Training Manual

Online Collaborative Training Program
On
"Integrated Watershed Management"
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Integrated Watershed Management

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Introduction

Watershed management has emerged a well accepted tool and sound strategy for long term agricultural sustainability through efficient management of natural resources, economic viability and social acceptability of production systems and environmental security. The Watershed Development Program (WDP) initially envisaged as a measure for poverty alleviation and improved livelihoods has gained even greater importance in light of the worldwide recognition of its effectiveness in combating climatic change. In India several Ministries namely, Ministry of Agriculture, Ministry of Rural Development and Ministry of Environment and Forests have been involved in Watershed Development Programs with substantial variation in their approaches. The Ministry of Rural Development had been coordinating sector-wise flagship schemes such as IWDP, DPAP and DDP under Watershed Development Programs. The main objective of the WDP was to improve water conservation, irrigation facility, andland use pattern leading to increased agricultural productivity in drought prone and desert prone areas. Poverty reduction, better livelihoods and improved bio-physical and socio-economic environment wouldbring about sustainable development.

Drainage lines, like veins and arteries in human body, play an important role in a watershed since through them water, if in excess, could be drained or if needed, could be stored. Sustainable production depends considerably upon proper development, conservation, management and use of water resources at watershed level involving the local community. Hence, a proper understanding of the basic principles, approach and application of participatory watershed management is essential for resource conservation and sustainable production.

Rationale of Watershed Management

Loss of vegetative cover followed by soil degradation through various forms of erosion has resulted into lands which are thirsty in terms of water as well as hungry in terms of soil nutrients. All such regions have predominantly livestock-centered farming systems; less biomass for animals not only reduces animal productivity, the inevitable uncontrolled grazing pressure on already eroded lands further accelerates the problem and deteriorates the ecological balance. Growing population pressure, higher demands for food and fodder coupled with impact of rapidly changing socio-economic conditions have added fuel to the fire. The piecemeal approaches such as contour bunding or terracing on individual holdings or a group of farms only marginally benefit as they are done ignoring to what happens to other areas which influence the hydrological characteristics. Such sporadic actions generally fail to attract farmers as they do not yield benefits proportional to the efforts and investments made. Thus, for maximizing the advantages, all developmental activities should be undertaken in a comprehensive way on watershed basis.

Watershed Management (WSM) has, therefore, emerged as a new paradigm for planning, development and management of land, water and biomass resources with a focus on social and institutional aspects apart from bio-physical aspects following a participatory "bottom-up" approach. A large number of projects for productivity enhancement are being implemented following watershed approach. Watershed management becomes increasingly important as a way to improve livelihood of people while conserving and regenerating their natural resources. The role and importance of community participation in ensuring the success and sustainability of watershed management is now widely accepted.

Watershed Approach/Concept

Effective use of land and water is fundamental to growth and sustainable development.

The concept of watershed management has evolved to ensure effective use of both natural and social capitals. Thus, the watershed development programs include land, water and human resources as essential components. The watershed program is primarily a land based program, which isincreasingly being focused on water, with its main objective being to enhance agricultural productivity through increased in situ moisture conservation and protective irrigation for socio-economic developmentof rural people (Joshi, et al. 2004, 2006).

Watershed, a hydrological unit of an area draining to a common outlet point, is recognized as an ideal unit for planning and development of land, water and vegetation resources. Watershed concept has been used extensively because of importance of water balances in the study of ecosystems. Watershed also allows accurate measurements and monitoring of components of water balance in hydrologic cycle, sediment, energy, heat, carbon and nutrients balances in an ecosystem. This can provide a network of monitoring stations on sites within a basin in a nested form or otherwise to track down the status of pollutants at different points. The monitoring at the level of watersheds or sub-watersheds in a basin will help in analyzing impacts of current and future activities and accordingly plan area specific management options or alternatives based on the priorities as per the intended project objectives. The concept of watershed is not very new. Its level of concern is evident by the wide variety of programs and institutions involved in the study and management of watersheds. However, the traditional top down approach of watershed management has not paid dividends, partly because of entire stress on biophysicalaspects without due regard to socio-economic aspects involving community participation. Watershed management programs should, therefore, be intimately linked with the people whose socio-economicand cultural backgrounds play a decisive role in meaningful planning, implementation and operation of watershed programs. Integrated watershed management covering the area from the highest point (ridge line) to the outlet is, therefore, the process of formulating, implementing and managing a course of actions involving natural and human resources in a watershed, taking into account of all the factors operating within the watershed.

Watershed Programs: Growth & Development

Watershed management, though less focused earlier, has a history of about 50 years in India. Multiple agencies have been involved in the growth and development of watershed programs over the years (Table-1). Biophysical aspects of watershed management were first addressed in the Damodar-Barakar basin under Damodar Valley Corporation, Hazaribagh (Bihar) by establishing a Soil Conservation Department during 1949-50. The focus on watershed research was further sharpened with the establishment of a network of Soil Conservation Research, Demonstration and Training Centers at Dehradun, Chandigarh, Agra, Kota, Vasad, Hyderabad, Bellary and Ootacamund (now Udhagamandalam) by the Union Ministry of Agriculture in 1954 to provide necessary research back up and trained manpower and these centers later became part of the Indian Council of Agricultural Research (ICAR) in 1969 (Samra, 1997).

