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PREVENTION AND CONTROL OF SOIL EROSION

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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 calls for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

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 Hydrological 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.

Soil and water have always been vital for sustainable life, and these resources are becoming more limited as population increases. The importance of conserving soil productivity and protecting the quality of both soil and water is becoming more clear to the people than ever before. The soil is a replaceable basis of agricultural production. The soil degradation by erosion effects enormous area of the world. Nearly 31% of the land surface of the globe is subjected to water erosion. It washes about 60 million tons of the soil to the oceans every year. The present report provides an overview of soil erosion process and summarises various techniques of soil and water conservation.

The Indian National Committee on Hydrology with the assistance of its erstwhile Panel on Water Quality, Erosion and Sedimentation has identified this important topic for preparation of this state-of-art report and the report has been prepared by Dr.V.N. Sharda, Principal, Scientist, CSWCR&TI, Dehradun. The guidance, assistance and review etc. provided by the Panel are worth mentioning. The report has been finalised by Dr. K.K.S. Bhatia, Member Secretary of the 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.

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INTRODUCTION

Out of total geographical area of 329 m ha of the country, about 167 m ha (about 61% of total) are affected by serious water and wind erosion and other land degradation problems (Das, 1977). This includes 127 m ha subject to serious water erosion, 3.98 m ha through gully and ravines, 4.36 m ha through shifting cultivation, 8.53 m ha through water logging, 3.58 m ha through alkalinity, 5.5 m ha through salinity, 2.73 m ha through riverine problems and 11.79 m ha through desertification. By the end of the VII Plan (1987-88), only about 32.08 m ha of agricultural and non-agricultural lands have been treated by various soil and water conservation measures both under State (29.34 mha) and Central (2.74 m ha) sector at an expenditure of about Rs. 1,739 crores (Anony., 1989). During the VIII Plan, it is proposed to treat another 14.565 mha area at an estimated cost of Rs. 4204 crores which will result in additional biomass production of 5 m tonnes from arable lands and 15 m cum from non-arable lands. It has been estimated that in India about 5334 m tonnes of of soil is eroded annually, of which about 61% is displaced from one place to another, about 29% is carried away by the rivers into the sea level and about 10% is being deposited in the tanks and reservoirs resulting in 1 to 2% loss of storage capacity. The average rate of soil erosion in India (16.4 t/ha/yr) is much above permissible erosion rate of 4.5-11.2 t/ha/yr (Dhruvanarayana and Ram Babu, 1983).

Owing to tremendous pressure of human and livestock population, per capita availability of land has reduced from 0.48 ha in 1950-51 to 0.20 ha in 1980-81 and is expected to decline further to 0.15 ha by the turn of the century. The projected human and livestock population is expected to increase from 700 million and 392 millions in 1980 to 1000 million and 582 million in 2000 A.D., respectively. Consequently, the fuel, fodder and food grain requirements will increase to 225 million tonnes, 850 million tonnes and 240 million tonnes by the turn of the century.

To support the ever increasing demands for food grain, fuel wood and fodder, the country may require 50 m ha of additional land by 2000 A.D. Since land resources are limited, it is of utmost importance to efficiently and judiciously utilize the existing land resources to maximise land productivity per unit area on sustained basis without further deterioration due to land degradation processes. It calls of serious efforts to properly plan and execute the soil water conservation measures in the country to improve productivity of the existing areas and minimise erosion hazards.

Herein, an attempt has been made to suggest appropriate soil and conservation measures in both arable and non-arable lands under different climatic, topographic, soil and land use conditions for the prevention and control of soil erosion.

FACTORS AFFECTING LAND DEGRADATION

The factors affecting land degradation can be broadly classified into six categories, viz; climatic, soil, physiographic, agri-pastoral, demographic and socio-economic. The major climatic factor resulting in land degradation is high intensity rainfall leading to severe soil erosion problems. Other factors include high evaporative demand and lack of moisture resulting in poor vegetal cover and consequently fragile ecosystem.

Soils having low moisture storage capacity, low infiltration rates, hard layer near the land surface are generally susceptible to land degradation problems. Physiography affects land stability in relation to eroding mechanisms which may get accelerated due to presence of gullies, steep and long slopes, seismic zones and poor drainage systems. The indiscriminate cutting of trees and overgrazing in non-arable land coupled with faulty cultivation practices in arable land are the agropastoral factors contributing to land degradation problems. The demographic factors include the ever increasing pressure of human amd livestock population reducing the per capita availability of land and water resources. Lack of requisite knowledge of soil conservation measures in conserving the natural resources and poor socio-economic conditions of the farmers are also major factor leading to improper execution of soil conservation programme.

Among the various agents of erosion, water is the most important agent affecting erosion in large tracts of land in the country. It may be in the form of splash, sheet, rill, gully, or stream bank erosion with varying magnitude of erosion intensity. The other agents of erosion are wind, glaciers, and gravity. Broadly, the erosion can be classified as geologic erosion and accelerated erosion. The former occurs when an equilibrium is established between the climate of a place and the vegetative cover that protects the soil layer under natural undisturbed conditions. It occurs at such a rate that the soil formation processes are almost in equilibrium with soil depleting processes thereby not affecting the land productivity. On the other hand, accelerated erosion occurs when removal of surface soil by natural agencies takes place at a faster rate than it can be built up by soil forming processes. It depletes soil fertility in disturbed agricultural land and severe land degradation in other areas and as much warrants immediate attention.

STRATEGIES FOR PREVENTION AND CONTROL OF SOIL EROSION

The basic principle involved in the prevention and control of soil erosion aims at mitigating the erosion capacity of agents of erosion through soil surface manuation, crop management and runoff disposal. While some of these practices prevent or minimize erosion, the others control it after the erosion has occurred. Needless to say that erosion prevention is always better than its control. The erosion control measures may be useful over a short period, whereas erosion prevention techniques are necessary of sustainable management of land and water resources. The control measures, though expensive, are required to minimise both on-site and off-site effects of soil erosion. They are based upon the principle of safe disposal of runoff, slope management through land forming and trapping sediment by biological and engineering structures. For effective management of erosion, a combination of both prevention and control measures is always better.

On cultivable lands, conservation strategies are aimed at establishing and maintaining good aground cover. This is achieved by enhancing soil resistance by improving its strength, decrease impact of agents of erosion and develop sustainable farming systems by managing crops, soil, slope and runoff. The favourable soil structure can be maintained by frequent and substantial additions of crop residues and organic amendments, ensuring a proper density of vegetation and minimising the soil disturbance. This can be achieved by mulch farming techniques, conservation tillage, frequent use of cover crops grown in rotation with grain crops, use of agroforestry techniques and liberal use of animal waste and manures.

