealed that these measures reduced the peak discharge rates by 37% (Singh and Das, 1981).

Jones and Hanser, (1975) reported that modern contour terraces (conservation bench terraces) can increase available water and crop yields significantly on gentle slopes in dryland regions, on the basis of series of experiments carried out over fourteen years at the South Western Great Plains Research Centre at Bushland, Texas (USA). The experimental area contained both conservation bench terraces which were continuously cropped with grain sorghum and graded bench terraces which were cropped in a wheat-sorghum-fallow sequence. Average annual precipitation of area is 466 mm and average April to September evaporation from water surface is 1,300 mm. Topography is nearly flat and treeless with natural drainage flowing to shallow depression sound the predominant soil is Pullman clay loam. When yields from these two systems were compared to those from sloping plots, it was shown that bench levelling increased mean annual sorghum yield by 43 percent; and contour bench terrace (which received a mean runoff of 70 mm per year from their collector areas) increased mean annual sorghum yields by 80 percent. Investigators concluded that the major advantage of bench levelling over the conservation bench terraces was that higher levels of production were achieved because all available land was cropped. This advantage was offset by the greater probability of lower yields. A major advantage of conservation bench terrace is that only one-third of the area requires levelling.

In a two year study at Bellary (Anonymous, 1980) two ratio (50:50 and 60:40) of contributing to receiving area of conservation bench terrace with and without gypsum in the receiving area were studied. On an average the receiving area recorded 5 q/ha higher jawar grain yield than the contributing area. Similar beneficial results of conservation bench terrace are also reported from Dehradun (Gurmel Singh et al., 1981).

Experiments at the Central Great Plains Field Station in Akron, Colorado (USA), have demonstrated that minimum run on areas containing a vertical mulched slot deepen penetration of water and reduce evaporation loss possibly by as much as 50 percent as shown in Figure (7a &b).

Rama Mohan Rao et al.(1981) reported that vertical mulching has been found to be suitable to black soils of Deccan Plateau in insitu conservation of moisture for increased crop yields, whose intake rates are very low. It consists of Jawar stubbles kepts in trenches of 40 cm deep, 15 cm wide protruding 10 cm above ground level. Such trenches spaced at 4 to 5 meter increased crop yields by 400 to 500% in drought years and 40 to 50% in normal years over control.

Microcatchments:

According to Parihar and Gajri (1970), in very

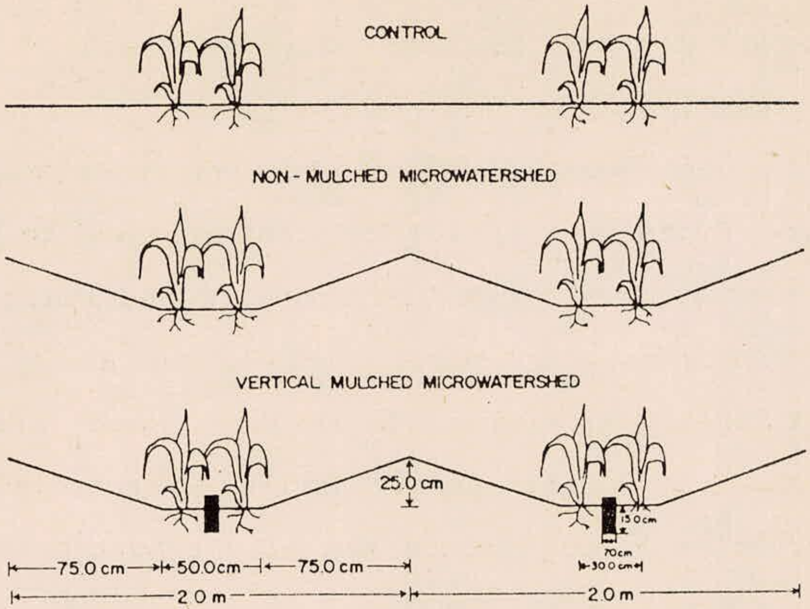
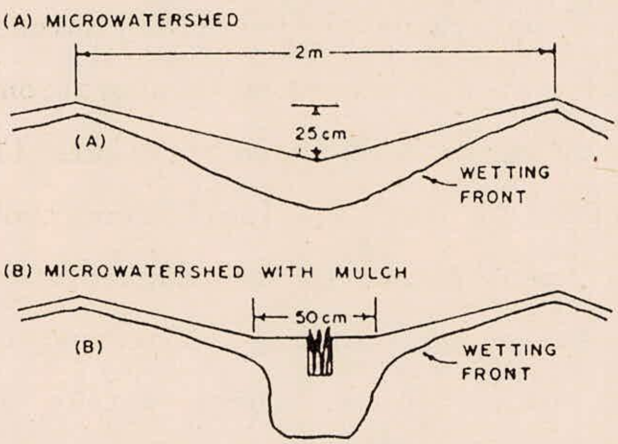