These Research Centers established 42 small experimental watersheds for monitoring changes in surface water hydrology, natural vegetation successions as an impact of closure and watershed interventions during 1956. The Centrally sponsored scheme of "Soil Conservation in the catchments of River Valley Projects" was launched by the Soil and Water Conservation Division of the Union Agriculture Ministry in 1961-62 for watershed protection in 27 catchments. Watershed technologies were first demonstrated in actual field settings through integrated watershed management approach in mid-seventies through the Operational Research Projects (ORPs) in watersheds at Sukhomajri (Haryana) and Nada (Haryana) representing Shiwalik foot hills, Fakot (U.P. hills) representing middle Himalayas and G.R.

Halli (Karnataka) representing red soils of low rainfall region. The people's participation was the key to the success of these projects. During 1980-81, watershed programs were initiated under Flood Prone Rivers Project by the Soil and Water Conservation Division of Union Agriculture Ministry.

As a result of the achievements and benefits of these ORPs, forty seven model watersheds were established in different agro-ecological regions of the country in 1983 for joint development by the Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun and Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad of the Indian Council of Agricultural Research, State Governments and State Agricultural Universities. Based on the tremendous success of model watersheds for drought mitigation during the drought of 1987, number of nationally and internationally funded watershed development projects/programs were initiated (Table-1). Major nationwide watershed programs included Drought Prone Area Program (DPAP) and Desert Development Program (DDP) that adopted watershed approach since 1987, National Watershed Development Program for Rainfed Areas (NWDPRA) in 1991 and Integrated Wastelands Development Project (IWDP) on watershed basis since 1994. Western *Ghats* Development Program of Union Planning Commission spread over an area of 16 M ha in the States of Maharashtra, Goa, Karnataka, TamilNadu and Kerala also started integrated watershed based approach since 1987-88 for eco-restoration including Hill Area Development Program (HADP). World Bank, DANIDA, EEC, Indo-German, Indo-Swiss and Japanese aided Watershed Projects are some of the examples of externally funded watershed programs. Apart from these national/international level programs, a number of State Government sponsored and NGOs supported watershed programs subsequently started during eightiesand nineties.

Table 1: Growth of nationally and internationally funded organized watershed management programs in India

Schemes/Projects	**Year of launch**	**Watershed Nos. /area**	**Sponsoring Agencies**
Experimental watersheds	1956	42 Nos.	Min. of Agri., GOI/ CSWCRTI, ICAR
Soil Conservation in RVP Catchments	1961-62	29 catchments in 9 States	Min. of Agri., GOI
Operational Research Watersheds	1974	4 Nos.	CSWCRTI, ICAR
Watershed Management in Catchments of Flood Prone Rivers	1980-81	10 catchments in 8 States	Min. of Agri., GOI
Model Watersheds	1983	47 Nos.	CSWCRTI & CRIDA, ICAR
Watershed Development in Rainfed Areas	1984	28 Nos. (3.47 lakh ha)	World Bank (A.P., Karnataka, MP & MS)
Watershed Development in Ravines Area	1987	0.62 lakh ha	EEC
Drought Prone Area Program (DPAP)	1987*	91 districts 615 blocks	MRAE, GOI
Desert Development Program (DDP)	1987*	21 districts 131 blocks	MRAE, GOI
Western *Ghats* Dev. Program (WGDP)	1987*	158 taluk 5 States	Union Planning Commission
Indo-German Watershed Project	1990-91	Maharashtra	Germany

German Watershed Project			Germany
Indo-German Bilateral Project	1990-91	Monitoring	Germany
NWDPRA	1991	2497 Nos.	Min. of Agri., GOI
IWDP (Hills & Plains)	1991	1.12 lakh ha	World Bank
Comprehensive Development Watershed Project	1991	1.13 lakh ha	DANIDA (Karnataka, Tamil Naduand Orissa)
Doon Valley Project, UP	1993	1.72 lakh	EEC
Integrated Wasteland Development Project (IWDP)	1994	25 States	MRAE, GOI
Indo-Swiss Participatory Watershed Development	1995	0.35 lakh	Swiss Government
Attapadi Wasteland Comprehensive Environment Conservation Project, Agali, Kerala	1996	507 Km^2	OECF, Japan
NWDPRA, IWDP, DDP *etc.*	1997-07	-----	MoRD, MoA, MoEF & others

MRAE - Ministry of Rural Areas & Employment
Since Programs adopted on watershed approach

Watershed Management Principles

Size and Selection of Watershed

Generally, a workable size of around 500 ha watershed is preferred. Watersheds could be classified into a number of groups depending upon the mode of classification. The common modes of categorization are the size, drainage, shape and land use pattern. The categorization could also base on the size of the stream or river, the point of interception of the stream or the river and the drainage density and its distribution. The All India Soil and Land Use Surveys
(AIS&LUS) of the Ministry of Agriculture, Government of India, have developed a system for watershed delineation like water resource region, basin, catchment, sub-catchment, and watershed. The usually accepted five levels of watershed delineation based on geographical area of the watershed are the following:

i) Macro watershed (More than 50,000 ha)
ii) Sub-watershed (10,000 to 50,000 ha)
iii) Milli-watershed (1 000 to 10000 ha)
iv) Micro watershed (100 to 1000 ha)
V) Mini watershed (1-100 ha)

After the impact evaluation and analysis of the meta- data of the watersheds, the size of watersheds having area 3000-5000 ha are being considered for development to fit a realistic output in compared to larger watersheds.