The detachment and transport of soil particles by raindrops and overland flow can be reduced by dissipating the energy of falling drops or flowing water. This can be achieved through mulching, grass cover, increasing infiltration rates and reducing degree and length of slope. Sustainable farming system aims at low cropping intensity, use of cover crops and planted fallow, integrated watershed management and water harvesting and recycling.

On pasture lands, erosion can be prevented by determining and maintaining suitable stocking rats, following proper grazing practice and planting erosion resistant grasses and shrubs. Forests provide excellent protection to soil by maintaining high rates of evapotransipiration, interception and infiltration. The erosion problems occur due to cutting of trees for fuel wood and timber purpose, livestock grazing and logging operations. An estimated 40% of the world's population use wood as the primary fuel (Brown, 1981). Afforestation schemes which include rapid-growing tree species that can be cropped for firewood forms an important feature of erosion control strategies. Selective feeling is always preferable to clear felling which leads to high erosion rats in the years immediately following logging operations. Replanting needs to be taken up quickly after clear felling before the loss of top soil and plant nutrients through erosion reduces the quality of the lands. Protection against the grazing and natural or man-made fire is necessary to establish protective cover. Establishing deep-rooted vegetation is quite effective in preventing land slides and restoring scars from previous landslides. The gully and stream bank erosion can be prevented through judicious combination of both biological and engineering measures.

CONSERVATION MEASURES FOR EROSION CONTROL

The ultimate objective of various soil conservation programmes in the country is to reduce runoff to the sea from the present level of 160 m ha-m to less than 100 m ha-m which apart from minimising soil erosion and mitigating floods will also help in recharging ground water profiles and in turn enhancing land productivity. This may be achieved by either providing mechanical or vegetative barriers across the direction of flow such that the energy of the flowing water is dissipated and the velocity is brought within permissible limits. Hudson (1971) observed that mechanical and biological or vegetative measures act like the foundation of a building while the vegetative measures act as a kind of super structure to protect the soil. On gently sloping lands where discharge is not high, vegetative measures are sufficient to minimise the erosion hazard. Mechanical or soil and water conservation measures are often necessary on moderate to steep slopes to sustain agricultural productivity, where biological measures alone may not withstand the erosive forces of flow.

MECHANICAL MEASURES FOR EROSION CONTROL

Mechanical measures are necessary on both arable and non-arable lands to improve crop productivity and control soil erosion. They have been briefly discussed in the subsequent sections.

Mechanical Measures on Arable Lands

These measures include contour bunding, graded bunding, bench terracing, conservation bench terraching, conservation ditching, broad based terraces, inter-terrace conservation measure, surplusing structures and grassed waterways.

Contour bunding

The primary objective of all mechanical measure is to reduce either the degree or length of slope or both in order to dissipate the energy of the flowing water. This measure only reduces the length of flow and water is impounded behind the bund. It is practiced on the mildly sloping (upto 6%), shallow to very deep soils and for light textured alluvial medium soils having good infiltration rates under rainfall varying from 500 to 1500 mm per annum. The design of contour bund involves the selection of vertical interval/spacing and determining the dimensions of the bund cross section (Schwab et.al., 1981; Rama Rao, 1974; Patnaik and Sikka, 1987; Dhruvanarayana, 1987; Bhardwaj and Joshi, 1987). The usual practice is to impound 30 cm water depth behind the bund. With 30 cm depth of flow over the outlet and 20 cm free board, the total height works out to be 80 cm. A top width of 50 cm and bottom width of 2.1 m gives approximate side slope of 1:1 resulting in cross sectional area of 1 sq.m. Another way is to design the cross section and height of bund to store runoff from 24 hours rain storm of 10 years frequency. Until 1980 contour bunding has been a common practice on 21 m ha land (Bali, 1980). It has been found to increase the crop yield by 15-33% (Patnaik and Sikka, 1987) and reduce runoff by 62% (Shastry et.al., 1982). Where occurrence of high intensity storms is a common feature, surplusing arrangement must be provided with the bund to prevent failure of bund due to breaching.

Graded bunding

The graded bunding is recommended in areas where intake rate of soil is low or the rainfall is more than 80 cm. Unlike contour bunds where the purpose is to intercept whole of runoff behind the bund, here the objective is to drain out excess water from the field through a graded channel at a non-scouring and and non-silting velocity. The spacing is decided similar to the contour bunds. In general grade of 0.1 to 0.4% is provided in the channel depending upon soil type which may be either uniform or variable. The cross section of the bund is such that the settled height is at least 45 cm to avoid elimination by faulty farming operations. The surplus water from graded bunds may be either stored in small farm ponds (Patnaik et.al., 1987) or conveyed to natural or artificially constructed grassed waterways (Chittranjan et.al., 1981). Under rainfed conditions in Rajasthan, graded bunding alone has been found to increase sorghun yield by 10 to 15 percent (Anony., 1989). Similarly, in Chinnatekur watershed in Andhara Pradesh, groundnut yield registered an increase of about.13% due to graded bunding (Anony., 1989).

Bench terracing

It is the most popular mechanical measure for hill slopes and is normally recommended for the slopes between 6-33%. The slope length as well as its steepness are reduced to minimize runoff and soil loss in bench terracing which are generally of four types. Level bench terrace is recommended in areas where uniform impounding of water is required as for paddy cultivation. The slope in such areas may be as low as 1%. Inwardly sloping terrace is suited for steep slopes and high rainfall areas where crops are extremely susceptible to water logging. Outwardly sloping terrace is usually a step towards construction of either level or inwardly sloping terrace and can be used in areas of low rainfall and shallow soils. The puertorican type of terrace comprise of either laying a mechanical barrier or establishing a vegetative barrier along a graded contour at the desired vertical interval resulting in the formation of a bench through downward inducement of soil. Pooranchandran et.al. (1970) have found that this type of terrace are progressively formed over a period of 2 to 4 years and cost 64 to 76 per cent of the conventional inwardly sloping terraces. Napier grass is found better as a vegetative barrier than Guatemala grass due to its higher fodder values and more green grass yield (24 t/ha and 18 t/ha, respectively). In a similar study at Chandigarh on 4% slope, Eulaiopsis binata grass was found promising in gradual formation of terraces and improvement in crop and green grass yields.