Figure 7 – Vertical mulched microwatersheds showing (above) design and (below spacing and wetting fronts (Fairbourn, 1975; Gardner, 1975)



low rainfall areas, where precipitation received before or during the crop growth period is insufficient in quantity for good crop growth, runoff may be induced by treating uncultivated catchment and diverted to cropped microwatersheds where water is concentrated to increase soil water storage.

A preliminary study of the technique of water harvesting from micro-catchment artificially developed in the field, was initiated by Singh et al. (1973) during Kharif 1969 using a ratio of 3:1 between microcatchment to cultivated area, at CAZRI, Jodhpur. The yield from runoff plot was 77 percent more than flat sown ones. By creating microcatchment, some area went out of cultivation but the net yield in treated plots was about 28 percent more.

Yadav et al.(1979) investigated the runoff potential of (i) interrow water harvesting system (IRWH) having microcatchments prepared with a two bottom ridger farming ridges and furrows and (ii) modified inter-row water harvesting system (MIRWH) having microcatchments prepared with two opposite runs of single mould board plough, in comparison with conventional system of planting. The experiment was laid out in a split plot design, with water harvesting systems assigned to the main plots. The treatments tried in the sub-plots included:

(a) application of bentonite clay @ 67 q/ha in between the rows in the flat system and on micro-catchment in the IRWH and MIRWH systems.

(b) application of wheat straw mulch @ 3.3 tons/ha under flat system and @ 2.0 tons/ha under the other two water harvesting systems.

(c) combination of above two metods and

(d) control

These combinations were tried with and without fertilizer application

The interplot harvesting proved to be advantageous over inter-row harvesting in improving the productivity. However, in the event of drought during life cycle of Kharif crops, water harvesting and recycling will be extremely useful to provide supplementary irrigation to the crop. In case no drought occurs during the life cycle of Kharif crops, the stored water can be used to provide pre-sowing irrigation to the rabi crops. As the sandy soils in the arid region do not encourage runoff when the rainfall intensities are light to moderate, optimisation of catchment characteristics in terms of slope and length of run of the catchment with water proofing is essential for collection of sizeable amounts of water.

Studies conducted at Central Arid Zone Research Institute, Jodhpur (Mann and Singh, 1977) have shown that the total production by cropping only two third of the field (leaving one third for microcatchment) by adopting the runoff farming is the same as obtained from conventional cropping on a flat surface. The runoff farming has been found to offer potentialities for increasing and stabilizing yields, thereby lowering the risk of crop failure and saving inputs required for crop production. However, in case no land is to be sacrificed for water harvesting as catchment, the inter row system of water harvesting is found more practicable than inter plot water harvesting system.

3.4 Chemical Treatment

Sodium salts, when mixed into the upper portion of the soil profile, tend to reduce the permeability of the soil by dispersing the clay fraction and thus, the surface runoff increased. A number of studies conducted to study the effects of chemical treatment on increasing surface runoff. The effectiveness and results of studies conducted are summarised in the following section:

Chemical treatments works only on the clay fraction and will not be effective if the soil is coarse-grained. Sodium treatment catchments are also susceptible to erosion unless well compacted. If the soil is properly compacted after application the runoff efficiency will be greatly increased (Cluff, 1974). The sodium becomes adsorbed on to the clay particles; thus the quality of the resulting water is very good. The quality generally drops to less than 200 PPM after the initial one or two runoff events. The initial runoff is usually less than 100 PPM. Sodium salts can be used to treat soils having a clay content in the range of 5 to 30 percent. Sodium is also effective in seepage control on expanding type clays when the clay content is above 15-20 percent. Treating minimally vegetated desert soils with sodium can reduce infiltration rates temporarily. Clearing, shaping and compacting the soil prior to or during the sodium applications can result in long term effectiveness. Compaction of even low-clay, sodium-treated soils can result in a significant increase in available runoff. Additionally, salt is an herbicide (Myers, 1967).