Basic Resource Survey

Base line/bench mark surveys for physiography, climate, soils, land use, vegetation, hydrology and

Community Organization and People Institutions

Participatory approach is more pertinent in the planning and development of watershed management programs, because it is basically the peoples' program and the government agency should participate as a facilitator. This is so because it not only requires the resources to be developed ormanaged properly but equitably distributed among the stakeholders or beneficiaries. It also requires thatalong with the Private Property Resources (PPR), the Common Property Resources (CPR) are developed,managed and maintained efficiently. For this, it is imperative that every stakeholder in the watershed accepts and implements the recommended management plan and is very much involved in the planning, implementation and maintenance processes (Samra and Sikka, 1996).

There are two basic points of consideration in this bottom up participatory communication process. The first one is that the proposed development plan should meet the needs of the people. To be desirable, the objectives proposed must be related to the local community's needs and interests. The second one is that it should be feasible.

Common guidelines for watershed development projects implemented by GoI since 2008, has laid greater emphasis on community organization and allocated 10 per cent of the total fund of the project for this vital component under preparatory phase of the watershed program. Before commencing the developmental activities of the program, sufficient attention should be paid towards generating awareness among the community members regarding the new strategy as well as main features of the "Common Approach for Watershed Development". For this purpose, repeated meetings in large or smallgroups may be arranged. It would be useful if traditional street plays, folk songs, *etc*., are adopted to communicate the spirit of the restructured watershed program during large group meetings. If required,summary version of the guidelines in local language may also be circulated /distributed to willing persons.The common guidelines for watershed development projects (Rainfed edition 2011) issued by National Rainfed Area Authority (NRAA) may be followed for the government sponsored watershed projects (www.nraa.gov.in).

Preparation for Watershed Development Plan/Detailed Project Report (DPR)

Based on the present land use, LCC map, problems, needs and priorities ascertained through Participatory Rural Appraisal (PRA), watershed treatment/development plan is prepared for arable and non-arable lands including drainage line treatments and infrastructural development. Components of a typical plan may include the following:

- **Protection and conservation measures:** Majority of the concluded projects suggest that a blend of structural and vegetative measures is a better option. This will include all the measures/structures including *insitu* soil and moisture conservation measures like bunding, leveling, terracing and vegetative barriers, water harvesting structures such as ponds, nalla bunds, small dams, percolation ponds *etc*., drainage line treatments with engineering structures and vegetation for checking land degradation and conserving water; and repair, restoration/strengthening of existing common structures for sustained benefits from previous investments made, if any.
- **Production Measures:** These include the activities that are required to make the efficient use of conserved soil and water resources in producing user products such as food, fodder, fuel, fruit, fibre, milk *etc.*, on sustained basis. These may include improved crop cultivation and management practices, afforestation, alternate land use systems, cultivation/raising of industrial, medicinal and aromatic grasses and plants for providing alternate livelihood support system, development of livestock,
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dairying, poultry, sericulture, fisheries and other essential income supporting activities.

Common approach guidelines for Watershed Development Projects, GOI, have very clearly indicated that out of 75 per cent allocated for development component, 56, 10 and 9 per cent are meant for watershed development works, production systems and micro enterprises and livelihood activities for the asset less persons, respectively.

Convergence Approach

Watershed management is a single window, integrated area development program. Integrated watershed management cannot perhaps be achieved just by following integration of resources using multidisciplinary approach with the funding or support provided alone under any watershed programlike NWDPRA, IWDP/DPAP *etc*. This may also involve harmonized use of resources available from other ongoing/existing sectoral and development schemes in the area/district. Such resources can be dovetailed with the watershed programs that will not only help in useful convergence of various schemes and programs for overall development of the area but also in effective monitoring. Some of these sectorsmay include education, health, sanitation, drinking water; roads *etc*., and most of these can also be dovetailed with the entry point activities. The current Five Year Plan offers an opportunity to converge andharmonize resources of different schemes and programs specially those under Bharat Nirman and other Flagship Schemes with watershed development projects. The DPR should elaborate the gap to be filledthrough other schemes following convergence approach

Social Acceptance & Approval of Plan by Society

The Detailed Project Report (DPR) for watershed development so formulated is summarized and presented in a general body meeting to invite discussions, suggestions and modifications, if any to seek social acceptance and approval of plan by the Society.