The design of bench terraces consists of terrace spacing, terrace grade, its length and cross section. Through systematic studies at Oatacamund in the Nilgiris, Lakshmipathy and Narayanaswamy (1956) and Das et. al. (1967) have evolved specifications for bench terraces. In North-Western Himalayas, rainfed benches generally have 10% outward and 8% longitudinal slope with a riser slope of 1:2 at

2.4 m vertical interval (Juyal et.al., 1988). Even in the neighbouring countries, 8% outward slope seems to be the upper threshold for the rainfed benches (Green, 1978). The shoulder bunds and terrace risers must be established with suitable grass species such as Eulaiopsis binata, Cimbopogon citrus, Dichanthium annulatum, Cenchrus ciliaris, Cynodon, dactylon etc. Bench terraces have been found effective in reducing runoff by 50%, soil loss by 98% and improved potato crop yields by 12% compared to up and down cultivating (Das et.al., 1967). The bench terraced fields have been found to possess better physical properties and nutrient status resulting in 2-3 times higher paddy and wheat yields with limited irrigation and fertilizer applications (Juyal et.al., 1988).

Conservation bench terracing

Conservation bench terrace consists of a terrace ridge to impound runoff wear on the level bench and a watershed which is left in its natural slope and produces runoff water for spreading on the bench (Zingg and Hauser,1959). They are well suited for the erosion control and water conservation in fine and medium textured soils that have good water holding capacity. They have been successfully tried in silty clay loam soils of arid tracts in Teaxs (Hauser, 1968), Kansas (Cox, 1968), Eastern Colorado (Michelson, 1968), Montana (Black, 1968), and North Dakota (Hass and Wills, 1968) with slopes varying from 1 to 5% and ratio of contributing to receiving area varying from 1:1 to 3:1. In India they have been also tried under arid (Sastry et.al., 1975) semi-arid (Prakash and Vrma, 1984) and sub-humid (Bhushan, 1979) areas. Sharda et.al. (1990) have reported that in addition to improvement in crop yields, they are effective in conserving runoff by 80% and reducing soil loss by 9 t/ha as compared to conventional practice in Doon Valley.

Conservation ditching

They have been successfully tried in the vertisols to serve the dual purpose of a terrace and a storage structure at the individual field level as an alternative to contour or graded bunds (Patnaik et.al., 1987). Studies have revealed that ditches stored more than 90% of the catchment runoff and retained all the sediment (2.6 t/ha/yr). Through supplemental irrigation, the yield increased by 24 to 47%. In clayey soils subject to swelling and cracking, this measure provides a promising alternative.

Broad based terraces

They cause no hinderance to farming operations and the entire area remains under cultivation as compared to contour and graded bunding where about 6% area is cost out of cultivation. They are usually not recommended on slopes less than 2% and steeper than 8%. They require proper maintenance and are practiced only in areas where mechanised agriculture is followed. Under high rainfall conditions at Dehradun, Channel grades upto 0.6% did not cause any scouring and the soil loss remained within permissible limits (Tejwani et.al., 1975). In the low rainfall vertisols of Bellary region, broad based terraces were found to reduce soil loss from 12 t/ ha/r to 1 t/ha/yr (Chittranjan et.al., 1981).

Inter terrace conservation measures

The primary objective of inter-terrace conservation measures is in-situ rainwater harvesting and moisture conservation in scarcity areas for improvement of crop yields. Contour cultivation alone can reduce soil loss upto 50% (Tregubov, 1981). Tied riding consisting of covering the land surface with closely spaced ridges in two directions at right angles forming a series of rectangular basins have been successfully tried on permeable soils. Bed and furrow system combines the element of erosion control with surface drainage and is suitable for water logged areas. Broad bed and furrow system is found to be suitable for managing the deep black soils in India where surface drainage during monsoon period is a problem (Kampen, 1979). A system of alternating 1 m wide broad beds and 0.5 m wide sunken furrow is found to reduce soil loss from 0.56 kg/m^2 under conventional flat planting to 0.16 kg/m^2 (Kampen et.al.,1981).

Surplusing arrangements

They are provided on the agricultural lands to drain off excess water safety into the natural or artificial drainage ways. They are necessary as sometimes unforeseen high intensity rainfall may breach the bunds or terraces. The crest level of such structures is fixed at a height upto which the water is to be impounded in the interbunded or inter-terrace areas. They are provided in the form of surplus weirs or grassed waterways. Surplus weirs are normally provided with contour bunds and do not cause any loss of area.

Grassed waterways are a must where graded bunds and other drainage type terraces are provided. Their design includes the estimation of peak rate of runoff, dimensions and shape of the waterway and grade of the channel. Parabolic, trapezoidal and V-shaped cross-sections are normally used, the former being most common and preferred where natural depressions already exist. The velocity of flow should be non-silting and non-eroding and varies from 1.2 to 1.6 m/sec depending upon type and density of grass cover. The grade is normally kept within 5% button no case steeper than 10%. Among eight grass species tried at Dehradun, Panicum rapines followed by Brocharia mutica were found to be best suited permitting velocities upto 2.75 m/sec (Dalal et.al., 1965). The terrace system with graded waterway is found to reduce annual soil loss on 17° slope in Jamaica from 13.3 kg/ m^2 to 1.7 kg/m^2 (Sheng, 1981).

Mechanical Measures on Non-arable Lands

Non-arable lands are generally those lands which are unfit for cultivation of agricultural crops due to limitations like slope steepness, stoniness, rockiness, soil depth, water logging, flooding extremes of climate etc. They are mostly under forest, wild life,pasture and recreation uses. To prevent and control erosion on such lands through concentration of runoff, vegetative and mechanical measures are normally used in conjunction with each other. The mechanical measures are briefly discussed below.

Gully control structures

They are broadly classified as temporary structures and permanent structures. When the runoff is not excessive and can be controlled by well established vegetation, temporary structures may be used in the gullies. Permanent structures are used where less expensive means are impracticable and where runoff is large and ultimate control by vegetation is not feasible.

Temporary structures

They have advantages of being cheap and requiring less technical skill. The most common are known as brushwood dams, loose rock dams, rock filled dams and woven wire dams. The rockfill and woven wire dams are more lasting than the loose rock dams. The brush wood dams are constructed in areas where wooden posts are abundantly available. They suffer from white-ant attack and consequential high cost in the long run restrict their use these days. In a loose-rock dam, a trench is first dug across the gully and filled with large rocks to form the toe of the structure. Heede (1976) reported that for efficient dam, the effective composition is 25% rocks between 100-140 mm diameter, 20% between 150-190 mm, 25% between 200-300 mm and 30% between 310 and 450 mm.