An experiment conducted by Dutt and McCreary (1975) on White House loan soils near Tucson, Arizona (USA), in an area receiving 200 -400 mm annual precipitation resulted in a 50 runoff over a three year period. Salt treatment of soils is appealing due to its low cost. However, its effectiveness can deteriorate after one year unless compaction and shaping is performed. One additional problem with this method is that increased runoff may encourage erosion (Cooley et al. 1975).

Studies were initiated in Israel in 1964 to evaluate sodium salt dispersion of clay aggregates as a means of increasing precipitation runoff. Precipitation runoff was measured during the winter rainy season from 2x2.8 m plots treated with various sodium salts. For a three year study period, the precipitation runoff efficiency from the salt treated plots ranged from 55 to 89% of the rainfall. Runoff from smoothed compacted controls ranged from 39 to 51% of the rainfall. There were no apparent changes in runoff efficiency of these treatments over the 3-year study interval that could be attributed to treatment deterioration. It was concluded that, at the study sites, soil erosion was a serious problem on the plots treated with sodium salts alone and that some form of soil stabilization would be needed (Hillel, 1967).

In 1965, an undisturbed, 1.0 ha watershed with 10% clay in the soil, near Tucson, Arizona was treated with granulated sodium chloride salt spread on the soil surface at a rate of 47 g of salt per m^2. During subsequent rain storm the salt dissolved and was translocated into the upper surface layers of the soil profile. During a single storm event of 74 mm, the treated area yielded 10.3% runoff compared to 0.4% from an adjacent untreated area (Cluff and Dutt, 1966). Cluff et al.(1972) reported that the runoff efficiency from the area declined with time and there was an apparent downward migration of the dispersed clay lenses.

On the basis of a paired catchment study of field sized water harvesting plots, Gray et al.(1965) reported that precipitation runoff efficiency from an area treated with a spray application of a sodium carbonate salt solution at a rate of 44.9 g of salt per m^2 was 46% of the total precipitation compared to 33% from an untreated catchment for a 3 yr. period. After 3 year the treatment was no longer effective. Runoff efficiency evaluations with a small spinkler of a 14 year old, operational sized, runoff farming catchment treated with granulated sodium chloride salt mixed into the soil at a rate of 1120 g of salt per m^2 showed that runoff was over 80% of the total precipitation from the treated area compared to 55% from similar untreated area. Measured runoff from sprinkler evaluations of treatment effectiveness was higher when distilled water was used than when using local tap water.

In research in Arizona, Mayers et al.(1969) found sodium methyl silanolate penetrated into soil to form an inert, hydrophobic resin which not biodegradable. Silicone treatment experiments involve spraying test sites with an aqueous solution of a silicon-water repellent which reacts with the calcium or magnesium in the soil to form an inert water repellent resin. A sodium methyl silanolate treated 200 m^2 plot on smoothed sandyloam soil in Arizona, U.S.A., initially yielded 94 percent runoff compared to 41 percent for an untreated smooth plot. Repillency dropped to 40 percent over the next four years, probably due to erosion and weathering, but was restored to 85 percent by retreatment (Myers and Frasier, 1969).

Another experiment indicate that high runoff efficiency can be achieved, by applying silicone with a soil stabilizer. Silicones are easy to apply and relatively inexpensive. However, the treatment does not work well on soils in which swelling clays are present, it is most appropriate for sandy soils with minimal structural development. One problem with silicone is that it provides no stability and increased runoff can lead to erosion problems (Myers, 1967).

3.5 Surface Binding Treatments

Surface binding treatment includes use of polyethylene cover, straw cover, parafin wax, asphalt pavement and compacted earth. Application of these materials, bind the soil particles together and provide an impermeable layer , which resulted in higher surface runoff. Results of various studies conducted on the use of the surface binding treatments to increase surface runoff and crop yield are summarized herein. A single season comparison of five soil treatments for water harvest radish cultivation in Mexico indicated that excellent crop growth was achieved by means of all five soil treatments. Table (3) summarizes the results obtained from treatments including: polyethylene cover, compacted earth, and two types of diesel fuel (Ananya and Fovara, 1975). The Maxican experiment suggests that in the case of similar yields, the cheapest soil treatment should be compacted earth or straw cover.