Capacity Building

Training and capacity building in this newer concept of multi-disciplinary integrated participatory watershed management is most important both for the field level project staff/officers and functionaries of people's institutions *i.e.*, watershed community which generally remains neglected. Apart from enhancing technical skills of project staff, this would also provide an opportunity to community members to develop their capacity to implement works as per DPR and to sustain the program as future custodians after project's withdrawal. In the new guidelines, GOI has earmarked five per cent of the total budget allocation for the purpose of building capacity of watershed community and functionaries.

Monitoring and Evaluation

This has been one of the weakest parts of all the projects in the past. For monitoring and generating data base both on space and time, provisions should be made in the project and suitable agency be identified to carry out this task so as to apply mid-term corrections if needed. A total of 2 per cent of the total watershed budget has been earmarked for monitoring and impact evaluation of the watershed programsin common approach guidelines for the watershed development.

Sustenance and Follow Up

In the traditional top down approach of management, the component of repair and maintenance of soil and water conservation/watershed management works has been lacking while it should have a priority. An institutional arrangement preferably with active involvement of local community should be formed and entrusted with this responsibility. Participatory watershed resource management is a good example in this endeavor. Village Resource Management Societies (VRMS) or Watershed Committees (WC) may generate revenue, manage the resources and look after repair and maintenance of these structures. The government agencies should provide necessary technical guidance/supervision whenever required. Under the new guidelines for the watershed development projects, an amount of five per cent of the total budget has been earmarked under consolidation / final phase of the watershed program to achieve sustainabilityof the program apart from creating corpus fund through community and project contribution in the nameof Watershed Development Fund(WDF).

Integration of Social Resource Management with Natural Resource Management

Integration of Social Resource Management (SRM) with Natural Resource Management (NRM) is crucial for achieving sustainable benefits. Such an integration would become easier if action plans of all components are developed separately within each SHG/UG; implementation of above plans are carried out by respective groups; adequate emphasis is given to production enhancement and livelihood support activities apart from protection and conservation activities, by combining short-term, medium-term and long-term gains for the watershed community. This is becoming increasingly important in the present day context of participatory watershed management for holistic development of rainfed areas.

Sustainable Development of Watershed

Watershed Sustainability: The concept of watershed management was pioneered and popularized in the country since 1970's based upon tremendous success of pilot Operational Research Project Watersheds including Fakot in Tehri Garhwal district of Uttarakhand undertaken by CSWCRTI, Dehradun. Fakot watershed is a live model of community- driven, self-sustainable and eco-friendly balanced development process in the Himalayas which has proved to be a torch-bearer for the subsequent massive watershed development program in the country.

Fakot watershed project was initiated in 1974 as per farmers' priorities and refinement of indigenous technologies in a resource sharing pattern. The project is being monitored continuously to assess its impact on the production, protection and employment from sustainability point of view. Continued increase in the production of food grains, fruits as well as milk and decline in runoff, soil loss and dependency on forest for fodder even after withdrawal of active intervention has indicated sustainability of the program as evident from Table-2.Further it was found that the increased income from watershed development program was relatively more equally distributed in the community. Time series data recorded in the 370 ha Fakot watershed where net cultivated area ranged from 72 to 80 ha during the 20 years period of observations is presented in Table-3. There was remarkable improvement in average yield of all crops ranging from 2.2 to 7.4 times after the watershed interventions (1975 - 86) (Dhyani *et al.* 1997).

Table2: Production and protection impact of watershed management program during pre-project, active interventions and after withdrawal of interventions (Fakot, Uttarakhand hills, area – 327 ha).

Product	PPP (1974-75)	Average of	
		IP(1975-86)	PIP (1987-08)
Food crops (q)	882	4015	7462
Fruit (q)	Negligible	62	2615
Milk ('000 lit.)	56.6	184.8	359.6
Cash crops ('000 Rs.)	6.5	24.8	1063
Animal rearing method	Heavily grazing	Partially grazing	Stall feeding
Dependency on forest fodder (%)	60	46	12
Runoff (%)	42	14	14
Soil loss (t/ha/annum)	11.1	2.7	<2.0

PPP:Pre Project phase, IP: Intervention Phase, PIP:Post Intervention Phase.

Table 3: Average yield (q ha^{-1}) of major crops in Fakot Watershed, mid Himalayas (Uttarakhand)

Crops	PPP* (1974-75)	IP* (1975-86)	PIP* (1987-08)
Paddy(irrigated)	6.5	48.2(7.4)**	38.4(5.9)
Maize(Rainfed)	5.0	33.8(6.8)	31.2(6.2)
Mandua(rainfed)	4.5	10.8(2.4)	8.7(1.9)
Jhingora(rainfed)	4.0	9.4(2.3)	8.5 (2.2)
Chillies (rainfed)	1.5	5.8(3.9)	7.6(5.8)
Ginger(rainfed)	35.0	78.7(2.2)	121.4 (3.5)
Pulses(rabi-rainfed)	3.6	10.8(3.0)	12.1 (3.4)
Wheat(rainfed)	4.5	18.6(4.1)	15.6 (3.5)
Onion-Garlic(irrigated)	55.6	296(5.3)	228.5 (4.1)
Tomato(irrigated)	Not cultivated	45.0	150.6 (3.3)
Gram(rainfed)	-do-	17.3	15.1
Oilseed(rainfed)	-do-	6.7	7.4 (1.1)

PPP:Pre Project Phase, IP: Intervention Phase, PIP:Post Intervention Phase.
Values in brackets indicate times increase over pre-project phase/Intervention phase.