Tejwani et.al. (1960) and Narayana et.al. (1962) have reported specifications for gully plugs of various materials such as brushwood, log, earth etc. Eastern gully plugs are most common due to their ease of construction and economics. For low runoff, earthen plugs of 1.1 m^2 cross section and spaced at 45 to 60 m distances are suitable. For catchments upto 1.6 ha, plugs of 2.2 m^2 cross section with proper outlets are required where as for catchments largest than 1.6 ha size, composite check dams comprising of earth in the non-flow sections and brick/stone masonary in the spillway section are necessary. They have also suggested methods for reclaiming and protecting small, medium, deep and narrow gullies for cultivating and productive purposes.

Permanent structures

They are constructed when the benefits from such structures are justifiable compared to the cost of construction. They should have adequate capacity to handle the runoff and should help in stabilizing the gully and storewater wherever necessary. Three types of structures normally used are drop spillway, drop-inlet spillway ad chute spillway. The design of all gully control structures consists of hydrologic design, hydraulic design and structural design. Hydrologic design involves estimation of peak runoff rate and volume which the structure is expected to handle. Hydraulic design determines the dimensions of the structure for handling the given runoff. In structural design, the dimensions of the structure are fixed from strength point of view. The three major component of design are the inlet, conduit and the outlet.

Drop spillway is a weir structure and is efficient for controlling low heads normally upto 3 meters. It is less liable to be logged by debris compared to other structures having similar discharge capacities. However, when the discharge is more than 3 cuments and drop is more than 3 meter, it is costlier than other structures. It is also not suitable where temporary storage is required. It may be constructed of reinforced concrete, plain concrete, stone or brick masonary or gabions. Gabions are most widely used for being flexible, permeable, stable and economical compared to other materials.

A chute spillway is an open channel with a steep slope in which flow is carried at super critical velocities. It usually consist of an inlet, vertical curve section steeply sloped channel and an outlet. It is used for gully head control upto 5 to 6 meters and serves as a spillway for flood prevention, water conservation and sediment collecting structures for higher heads as it requires less construction material. However, chute structure is not suitable in poorly drained soils where seepage may weaken the foundation. Also there is considerable danger of undermining the structure by rodents. It is generally constructed of masonary, plain concrete or reinforced concrete. A drop-inlet spillway is a closed conduit designed to carry water under pressure from above an embankment to a lower elevation. In addition to protecting gullies, they also help in storing water which may be used for irrigation. It is used as a principal spillway for farm ponds or reservoirs, for debris basins, and as a flood control and road way structures. It is very efficient structure for controlling relatively high gully heads,usually above 3 meters where appreciable temporary storage is required and helps in grade stabilization. However, it is likely to be clogged by debris and is limited to locations where satisfactory earthen embankment can be constructed.

Contour and Staggered Trenches

The trenches constructed along contour are known as contour trenches. They are provided on hill slopes specially on degraded an bare waste lands and pastures for moisture and soil conservation and also for afforestation purposes. They are also recommended on pasture and forest lands where plant cover is scantly and water erosion is serious. They are especially suited to deep to moderately deep, medium textured permeable soils but their benefits are limited in vary sandy soils or soils with heavy clay pan.

The contour trenches may be continuous or interrupted type. The former type stores more water but the cost is high. There is potential danger of flowing of water along the upper edge in case the trench breaks. They are essentially used in low rainfall areas for moisture conservation and require careful layout. The interrupted or intermittent trenches are adopted in high rainfall areas and may be in line or staggered with respect to each other.

The design is generally based upon runoff volume from the contributing area for 2 years frequency. Normally squarecross-sections used with the size varying from 30 x 30 cm to 50 x 50 cm. The trench may also be trapezoidal in cross-section with side slope of 1:1. The spacing usually vary between 3 and 5 meters. For convenience of lay out and construction shorter lengths of 3.5 or 7 meters are generally adopted. In pasture lands longer lengths upto 300 m are also adopted. Construction of trenches should always start from the ridge and progressively extend towards the valley. The top soil is put on the upstream side whereas boulders and gravels are stalked on the lower side to serve as toe to the spoil bank. The staggered contour trenches in a ravinous watershed at Agra have resulted in practically nil runoff and soil loss (Sharda et.al., 1982).

Diversion Drains

A diversion drain is an individually designed channel constructed across the slope for the purpose of intercepting runoff and conducting it to a safe outlet, to reduce the length of slope, divert water away from the farm buildings, protect bottom land from overflow and to cut-off headwater from the top terrace where the land above in not terraceable because of topography.

Diversion should ordinary be designed to keep velocities as high as will be safe for the type of vegetation present in the channel. The safe velocity for bare channel is 0.5 m/sec for sand and 0.6 m/sec for other soils. For vegetated channels, a velocity of 1 m/sec for poor cover, 1.25 m/sec for fair cover and 1.5 m/sec for good cover is permissible. The dimensions of the channel are fixed to carry peak rate of runoff for 10 years frequency. The design procedures is similar to that of grassed waterways. Establishment of good channel vegetation is essential. Mowing of channel is very important as otherwise bushy growth may obstruct the flow. The spoil bank of the diversion drain should be planted with suitable grasses and bush species.

Measures for Landlside, Mine spoil and Torrent Control

The unscientific development activities including road construction, mining etc., indiscriminate cutting of vegetation, overgrazing and faulty management practices lead to mass erosion problems. It is estimated that major landslides in Himalayas result in an annual loss of 50000 man hours and 5000 vehicle hours per kilometer of the hill roads due to communication failures (Bansal and Mathur, 1976). Krishnaswamy and Jain (1975) have identified 31 major landslides in Northern and North-Western Himalayas covering over 12000 sq. kms area.

The total no of working mines in the country have been reported as 4052 which cover an approximate area of 7850 sq. kms. (Baliga, 1985). In India, very little work has been done to stabilize mine spoil areas which pose a potential danger to water quality in the down reaches and lead to enormous land degradation problems. The total area affected by torrents in the country has been estimated as 2.73 m ha. The damages caused by hill torrents has been a menacing problem in the entire Himalayan and Shiwalik foothill regions extending from Jammu and Kashmir in the North-West to Arunachal Pradesh in the North East and beyond.