In a study at Mexico, Fink et al.(1973) reported that paraffin can be applied in the form of granulates of flakes and allowed to melt and spread, forming a surface that, in one experiment, yielded a 90 percent runoff, compared with 30 percent runoff from untreated plots, and a 100 percent from a butyl-covered plot. In another experiment two collector areas, one a 0.4 ha catchment and a clay loam soil with a slope of 5 to 8 percent and 300 mm annual precipitation, and another, a 0.3 ha catchment on a sandy clay loam soil with similar slope and 300 to 400 mm annual precipitation, were both sprayed with melted paraffin after having been graded, sterilized and wel-compacted. Both catchments harvested water at a cost that

Table 3 Radish yields with five soil surface treatments

Soil surface treatments	Yields of radish for the following percentages of area used to collect rainwater			
	25 tons/ha	50 tons/ha	75 tons/ha	Average tons/ha
Polyethylene cover	55.65	63.50	76.72	65.29
Straw cover	48.22	59.00	64.36	57.20
Compacted earth (CE)	54.28	60.58	78.80	64.56
CE diesel treated 250 ml/m^2	49.82	61.86	79.04	63.57
CE diesel treated 125 ml/m^2	54.78	61.45	77.64	64.62
Average[a]	52.55	61.?8	75.32	

[a]Check yielded 36.66 ton/ha with no soil surface treatment and no area dedicated to harvest rainwater.

Source: Anaya and Tovara, 1975

was competitive with that of hauled or pipe water. Moreover, it was found that the method worked best on the sandy soil (Cooley et al.,1976). These experiments that paraffin treated soils provide high-quality water, are durable, and low in cost for materials and application (particularly when granules are hand applied) relative to other chemical treatment methods. Moreover, its use as a seepage control method in water storage structures is not recommended, because it acts as a water repellent only and will not resist hydrostatic pressure.

Melten asphalt cement was used to build a 16,940 sq.ft rainfall catchment in Hawaii during 1958 (Chinn, 1965). The oval catchment area, which had a longitudinal slope of about 7%, was cleaned, smoothed, and compacted with a bulldozer. The soil was not described. An unspecified soil sterilant was applied and the area was primed with liquid asphalt, probably either cutback or emulsified asphalt. Membrane asphalt was sprayed on the soil surface to form a surface coating asphalt based aluminium paints was painted on the membrane asphalt surface to retard photo chemical damage. The catchment received no maintenance and soon began to deteriorate by cracking and growth of vegetation through the membrane. Runoff, in percentage of rainfall, was 93% in 1959 and 78% in 1961. The failure of the relatively thick asphalt membrane by cracking so soon after installation was undoubtedly associated with the use of a hard, brittle asphalt which was probably selected to avoid creep or cold flow of the asphalt down the catchment slope. The performance of this surface membrane of asphalt cement did not justify the relatively high construction cost. Myer et al.(1967) reported that properly constructed and maintained asphalt pavements have provided essentially 100% runoff of precipitation. However, water running off asphalt pavements is usually coloured by asphalt oxidation products in regions of high solar radiation and low precipitation. The coloured water is normally odourless and tasteless, has been readily consumed by cattle, and is believed to be harmless. A satisfactory method of prevention or removal of oxidized asphalt compounds should be developed before asphalt pavements are recommended for obtaining domestic water supply.

The plastics, both polyethylene and vinyl, were found to be effective but short-lived, generally lasting less than one year. Exposed butyl rubber and chlorinated polyethylene sheeting has been found to be long lasting and resists degradation for more than fifteen years if occured to the ground to increase resistance to wind damage and other mechanical damage. This material is relatively expensive, however, and its use has been limited to the more developed countries.