The drought proofing potential of the watershed technology was amply demonstrated in the drought year of 1987, when the per cent yield reduction in the treated watershed was far less than in the untreated one.

The CSWCRTI, Dehradun recently (1998–2003) demonstrated the benefits of participatory watershed management in six watersheds developed in different agro-climatic regions through its six research centers (Sharda, *et al*., 2006). Apart from reducing runoff by 58 per cent on an average and soil loss by 72 per cent, additional average causal employment of 17004 mandays was created besides regular employment varying from 60 to 137 man days per annum. The average annual family income increased by 49 per cent and all the projects were found to be economically viable with benefit cost ratio varying from 1.14 to 1.72.

Water Resource Development: Development and efficient management of water resource is an issue of utmost importance at national as well as international level. Our country has an old tradition of water harvesting through *Tanka, Ponds, Bawories, Khadins, Ahars etc.* The technology of constructing small embankment/dug out type ponds in the watershed program for water resource development provides a viable alternative to the major river valley projects for which environmental stipulations are becoming very stringent. The cost of generating micro-irrigation through small harvesting structures varied from Rs.9000 to 20,000 per ha, while the cost of minor irrigation projects was estimated to be around Rs.45,000 per ha (1995 price level). Many catchments were protected by the community through social fencing for saving the water harvesting structures and their economical use for irrigation purposes. Creation of local institutions was much easier and success rate was found to be higher wherever some irrigation could be provided by constructing small structures in a watershed program. Supplemental irrigations increased yield by 119 to 485 per cent depending upon the crop and soil conditions. These practices are known for their highly desirable equity considerations. A study by Arya and Samra (2001) in 27 Shiwalik foothill watersheds in Haryana State clearly revealed that wherever (in 7 cases) watershed management projects have been successful and both the farmers as well as implementing agencies have jointly governed, maintained and managed the system over a period of time, the programs have yielded sustainable development. Multiple or cascading use of water, recycling of waste waters and value addition are outstanding conservation alternatives of planning at basin, sub-basin or watershed level. Aquaculture development through water harvesting structures holds a large potential for livelihood security of rural masses.

Mass Erosion Control: A large area of the hill region of the country is affected by the mass soil erosion and degradation problems caused by landslides, mine spoils and torrents. Pilot projects were undertaken by CSWCRTI, Dehradun for rehabilitation of such highly degraded lands through bioengineering technology. Nalota nala landslide project on Dehradun – Mussoorie highway, Sahastradhara mine spoil rehabilitation project and Bainkhala torrent control project are the successful examples of this technology. The highly degraded mine spoil and landslide slopes were treated with small engineering structures such as loose stone/gabion check dams, contour trenches, Watling, geojute *etc.*, and planted with suitable vegetative species. Drainage line treatment through gabion structures was one of the important interventions. The bioengineering technology not only rehabilitated the area but also improved the water and vegetation resource in the area on a sustained basis for use by the local people.

For example, the rehabilitation measures in the landslide and mine spoil affected watersheds rejuvenated water springs with sustained water yield even during dry season (Juyal *et al.*, 1998) as depicted in Tables 4&5. The projects were found economically viable too in the long run, since the rehabilitation efforts saved an amount of about 1.5 lakh being spent annually by the State PWD in removing the debris before the project was undertaken.

Table 4: Effect of bio-engineering measures on landslide stabilization in Uttarakhand hills, treated since 1964 (Nalota Nala: 60 ha)

Impact parameter/indicator	Before treatment	After treatment
Runoff (mm)	55	38
Dry weather flow (days)	100	250
Sediment load, (tones/ha/yr.)	320	5.5
Vegetation cover (%)	<5	>95
Nala bed slope (%)		
Lower reach	12	7
Middle reach	23	14
Upper	54	44
Toe cutting	severe	Nil

Table 5: Impact of rehabilitation on mine spoiled watershed at Sahastradhara (64 ha), DoonValley, Uttarakhand Hills

Impact parameter/indicator	Before treatment (1983)	After treatment (1996)
Debris outflow (t/ha/yr.)	550	8
Monsoon runoff (%)	57	37
Lean period flow (days)	60	240
Vegetation cover (%)	10	80

The hill torrents and rivers have been causing a heavy damage to the adjoining agricultural / forest lands and population by bank cutting and floods due to frequent changes in their course. The institute has evolved measures for torrent training and utilization of reclaimed lands along their banks. The laboratory studies carried out on the hydraulic flume helped in safe and economic design of spurs for torrent training.

Since the inception of various soil conservation and watershed development programs by various Ministries including externally funded projects, an area of 56.54 million ha has been treated till theend of Xth Five Year Plan (March, 2007) at a total cost of about Rs. 19500 crores (Sharda *et al*., 2008).