The remedial measures to control erosion from landslide, mine spoil and torrent areas and to stabilize these areas are briefly discussed below :

Land Slide Control

The factors causing landslides may be broadly classified as Non-preventable and preventable (Deb et.al.,1969). The non-preventable factors include weak and unstable geological formation, seismic disturbances and hydrological factors. The preventable or man made causes which lead to land slide problems are felling of trees, overgrazing, forest fires, unscientific agriculture on steep slopes, road construction and mining activities. Tejwani et.al. (1975) have broadly divided the reclamation measures for landslides into three categories, viz; protective, structural/ engineering and vegetative. The protective measures include closure by barbed wire fencing, stopping of grazing by cattle and stoppage of fuel cutting. Such measures help in natural regeneration of the vegetation in the problem area. The mechanical or engineering measures are adopted essentially to stabilize the channel bed and prevent the toe cutting of slide face in th lower reaches. Series of stone checks and crib/logwood structures are constructed to arrest the soil mass. In the middle reaches, construction of series of gabion drop structures to stabilize the bed slope and conserve the soil moisture is taken up. The lower reaches are stabilised by constructing toe/retaining walls to prevent undercutting of slope face and supplemented by gabion spurs to divert the flow towards the centre line. A landslide control study at Dehradun has shown that a series of drop spillways reduced the torrent bed slope from 12.3 to 7.3 in the lower reach and from 23.1 to 14.2% in the middle reach (Sastry et.al., 1981).

The vegetative measures help in the interception of rain, retard the flow velocity and bind the soil particles wherever feasible. Fast growing, drought resistant, hardy plant species suitable for a given region such as Arundo donax, Morus,alba, Acacia, catechu, Agave, americana, Erthyrinasubrosa,Salix tetrasperma, Grewia optiva etc. should be planted. The landslide face should be stabilized through contour wattling and mulching techniques. Contour wattling is adopted upto 33% slope and consists of trenches 0.3 m wide and 1 m deep dug out on contours across the slope at 5-7 m intervals. Self sprouting posts of the species like Salix tetrasperma and Vitex negundo are planted at 1 to 1.25 m spacing. The brush wood meshes are woven around the posts 2 cm above the ground. A thick layer of locally available grases when spread as a mulch between the wattled area helps to retard the flow velocity and arrest the silt load. To prevent flowing away of grass with water, it may be tied across with 20 gauge G.I. wire. For efficient control of landslide the engineering and vegetative measures must be taken up simultaneously in the affected area.

Erosion Control in Mined Areas

Huge quantities of over burden and mineral wastes in mined areas, if not stabilised properly get washed down and cause degradation on agricultural lands and pollution of water besides disruption of communications. The mechanical and vegetative measures similar to those for control of landslides can be adopted for stabilizing the mined areas. Other mechanical measures include construction of silt detention basins, diversion drains or road drains and culverts for mine haul roads. Studies conducted at Sahastradhara on a limestone mine has shown that conservation measures drastically reduced the debris flow, improved the water quality and made the flow perennial (Katiyar et.al., 1987). The equivalent nala slope reduced from 38.3% to 23.1%. The average monsoon runoff reduced from 57% to 39.5% while the dry weather flow has significantly increased. Through natural regeneration, the vegetation cover has increased from 10% to 50%.

Erosion Control in Torrent Areas

Gorrie (1946, 1957) made pioneering work to treat torrent affected areas in Punjab by primarily employing vegetative measures. Sethi (1960) used engineering measures consisting of constructing a central channel with two parallel earthen embankments on both sides. Deflecting spurs with their noses armoured were provided at suitable spacing. In the Shiwalik foothills, a package of practices was evolved to reduce the heavy silt load from the highly denuded watersheds. It consisted of staggered contour trenches and afforestation with Acacia catechu and Dabergia sissoo, construction of earthen, brushwood and logwood gully plugs in the tributaries and masonry check dams and debris basins in the main nalas. These practices reduced annual sediment yield from 80 t/ha 4 t/ha.

At Dehradun, Patnaik et.al. (1985-90) initiated a project to study the mechanics and behaviour of torrents and to suggest remedial measures for their control during 1985. Both mechanical and vegetative measures were tried. Patnaik (1990) concluded that braiding and secondary anastomosis result in the frequent shifting of the thalweg from side to side across the width of the torrent bed which creates uncertainty about locating the torrent training works such a spurs. Large quantities of water infiltrates and flows through the profile of the porous beds causing continuous partical readjustment resulting in undermining of the structural control works. The frequent shifting of bed forms results in gravel bars. The low ill-defined banks are overtopped during high flows resulting in overflanking of the spurs abutting these banks. Storms (1962) reported that in Newzealand, the low flows during receding floods tend to wander off around the gravelbars deposited in the central channel and attack the relatively more erodible alluvium banks of the torrents known as shingle rivers. The shingle rivers are trained by concentrating the flow in a defined and narrow course so as to attain a sufficiently high velocity to move the shingle beds and clear the river course. A system of groynes is used to confine the main flow in a defined course which is kept clear of willows and other vegetation to prevent fixation of shingle and checkig flood flow. The plantation of willows and poplars is done in the area between the groynes and stop banks (levees) are constructed on both sides of the course The width is progressively narrowed to attain the scouring velocity of flow at the mouth of the river.

Broadly the torrent training works consist of retards, rivetments, spurs and grade stabilization structures. Retards help in reducing the stream velocity to prevent erosion of the bank or scour of its toe by inducing deposition. The three types of retards commonly used are live hedges, jacks and jetted posts. Livehedges consist of fast sprouting tree species planted in trenches with bottom 30 cm filled with good soil. the jacks are posts of 8-10 cm diameter and 2-3 m length, placed closely in series close to the eroding bank and tied together with an iron cable of 2 cm diameter. The jetted posts are green posts of 2 to 2.5 m in length and 6 to 12 cm in a diameter which are erected along the actively eroding banks in the tworows, 1 m apart.

The rivetments are used for stabilization of vertical and steep banks from direct impact of flood water. One way is to slope back the banks and plant them with suitable grasses at 45 cm x 45 cm spacing. Alternatively, brushment rip-rap (15 cm thick) can be placed on banks sloped backto a grade of about 1.5:1 and planted with cuttings of suitable vegetation at 30 cm x 30 cm spacing. Sometimes locally available boulders are also used for dry pitching of bank in place of brushment rip-rap.

Spurs are used to deflect the direction of flow towards centre of the channel and reclaim excess are of the torrent bed. Depending upon the function and alignment, they have been classified as repelling type (making acute angle (30° to 45°) with the upstream side), attracting type (making acute angle (45° to 60°) with down stream side) and deflecting type (making right angle with the blanks).

Depending upon the material of construction, they may be permeable or impermeable. The permeable spurs are constructed from vegetative material and are useful in areas where deep scours are not expected due to high velocity of flow. They may be of single row type, made of logwood post jettees, or brushwood reinforced with vegetation. The impermeable spurs are constructed from loose dry boulders or wire creates, cement stone masonary or cement concrete block s and are useful where the attracting current is very swift and boulders are abundantly available. Patnaik (1990) found spelling type spurs most suitable for quic reclamation of concave banks. However, they require special protection at their nose which is subjected to excessive scouring due top swirling action of the flow around it. Deflecting type spurs are more suitable for checking erosion along straight reaches.