At IARI, Delhi Ghosh et al.(1979) conducted various experiments to determine effectiveness of different mulches for moisture conservation. They reported that in all experiments the polyethyelene mulches were found to conserve more moisture than the straw mulch. Among the polyethylene mulch although showed greater moisture conservation than the black polyethylene. They did not differ much in their effect on soil moisture. Higher soil moisture conservation by plastic films were observed by Bhatia et al.(1966). They compared polyethylene and straw mulches on irrigated cotton and obtained similar results. Higher rate of soil moisture conservation and higher yield of crops by use of black plastic mulches have been reported by (Emmert, 1956);1957; Army and Hudspeth, 1959 and Willis et al.,1963 cited in Ghosh et.al.,(1979). Ghosh et al.(1979) also reported that different coloured materials of mulches (while reflecting type and black absorbing type) were observed not to differ much in their ability to conserve moisture, however, both are better than the straw mulch. Murty et al.(1980) evaluated the performance of different water proofing technique using indigenous materials. A number of treatments were applied on plots of size 2 x 20 m with an average slope of 0.5 to 1%. The details of treatments applied along with their performance are given in Table (4). The water yield was highest from Janatha emulsion treatment followed by the next highest yield by sodium carbonate treatment. Water yield in the mechanically stabilized goes on decreasing from 65% to 8% from year to year. This may be due to loosing of compactness in upper surface layer. Also, it is seen that soil erosion is high in this treatment. The cost per litre of water conserved in various treatments are given in Table (5). Cost of water in case of Janatha emulsion is 74.87 paise per 100 litre compared 0.4 paise per 100 litre in case of bentonite treatment. Bentonite treatment initially creates water

Table 4. Run-off generated from different treatments used for water proofing.

(after Murty et al : 1980)

S.No.	Years					Cost of lining per sq. m. (Rs.)
	Rainfall in mm	316.90	502.05	130.60	497.32	
	No. of rainy days	11	19	5	21	
	Treatments	Runoff %	Runoff %	Runoff %	Runoff %	
1.	Control	.57.42	22.15	29.81	6.62	0.00
2.	Bentonite 20% mixed with soil 1.25 cm thick.	87.53	62.71	51.30	12.80	1.25
3.	Cement 8·/. mixed with soil 1.25 cm thick.	41.14	28.52	22.74	12.80	1.25
4.	Mud plaster (local) 1.25 cm thick.	66.62	52.00	38.23	9.18	0.45
5.	Lime concretion, 5 cm thick.	74.48	65.21	47.99	36.07	0.45
6.	Janta emulsion premix, 1.25 cm thick 8·/. solution of Janta emulsion and kerosene oil @ 4:1	94.06	82.26	66.20	29.20	3.10
7,	Mechanical stabilisation	65.22	48.28	28.15	7.78	0.30
8.	Sodium carbonate spray @ 1 kg/10 sq.m. over 1.25 cm thick tank silt compacted	91.75	.75.70	63.46	34.40	0.60
9.	Mud plaster (RRL) mixture of mud, bhusa and Janta emulsion (95:3.2)	78.76	67.62	48.82	20.27	1.20
10.	Grass cover *Lasiurus sindicus* (25 cm × 25cm)	63.35	18.91	22.58	4.28	0.50

Table 5. Cost per liter of water under different treatments of water proofing of catchments.

(after Murty et al : 1980)

Treatment	Cost (Rs.)	Total water yield for nineteen rainfall events/ sq.m. (mms)	Percentage runoff	Cost per litre of water
Control	—	111.21	22.15	—
Bentonite	1.25	314.86	62.71	0.0040
Soil treatment	0.90	143.22	28.52	0.6248
Mud plaster	0.45	261.07	52.00	0.1723
Lime concentration	0.45	327.40	65.21	0.1347
Janta emulsion	3.10	414.02	82.46	0.7487
Mechani cal stabilisation	0.30	242.20	41.828	0.1238
Sodium carbonate	0.60	380.07	75.70	0.1578
Mud plaster (RRL)	1.20	339.50	67.62	0.3534

proofing at the surface. But in the long run, cracks might develop at the surface on drying contribution to the seepage losses. Janathan emulsion was found to give good surface imperviousness. However, use of surface sealents have the obvious disadvantages. The quality of harvested water may not be suitable for drinking and at times for growing crops as the sealents will dissolve with runoff. Further, the efficiency of such catchments get reduced due to weathering and burrowing by ants, rats, rabbits etc.

One of the big advantages of the gravel covered plastic catchment is that it can be installed using hand labour. In this method relatively low cost and high runoff efficiency plastic sheet has been spread over the ground and cover it with a layer of gravel. The gravel protects the sheet against wind and weathering, but it does reduce runoff efficiency by retaining the water that is lost to evaporation. This method is superior to asphalt catchments as it does not produce potentially toxic phenols. The water produced by a gravel covered plastic catchments is of excellent quality and can be used directly for domestic use. The life appears to be in excess of fifteen years if a gravel cover is maintained and the plastic is protected against mechanical damage.