Applications of New Science Tools for Watershed Development

Remote Sensing (RS) and Geographical Information System (GIS): The Remote Sensing (RS) data, both from aerial and space platforms, offers a better means of faster, efficient and reliable data acquisition. RS data have a unique character and constitutes an integrated view of the landscape with all its features manifested together. Remote sensing derived information will have to be merged or integrated with the conventional database using suitable software. Geographic data base can be built from data derived from various sources such as topographical maps, thematic maps prepared from remote sensing data or ground surveys, cadastral maps, census reports, etc. These diverse data systems can serve as inputs and can be converted into consistent map format. Using suitable software's, specific integration and analyses of these data can be performed to derive useful outputs in the form of maps or statistical data.

Geographical Information System (GIS) serves as an efficient system of compilation, classification, storage, synthesis/analyses or retrieval of relevant information of spatial and non-spatial origin. GIS is a computerized tool that analyses and manages spatial and non-spatial data. GIS combines two computer software technologies *viz.*, database management and digital mapping. Database management is a systematic way of organizing and accessing tabular data. Digital mapping represents map elements as points, lines, polygons or grid cells. The key feature of GIS is that digital map elements are linked with tabular information in such a way that, when either the map or the tabular data are manipulated, both sets of data are updated and adjusted to the relationship between them. In recent times, GIS is undergoing rapid improvement by which it is possible to create, manipulate, store, retrieve and use spatial data at a much faster rate than conventional methods. As management and topological overlays of large amount of spatial and non-spatial data is a prerequisite in watershed planning, GIS is an ideal system to support this process.

Global Positioning System: Global Positioning System (GPS) is a satellite based navigation system capable of providing instantaneous position and time anywhere on the globe. It consist of a constellation of 24 orbiting satellites which orbit twice daily at an altitude of about 20,000 km. Each satellite transmits precise location (Latitude, Longitude and Altitude) and time. Hand held GPS receiver triangulates its position with reference to transmitted signals from the GPS satellites. There are numerous uses ofGPS in managing regional resources and monitoring activities within large areas. The use of GPS receiverto collect detailed attribute information and to verify/ground truth the data collected by remote sensing ison the increase. GPS data can be a vital input to the GIS, especially for generating thematic maps requiredin watershed planning. Data gathered from GPS surveys and from remote sensing can be fused within GISfor a successful characterization and assessment of watershed functions and conditions. For higher accuracy, Differential Global Positioning System (DGPS) are used to enhance the quality of location datagathered using global positioning system (GPS) receivers. Differential correction can be applied in real-time directly in the field or when post processing data in the office. Although both methods are based on thesame underlying principles, each accesses different data sources and achieves different levels of accuracy. Combining both methods provides flexibility during data collection and improves data integrity.

Total Survey Station: A total station is one of the major survey testing equipment, more precisely, an optical instrument that serves many purposes in surveying. A total station is an electronic optical instrument widely used in modern surveying. The total station surveying instrument is a combination of an electronic theodolite (transit); an electronic distance meter (EDM), which is a measuring device to read distances; and software running on an external computer. The modern versions of survey total stations called robotic total stations let the user control the instrument from a distance with the help of a remote control. The main functions performed by this surveying instrument include coordinates determination, angle and distance measurement and data processing. This is used extensively in land surveying, mining, road mapping, aerial photogrammetry etc.

Telemetry Monitoring: Telemetry is a highly automated communications technique with the help of which measurements and data collection are done at remote locations and transmitted for monitoring. This technique commonly uses wireless transmission, though original systems used wired transmission. The most important uses of telemetry include weather-data collection, hydrological data monitoring, monitoring power generation plants and keeping track of manned and unmanned space flights. A telemetering system typically consists of a transducer as an input device, a transmission medium in the form of wired lines or radio waves, signal processing devices, and devices for recording or displaying data. The transducer converts a physical quantity such as temperature, pressure or vibration into a corresponding electrical signal, which is then transmitted over a distance for the purpose of measurement and recording.

Google maps are the web based maps which provide resource information on earth surface at higher resolution. This can be effectively used for delineation of watershed boundaries, resource mapping (Land use, vegetation, water resources, etc.), monitoring and evaluation of watershed programs even at micro-watershed level.

Hydrological Instrumentation

Digital Rainfall Recorder: The digital rainfall recorder consists of a weatherproof enclosure which contains the data logger and power supply, and comes complete with a solar panel, tripod stand and a tipping bucket type rain gauge sensor. The main feature is unattended recording of rainfall with standard program and user-friendly software. Suitable for mounting in a variety of locations and memory range with more than 16500 data sets extendable up to more than 33000 data sets.

This instrument is also available with IMD Pune. ***Rainfall Event Logger:*** The 8" diameter collector meets specifications for statistical accuracy. This event logger connects to most standard tipping-bucket rain gauges and records rainfall times, and duration as well as momentary contact events and temperature. Because event data is stored when it happens, memory is efficiently used. The data logger has event/measurement memory of 32,000 events. Data can be viewed in inches or millimeters. Tips are logged with time-stamps to gauge rainfall intensity, and the lockout feature eliminates false readings from tipping-bucket bounce. Owing to onboard USB connector, no external devices are required for downloading the data & configuration for data logger operation.