The grade stabilization structures are required to prevent scouring of the steep bed of the torrents and reduce the slope steepness by transforming the bed into series of flat terraces. Check dams and logwood or gabion cross barriers/silt detention dams have been found effective in reducing the bed gradient. Heede (1977) has provided guidelines for the construction of check dams and the conditions required to ensure their stability. The detention structures should be located at such places where they may collect maximum debris and should, therefore, be constructed across the narrow sections of the gorge. Once a detention dam is silted up, another may be constructed on the deposited debris behind the first one rather than raising the first one. Pathak and Katiyar (1987) have provided details for treating different types of torrents classified as eroding, collapse, glacial and composites type. The evaluation of torrent treatment works (Singh et.al., 1971) has indicated that permeable structure functioned better than the impermeable ones which often got damaged due to obstruction caused by flow. For grade stabilization, gabion cross barriers proved to be better than log cross barriers. Among the various type of spurs, boulder spurs reinforced with vegetation and created at the nose and gabion spurs performed better in terms of their function and life. Vegetative spurs alone failed due to bending of vegetation during high floods and usually got buried under the sediment.

AGRONOMICAL MEASURES FOR EROSION CONTROL

Agronomical measures help in reducing the soil erosion by providing a plant cover over the land surface thereby dissipating the energy of the falling raindrops and reducing the velocity of flowing water. However, they are always adopted in conjunction with mechanical or engineering measures and form second line of defence. The effectiveness of these measures depends upon the type of crops, their density, morphology and stage of growth. Row crops, categorised as erosion permitting crops have been found to be least effective due to high percentage of bare ground which leads to serious erosion problems. Hudson (1957) reported that under identical situations, an ill-managed corn crop can cause 15 times more soil loss then a well managed corn.

Erosion resistant crops like legumes and grasses on the other hand will cause less erosion de to good canopy cover. At Dehradun, Cynodon dactylon grass has been found effective in reducing runoff and soil loss from 71.2% and 42.4 t/ha under bare fallow land to 27.1% and 2.1 t/ha (Gupta et.al., 1963).

Crop Rotation

The purpose of crop rotation is to combine different crops and grow them consecutively such that erosion permitting and erosion resistance crops in a sequence yield average annual soil loss within permissible limits while maintaining the soil productivity. Hudson (1981) has found that a rotation of tobacco-grass-grass-tobacco-grass-grass reduced mean annual soil loss to 1.2 kg/m^2 compared to 1.5 kg/m^2 under one of two consecutive years of tobacco followed by four years of grass. Similarly, when the maize crop was grown in rotation with meadow the soil loss was found to reduce significantly (Moldenhauer et.al., 1967).

Crop Geometry

Plant population and vegetative cover must be optmised to minimise runoff and soil loss through optimal seed rate and crop geometry. In addition, it also helps in avoiding severe moisture and nutrient stresses from soil which may lead to crop failures under rainfed conditions. Bhardwaj et.al. (1980) found 90 cm x 20 cm as the optimal crop geometry yielding minimum runoff (33%) and soil loss (13.9 t/ha) in maize crop at 4% slope.

Mannering and Johnson (1969) found that by growing soyabeans in narrow rows of 510 mm spacing instead of 1020 mm spacing reduced soil loss by 30%.In Zimbabwe, increasing planting density of maize from 2.5 to 3.7 plants per squre meter and using a trash mulch at the high density reduced the annual soil loss from 1.23 to 0.07 kg/m^2 (Hudson, 1981).

Mulching

Mulching helps to reduce the impact of raindrops, conserve soil moisture, check evaporation losses, reduce excessive heating and reduce the velocity of runoff. It is most useful as an alternative to cover crops in dry areas where insufficient rain prevents the establishment of a ground cover. It may be achieved by spreading stubble, trash or any other vegetation. Stubble mulching poses problems of weed infestation and seed-bed preparation. In trash farming, crop residues are cut, chopped and partly mixed in soil and partly left on the land surface. Martson and Perrens (1981) reported that stubble burning, stubble incorporation and no tillage have decreasing order of erosion potential. The limitation with mulching is the availability of mulch material or plant residues. Other problems are that the mulch competes with main crop for nitrogen as it decomposes and weed growth is encouraged. Borst and Woodburn (1942) have demonstrated the effectiveness of mulching in reducing soil erosion. At Dehradun maize crop with much @ 4 t/ha recorded significantly lower runoff (22.3%) and soil loss (6.2 t/ha) as compared to normal ploughing (49.4% and 36.5 t/ha, respectively) (Khybri et.al., 1980).

Tillage Effects

Tillage and planting systems which leave a protective cover of crop residue on the soil surface have been shown to reduce soil losses and are among the least costly erosion control practices. Leaving as little as 20% of the soil surface covered with corn residue reduced erosion by 50% of that which occurred from a cleanly-tilled, residues free surface (Dickey et.al., 1981). Growing cowpeas followed by maize but with tillage resulted in soil loss of 0.62 kg/m^2 which reduced to only 0.02 kg/m^2 for maize followed by one of cowpeas with no tillage (Lal, 1976). In Nigeria, Osuji et.al. (1980), while studying the effect of different tillage practices on soil loss, found that maximum erosion occurred from conventional tillage (8.46 t/ha) followed by ploughing (7.76 t/ha), manual (4.61 t/h) and no-tillage (0.05 t/ha) operations. Stewart et.al. (1975) discussed the effect of crops, tillage systems, rotations and other management practices on 'C' factor of universal Soil Loss Equation (Wischmeier and Smith, 1978). Chisci and Zanchi (1980) also observed that soil loss was highest from conventional tillage systems though runoff was highest from minimum tillage system.

Strip Cropping

Strip cropping is best suited to well drained soils as on poorly drained soils, the reduction in runoff velocity can result in water logging problems. It is normally recommended on slopes between 3 to 8% and the strip widths may vary with degree of erosion hazard and generally vary between 15 and 45 m. It involves growing of few rows of erosion resisting and erosion permitting crops in alternate strips on contour across the slope. On the steeper slopes or on very erodible soils, it is necessary to retain some strips under permanent vegetation like grasses and legumes. These buffer strips are usually 2 to 4 m wide and are placed at 10to 20 m intervals (Wischmeier and Smith, 1978).