In Arizona, runoff efficiency of asphalt-plastic asphalt-chip coated catchment was observed to be 85-90 percent with an estimated life of ten to fifteen years. The researchers suggest that the APAC method be used where less sophisticated methods are somehow impractical or where a very high runoff efficiency is needed to man a dependable water supply (Cliff, 1975; Cooley et al.1975). Both APAC and FAC(Fibre glass asphalt chipcoated) combinations can effectively deliver close to 100 percent runoff efficiency. The APAC method must be applied with special equipment such as asphalt distributor trailers or trucks, which are not always available in developing countries or remote areas.

3.6 Rigid Surface Coverings:

Rigid catchment covering includes use of corrugated aluminium sheets and runoff harvesting from highway catchments. A limited number of studies have been conducted in USA and Australia to show the applicability of rigid surface coverings for increasing runoff from catchment. The results of some studies are presented in the following section.

In South Australia roof catchments of iron or timber structures were constructed as early as 1885. They continue to be a practical and necessary solution to water supply problems in this area. Three schemes built in 1960 consisted at Rainsheds of galvanized steel supported on a steel frame about 2 metres above ground giving 650 square metres in area two 40,000 litre steel tanks stored water under each shed (Martin, 1910).

On the basis of preliminary calculations Cooley et al.(1975) reported that the interstate highway systems of the state of Wyoming (USA) would provide 2 hectares of catchment per kilometer with a 90 percent catchment efficiency and a 250 mm average annual rainfall. The amount of harvested water would be close to 4.7 million litres per km. The water harvested in this manner can be diverted to adjacent agricultural fields or it can be used to irrigate the right of way which, when properly levelled, fertilized, and seeded can yield up to 2.5 metric tons of hay per high way kilometre in semi-arid Wyoming (USA).

3.7 Flexible Surface Coverings

In order to achieve runoff efficiency more than 90 percent, the catchment is generally covered with the flexible surface covering (butyl rubber, polyethylene, fibreglass etc.). The following section deals with the results of studies conducted in USA on the application of flexible coverings to increase surface runoff.

In Howaii and other Pacific Islands, over 300 rubber catchments and storage units were installed. The nylon-reinforced butyl rubber was used for lining these catchments up to a slope of 40 percent (Dedrick, 1975). The capacity of these structures in terms of the volume of water they can harvest and stored ranges from several thousands litres to 5.3 million cubic metres, much of this used for livestock or irrigation. The technique is competitive with other kinds of water provision in both cost and dependability. Thirty catchments in Hawaii ranging from 1 to 7 hectares in size were reported in good condition after four years of use. Wind uplift has been minimized by smoothing slopes and weighting the surface with soilfilled butyl bags. A livestock reservoir of 1,325 cubic metre capacity was installed in the area receiving 914 mm of annual rainfall. This structure is capable of harvesting and storing water through a three-month drought.

The most robust of the flexible coverings currently available is butyl rubber. Its advantages are its lower cost (compared to sheet metal or concrete) and the fact that it can be installed over moderately rough surfaces if sharp stones and shrubs are removed. Table (6) shows the comparative costs of catchment covers. Problems with rubber catchments are reported to be caused by poor materials and damage by animals. Replacements may be required after five to six years (Dedrick, 1973 and 1976).

Table 6 – Estimated catchment and water costs

Material	1,100m² catchment cost $/m²	Probable life Years	Annual cost[a] $/m²	Catchment efficiency (%)	Runoff in 36 cm rainfall zone litres per m²	Water cost $/4000 litres
Butyl, nonreinforced (15 mm)	2.10	10	0.41	95	320	5.15
Butyl, cotton reinforced (20 mm)	2.40	15	0.41	95	320	5.15
Aluminium foil (1 mm)	1.00	10	0.21	80	268	3.15
Polyethylene, black, (1.5 mm)	0.60	3	0.27	90	304	3.55
Polyethylene, black, (6 mm)	0.70	5	0.22	90	304	2.90
Polyethylene, black, (20 mm)	0.90	8	0.21	90	304	2.75
Chlorinated polyethylene, (30 mm)	1.60	5	0.46	100	336	5.50

Includes $0.03 per m² maintenance costs and amortization at 6 per cent interest based on probable life of catchment.