Digital Evaporation Recorder**:** Digital evaporation recorder used for monitoring of water evaporation comes with a weather proof enclosure which contains the data logger power supply, sensors and comes complete with a solar panel & pan .The system is powered by two rechargeable sealed maintenance free batteries with integral solar panel, which easily keeps the batteries charged throughout the year. The evaporation sensor can be attached with this data logger for the collection of real time data automatically.

Digital Water Level Recorder*:* Digital water level recorder consists of a weatherproof enclosure which contains the data logger and power supply, and comes complete with a solar panel and a Shaft encoder type water level sensor. Measurements can automatically store in systems memory with date and time stamp, as per user selectable logging period. Comes with integral solar panel, which will easily keep the batteries charged throughout the year. A durable hard enclosure protects the data logger from weathering. Data fileis saved in Microsoft's Excel.

Digital Water Level Recorder (Pressure Type): This is a micro controller based digital water level recorder (Pressure type) and reflects state of the art in micro controller based instrumentation design. The water Level sensor can be attached with this data logger for the collection of real time data automatically. The micro controller has its internal memory along with an additional 128K EEprom, a real time clock with an LCD (16 X 2) to display the instrument status. Piezo-resistive silicon strain gauge, bounded to 316 SS diaphragm and integral cable contains a vent tube for Barometric pressure compensation. It comes with different ranges, *viz;* 10, 35, 100, 200, 300 meters. Data file is saved in Microsoft's Excel. This instrument is used for water level monitoring of wells. This instrument is also useful for open channels, dams and lake level monitoring. Such levels can be used for monitoring the groundwater levels.

Micro-Processor Based Auto Sediment Sampler: The main features of this instrument are;

- Fully automatic runoff samples collection.
- Can be used for soil loss estimation as well as temporal distribution of sediments during runoff hydrographs.
- Samples can be collected at required time interval (15, 30, 60 and 120 minutes or any desired time intervals) as well as at required flow depth.
- The 8748 microprocessor based controller is used which can be reprogramed easily.
- Suitable for remotely located gauging station as well as small to medium watersheds (2-1000 ha)
- Accurate and reliable data acquisition.
- Simple and easy to operate.
- Efficient and cost effective.

The microprocessor based control unit, which when initialized by the water level sensors, operates the system, first by purging the pipe to clean off the old water sample, positions the nozzle on sample hole and then pumps the sample water into a bottle and positions the nozzle on to the next purge whole. The pump is kept in the channel, completely immersed in the flowing water, About 750 ml of runoff water is pumped into each bottle.

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2. Map Reading, Delineation and Characterization of Watersheds

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Introduction

Maps and plans at different scales of different areas/locations are used for planning various measures in watershed management. A plan is defined as a graphical representation at some scale of the features on near surface of the earth as projected on a horizontal plane, which is represented by plane of paper on which the plan is drawn. If the scale is small, the representations called a map. It is called a plan, if the scale is large.

For watershed planning generally the topo sheets supplied by Survey of India are used. These topo sheets are available in different scales. In addition to topo sheets, other maps such as land capability classification map, present land use map, soil map, drainage map, and slope map etc. are required for planning integrated watershed management practices. Topo sheets furnish the base information about the geographical condition of the watershed. These maps are also essential for selection, delineation and characterization of the catchment. In this topic the techniques of map analysis and interpretation with respect to watershed planning are discussed.

Map Reading

Map reading is the first important step for obtaining information relevant to watershed planning and management. The following steps are involved in map reading.

1. Orientation of the map
2. Legend and symbol
3. Scale of the map
4. Horizontal and vertical distances and angles
5. Identification of natural and manmade ground features
6. Delineation of watershed boundaries.

The orientation of the map consists of aligning the north of the map with the actual north, in case map is being used in a field situation. Otherwise the first step is to ascertain north on the map and there by fixing the other direction on the map. Secondly, the scale of the map is very important component of map reading. The scale of a map or drawing is the fixed proportion, which every distance on the map or drawing bears to the corresponding distance on the ground. Thus if 1 cm on the map represents 10 m on the ground, the scale of the map is 10 m to 1 cm often written simply as 1 cm = 10 m or 1: 1000. The ratio between given distance on the map and the corresponding distance on the ground is called “Representative Fraction' (R.F) and it is independent of unit and measurement. It may be remembered that the distance between any two points on a map or a plan is always the horizontal distance between them irrespective of elevation.

Horizontal distance on the map are taken along the plan of the paper, but vertical distance (elevation) are generally shown by line joining points of equal elevation called the contours. These lines help to find out the features like hills, ridge, valley, depression and plains on the map which are important for locating various measures of land use management.