It has been widely practiced to control wind erosion (Brown, 1970). This practice is, however, applicable in small size farms and is not compatible with highly mechanised agricultural systems. Insect infestation and weed control are additional problems associated with strip cropping.

Multiple Cropping

This system involves growing two or more crops closely together in time and space. This is further classified as sequential cropping and inter-cropping (Andrews and Kassam, 1976). The former is adaptable in any type of cultivation system for intensification of crop production in time dimension where water and other resources are not limiting. The inter-cropping is adaptable mainly to the shifting, labour intensive and animal and small tractor cultivation systems where the crops are grown in close proximity to each other resulting in inter-crop competition during at least a part of the crop growth period. Multiple cropping system results in more intensive use of land than is achieved with continuous cropping and crop rotations. In medium black soils of Kota, cultivation of sorghum and pigeonpea mixture has been found more beneficial in reducing runoff, soil loss and nutrient losses and improving crop productivity (Verma et.al., 1983).

Multiple cropping is found more effective in controlling weeds, insects, disease and other pests than continuous cropping (Listinger and Moody, 1976). Weed control is, however, more difficult in this system as major tillage or herbicides often can not be used because of variety of crops grown. This especially is a problem with inter-cropping system which becomes labour-intensive.

EROSION CONTROL ON PASTURE AND FOREST LANDS

The forests and grass lands play a vital role in protecting the soil from erosion and maintaining ecological security. Though India has 15% of world population, only 67.2 m ha area constituting 2% of world forest area is under forest cover (Annoy., 1988). Thus, per capita availability of forest area in the country is only 0.08 ha against the world average of 1 ha. Similarly, in view of the tremendous increase in livestock population, the requirements of the green fodder, dry fodder and concentrates for the productive livestock has been estimated as 594.8, 373 and 82.8 m tonnes by the year 2000 A.D. (Anony., 1976). This may require about 16.5 m ha area under fodder crops by 2000 A.D. and increase in the production through advanced technology. The unscientific management of forest and grassland covers coupled with indiscriminate cutting has lead to serious erosion problem. To restore the eco-balance in a given region, these dwindling resources need to be conserved such that they provide adequate cover to the soil against water and wind erosion.

Chatterjee and Sen (1964) reported that perennial grasses like Dicanthium annulatum are more effective in reducing runoff and soil loss. At Dehradun Pueraria hirsuta followed by Dicanthium annulatum was found superior in conserving runoff and soil loss (Tejwani et.al., 1975). Table 1 (Hukam Singh, 1985) presents the effectiveness of different grass cover in various agro-climatic conditions in reducing runoff and soil loss.

TABLE 1 : Effect of Grasses on Runoff and Soil Loss in Various Agro-Climatic Conditions

Location	Treatments	Runoff as % of rainfall	Soil loss (t/ha)
Dehradun (U.P.)	Cynodaon dactylon	27.1	02.1
	Cyumbopogon citratus	11.0	02.31
	Bare fallow	71.1	42.2
	Bare & ploughed fallow	59.6	155.9
	Natural grass	21.2	01.0
Vasad (Gujarat)	Natural fallow	02.1	02.0
	Grass cover (D. annulatum)	01.1	01.5
Kota (Rajasthan)	Natural cover	00.4	04.9
	Cultivated fallow	03.7	17.3
Ootacamund (T.N.)	Eucalytus globulus	01.1	00.2
	Shola forest	01.3	00.6
	Grassland (Protected)	00.02	Nil
Deochanda (DVC) (Bihar)	Natural fallow	09.5	-
	Cynodon pletostachyon (Giant grass)	33.5	-
	Pennisetum polyctachyon (Thin Napier)	29.0	-
Muzafrabad (U.P.)	Bare plot	59.0	51.2
	Cynodon dactylon	30.0	11.0

In addition to providing a protective cover, grasses also help in stabilizing the soil conservation structures such as contour and field bunds, grassed waterways, terrace risers, ravine reclamation and landslide, mine spoil and stream bank protection (Hukam Singh, 1984; Dalal et.al., 1965). Techniques for developing and managing grasslands in different regions and their productive and potentials have been reported by Shankrnarayana (1977), Ahuja and Mann (1975) Sud and Singh (1974), Mathur and Joshi (1975) and Prajapati and Nambiar (1980).

To prevent degradation of pasture land through over grazing, proper grazing system must be adopted. The grazing methods in practice are rotational grazing, strip grazing, continuous grazing and zero gazing. Fournier 1972) has reported that grassland should not be exploited to more than 40 to 50% of their annual production of should be allowed to regenerate sufficiently to provide a 70% ground cover at the times of erosion risk. Prajapati et.al. (1988) found that moderate rate of grazing does not have adverse effect on vegetation, runoff and soil loss.

To stabilize bouldery and torrent lands in Doon Valley, Dalbergia sissoo, Acacia catechu and Eulaliopsis binata have been found promising. Mathur et. al., (1979), and Arora and Saraswat (1983) reported that in the old riverbeds, sweet oranges can be successfully and economically grown. Contrary to the belief, that no erosion takes place from forest land, occurrence of very deep and wide gullies has been noticed in such areas which need immediate attention. Leaf (1970) reported that immediately after logging operations, the sediment production increased by 150%. Ei-Swaity, Dangler and Armstrong (1982) have discussed afforestation programmes for arresting erosion particularly in developing countries including India.

WATER HARVESTING STRUCTURES FOR EROSION CONTROL

As already reported, of the 5334 m tonnes of soil eroded annually, about 480 m tonnes is deposited in various reservoirs in the country (Dhruvanarayana and Ram Babu, 1983). The observation of sediment load from 18 major river systems reveal that Ganga basin ranks the highest in the sediment load production of 586 m tonnes per year, followed by Brahamputra with the load of 470 m tonnes per year. The observed sedimentation rates in the major reservoirs (5.29 to 23.59 ha m/100 sq km/yr) for exceed the design rates which were assumed between 0.29 to 4.29 ha m/100 sq km/yr (Mukherjee et.al., 1985). The monitoring of 365 stream gauging and sediment measuring stations has indicated wide range of sediment production rates from small watersheds varying from 0.005 to 273.68 ha m/100 sq km/yr (Ramesha et.al., 1985). The severity of the problem thus calls for immediate treatment of the catchments of these reservoirs on priority basis through appropriate soil and water conservation series measures. One way of arresting heavy silt loads is to construct a series of small reservoirs/pond/tanks to harness the inevitable runoff which will consequently reduce the heavy silt load. In addition, the harvested water can be beneficially utilized for irrigation to boost crop production in rainfed areas and prevent food hazards. The Central Water Commission (1977) has reported that as many as 8000 tanks in Andhra Pradesh and 35000 tanks in Karnataka, though individually small, collectively give considerable moderation in flood peaks during the earlier part of the monsoon. The aggregate impact of micro-storage structures is even bigger than large dams in effectively conserving runoff and thereby soil loss, improve land productivity, argument ground water reserves, mitigate droughts and reduce the flood fury.