Measured in a 24-cm rainfall zone

Source: Frasier and Myers, 1972

4.0 CONCLUSIONS AND CONSTRAINTS

4.1 CONCLUSIONS

Over years a wide variety of experimental techniques for collection and storage of runoff water have been developed. A detailed description of various such techniques as employed in different countries has been discussed in the report. As can be seen that most of the techniques were developed in developed world, specially USA and therefore owing to a number of differences in social and physical conditions these can not be applied as they are to Indian conditions. However, these can well serve as guidelines for development of similar techniques in the country. Nevertheless, the best methods are those that produce sufficient and dependable supplies of harvested water at the lowest cost. On the basis of studies reported in the earlier chapters following conclusions can be drawn:

i) Land alteration is probably the simplest and least costly of the experimental techniques. By means of land alteration measures such as rock outcropping land clearing and soil smoothing, runoff inducement can be obtained of the order of 20-40, 20-30 and 25-35 percents alongwith probable life of treatment 20-30; 5-10 and 5-10 years, respectively. The land alteration technique is a flexible strategy which can be easily integrated with other water harvesting techniques. One important drawback exists in the form of the unpredictability of the water harvests. Variable yields and occasional crop failure are an unavoidable part of this technique. This makes simple forms of land alternation unattractive for some crops (fruit tree crops) or for those farmers requiring a high degree of control and dependability.

(ii) The vegetation management practices have been proved to have potential to increase water yield from watersheds. However, results reported so far have been mainly of studies conducted in small watersheds which may not be applicable to larger catchments.

(iii) Application of mechanical measure results in moisture conservation and reduction of erosion losses. Therefore, these measures are useful in regions where rainfall is scanty and dependence on rainfall is cent percent for agriculture. Mulching has been found useful for conserving moisture. The approach to treat a part of agricultural field (micro-catchment) for runoff yield has been found useful in less rainfall areas and needs further modification.

(iv) The wide away of surface treatments provide varying degrees of effective runoff, durability at varying costs., In general, chemical treatments are much more effective at inducing runoff than vegetation management or land alteration, however, in many cases their cost and limited durability make them an unattractive option. The salt treatment of soils is appealing for its low cost though its effectiveness as runoff increasing measure is of short term. Runoff efficiencies of sodium dispersant and silicon water repellents have been found in the ranges of 40-70% and 50-80% respectively with an estimation lief of 3-5 years.

(v) The surface binding treatments have also been used with varying degree of success for increasing runoff. Various binding agents including silicon water repellents, paraffin wax, asphalt pavement etc. have been used in various studies with different percentage increases in runoff. However, the economic viability and durability is an important matter of investigation. Also, the quality of water from chemically treated catchments may not always be useful for drinking and other purposes. Runoff efficiencies and estimated life of some surface binding treatments are given below in table 7.

Table 7: Runoff efficiencies and estimated life of some land treatme

Treatment	Runoff %	Estimated life
Rock outcropping	20-40	20-30
Land clearing	20-30	5-10
Soil Smoothing	25-35	5-10
Sodium dispersant	40-70	3-5
Silicon Water repellents	50-80	3-5
Paraffin wax	60-90	5-8
Concrete	60-80	20
Gravel covered membrane	70-80-	10-20

Asphalt fibreglass	85-95	5-10
Artificial rubber	90-100	10-15
Sheet metal	90-100	20

(vi) The method of runoff harvesting from rigid surfaces is under experimentation and will need examination of overall highway designing process in view of addition of runoff collecting business from such rigid surfaces.

(vii) The techniques of covering the catchments by flexible covers like butyl rubber, polyethylene, fibreglass etc. have also yielded good results in increasing runoff as the runoff efficiency of about 90% has been reported in some such cases through these materials are not experience but their durability is questionable.

4.2 CONSTRAINTS

The applicability of various techniques to varying conditions in the country is the major constraint. The environmental considerations may be important to consider while going in for any such techniques. Soil erosion is a potential danger in land alteration schemes. With regard to chemical treatments and covers, cost is the most important material and equipments may not be available indigenously. Often the quality of water provided by some of these methods is fit only for agriculture and livestock, not for human consumption.

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