The experience has shown that cost of irrigation through major and medium irrigation projects has escalated to Rs. 27000 per ha compared to Rs. 8000 in case of minor projects by the end of VII Plan. Hence, emphasis should shift to small reservoirs/ponds and medium and major projects need by under-taken only under conditions of absolute necessity. No big dam/reservoir should be constructed until sediment production rate is brought down to less than 3-5 ha m/100 sq km/year through proper execution of soil and water conservation measures in the catchments of such reservoirs.

Table 2 presents water yield potential of watershed in different regions of the country which can provide a tentative guide for the design of ponds or water storage structures (Sastry and Mittal, 1987).

Table 2 : Expected Water Yield into Farm Ponds in Different Regions of the Country

Region	Soil	Annual Rainfall (mm)	Land slope (percent)	Expected water yield (%)
Dehradun, UP	Silty loam	1600	2-4	16.5
Bellary, Karnataka	Deep black	508	1-2	20
Shiwalik Region	Sandy loam	1150	10-15	55
Anantpur, AP	Shallow red	540	5	20
Hyderabad, AP	Red sandy Loam	770	2-5	10
Banglore, Karnataka	Red	830	2-3	20
Karnal, Haryana	Alkali	650	0-2	40
Chitradurga, Karnataka	Red loam	612	5-10	10
Bunga, Haryana	Silty clay loam	1116	10	50

The harvested water when utilized for supplemental irrigation has significantly improved the crop yields in rainfed areas. With one supplemental irrigation of 5 cm, the wheat, barley and gram yields have registered increase of 82-85%, 32% and 36% over unirrigated plots (Singh et.al., 1981). At Chandigarh, the yields of major crops of wheat, gram, mustard and Taramara increased by 50% to 300% with supplemental irrigation during presowing and CRI stages (Sud et.al., 1988). Similar trends have also been reported from semi-arid regions of Kota and Jodhpur, black soil region, and red soil regions (Verma et.al., 1986; Mann et.al., 1981; Hegde et.al., 1981).

EROSION CONTROL THROUGH WATERSHED MANAGEMENT

Integrated and scientific management of natural resources, namely soil, water, plant, man and animal and environment on watershed basis for optimising production of food, fodder, fuel, fibre and fruit on sustained basis without deterioration of these resources to meet increasing demand of growing human and animal population is the key to prosperity of the country. For efficient and judicious management of land and water resources, all the developmental programmes in the country should be systematically implemented on watershed basis which apart from preventing gigantic loss of soil will also improve land productivity and ground water recharge. Planning and execution of soil conservation programmes on watershed basis involves reconnaissance and detailed survey of the watershed area, preparation of present landuse map, land capability classification map, socio-economic survey, proposed landuse map with recommended engineering, agronimical and vegetative measures, benefit-cost analysis and phasing out of the proposed works. The watershed under different landuse and treatments vary in their efficiency in conserving runoff and soil loss under different agro-climatic situations in the country.

At Dehradun, in a small agricultural watershed treated with soil and water conservation measures, the peak rate and volume of runoff reduced by 86% and 62% respectively compared to pretreatmental period. Similarly, in a forest watershed when treated with brushwood check dams, the soil loss reduced by 54% though there was no appreciable reduction in runoff (Sastry and Dhruvanarayana, 1984). A study in a Shiwalik watershed at Chandigarh has shown that engineering and vegetative measures were effective in reducing runoff and soil loss by 67% and 94% respectively (Mishra et.al., 1980).

In Southern hilly region of Nilgiris, a watershed when planted with Eucalyptus globulus yielded 16% lesser runoff during first rotation of 10 years compared to natural grasslands (Samraj et.al., 1988). A ravinous watershed planted with Dalbergia sissoo produced 58% and 41% lesser runoff and soil loss compared with watershed planted with Cenchrus ciliaris (Sharda et.al., 1982). Pradhan and Vasava (1980) have reported 50% reduction in runoff volume and peak rates of runoff after only 2 years of closure of a ravinous watershed. At Kota runoff and soil loss reduced from 15.1 to 6.8% and 3.83 to 1.15 t/ha when the watersheds were protected with D. annulatum and Acacia nilotica (Anony., 1988). When protected with D. annulatum and mechanical measures, the runoff and soil loss from this ravine watershed further reduced to 1.9% and 0.43 t/ha. Das et.al. (1980) has reported that when the catchment areas of different river valley projects, viz; Bhakra, Mahkund, Hirakund and Chambal basins were treated with soil and water conservation measures (silt traps, silt detention structures, gully control structures, water harvesting structures), the sediment production rates (SPR) dramatically decreased with the percentage of watershed areas treated. While 80% treated area decreased SPR by over 40%, conservation measures in 40% area, significantly reduced SPR by over 65%. This finding is of great significance when the financial resources are limited.

The Central Soil and Water Conservation Research and Training Institute, Dehradun was entrusted with the preparation of 21 model Watershed Management Plans in different agro-climatic regions of the country. Table 3 presents the impact of soil and water conservation measures in conserving runoff and soil loss in some of these watersheds which were taken up during 1984-85 (Bhardwaj and Singh, 1990).

Table 3 : Reduction of Runoff and Soil Loss through Soil and Water Conservation Measures on Watershed Basis

Watershed name	State	Runoff %		Soil loss t/ha	
		Pre-project	1987	Pre-project	1987
Bajar-Ganiyar	Haryana	7.3	3.5	N.A.	8.5
Behdala	HP	30.0	10.0	12.0	7.0
Chhajawa	Rajasthan	N.A.*	N.A.	N.A.	10.6
Chinnatekur	AP	N.A.	4.3	N.A.	N.A.
Fakot	UP	42.0	0.7	11.0	2.7
G.R. Halli	Karnataka	1.4	1.0	N.A.	1.0
Joladarasi	Karnataka	N.A.	6.7	N.A.	2.3
Siha	Haryana	N.A.	1.5	N.A.	9.7

*N.A. = Not available

As is evident the soil and water conservation measures on integrated basis significantly reduced runoff and soil loss in all the watersheds thereby inducing more in situ conservation of water and hence natural regeneration of vegetation.

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