The legends/reference, symbols are given to facilitate the location of various land marks of the ground. Natural and manmade features like hills, streams, roads, bridges, hutment, etc., can be identified by means of these symbols. Table 1 shows the kinds of map and sources from where they can be procured for watershed planning:

Table 1: Kinds of maps used in watershed planning

	Maps:	Scale	Source	Use
Primary	Topo map	1:50000	Survey of India, Dehradun.	General physical features – Gullies, Ravines and Ponds etc.
	Cadastral Map	1:5000	Gram Panchayat, Collectorate	Land ownership and land use
	Soil Map	1:2,50,000	National Bureau of Land Use Survey and Planning, Nagpur.	Land capability classification and Management.
Secondary	i) Drainage and contour maps a) For large watershed b) For small watershed	1:50,000 1:5000	Topo sheets Magnification of topo map or GISbase map of given area	Determination of physiographic characteristics
	ii) Rainfall map	1:50,000/ 1:5000	Prepared by analyzing rainfall data	Determination of Hydrologic Characteristics
	iii) Land use capability Map	1:50,000/ 1:5000	Field Survey	Soil erodibility and erosion risks
	iv) Present land use map	1:50,000/ 1:5000	Field Survey	Identification of extent and kind of land uses

Interpretation of Maps

1. On steep slope the contour lines are spaced closely together, while on gentle slope they are spaced apart. In Fig. 1, close spacing of contour lines indicate the steepness of hill.
2. A uniform slope is indicated when contour lines are uniformly spaced, while a plane surface (such as embankment of a pond) is indicated when they are straight and parallel.
3. As contour lines represent level lines, they are perpendicular to the lines of the steepest slope.
4. Contour lines cannot merge or cross one another on the map, except in the case of a overhanging cliff. A vertical cliff is indicated when several contours coincide, the horizontal equivalent being zero.
5. Contour lines cannot end anywhere, but close on themselves either within or outside the limits of the map.
6. A series of close contour lines on a map indicate a depression or a summit, depending on whether the successive inside contours have loser or higher values inside. Fig. 2 (a) and (b) represent a typical hill and valley respectively.
7. Contour lines cross ridge lines or valley lines at right angles. A ridge line is shown when the higher values are inside the loop or bend in the contour, while in the case of a valley line, the lower values are inside the loop as shown in Fig 2 (c) and (d). The same contour appears on either side of a ridge or valley.

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Uses of Contour Map

1. By inspection of contour maps, information regarding the character of the tract of the region is obtained; whether it is flat, undulating or mountainous, etc.
2. Contour maps are very useful for planning soil conservation works. The most economical and suitable site for engineering structures, such as check dams, ponds, bunds etc. can be selected.
3. Watershed areas measured from maps are used in estimating runoff to be handled by gully control structures, waterway and pond spillways.
4. Area and slope measurement from contour maps can be used in preparation of land capability map of the watershed.
5. Preliminary selection of the most economical or suitable alignment for irrigation, channels, diversions, drainage ditches, roads etc. can be made.
6. Contour map may be used for computing the capacity of a reservoir and volume of earthwork involved.

Uses of Map Slope

A map of slope is such a drawing which shows the variation in degrees of land slope. The runoff will run faster with the increase of land slope, so the intensity of soil erosion will be higher with the increment of gradient, if the other conditions are same. Therefore, maps of slope can be regarded as referential indexes to determine the intensity of soil erosion and potential destruction of soil. At the same time, it can provide some theoretical basis for the evaluation on soil grades and suitability of different proportions of land to agriculture, forestry, grassland, agro-forestry, horticulture and animal husbandry. Slope map along with the information on soil type, rainfall can also be used for deciding the suitability of engineering structures such as contour bunding, graded bunding, terracing and trenching for specific fields occurring in watersheds, hence it is necessary to draw up map of slope.

Priority Delineation Methodology

For demarcation of priority areas in the lake catchment following steps should be followed in the order mentioned below:

1. Delineation of watershed
2. Characterization of Watershed.
3. Selection of priority watershed.

The term basin, catchment, sub-catchment, watershed or sub-watershed are synonymously employed because all describe the area drained by single river system. Yet they could be meaningfully applied for denoting various stages of delineation from macro to micro level.

Fig. 1: Elevation and plan of a hill

Fig. 2 Characteristics of contour lines (a) Hill (b) valley (c) Valley line (d) Ridge line

Delineation of Watershed

The delineation of priority watershed can be performed to some extent by the reconnaissance survey and study of topo sheets. However, this technique is cumbersome and time consuming. Hence, a cost effective and efficient technique of remote sensing can be used for delineation of priority watersheds. Normally, the photographs of 1:60,000 obtained from satellite imagery can serve the purpose, but photographs of large scale 1:15,000 can also be used. The three stage hierarchical system of delineation of River Valley Project catchment into sub watersheds has been adopted by AISULS. The three stages are catchment, sub catchment, watershed and sub-watersheds. The three stages of delineation are as under:

Stage 1: Divide the catchment into sub-catchment following the major tributaries. Cutting of river or stream should be avoided. Normally, 1:1 m scale thematic map of survey of India is used for this purpose.

Stage 2: Sub-catchments delineated in stage 1 are transferred on 1:2,50,000 scale base map of survey of India. Each of these sub-catchments are divided into watersheds following distinct streams and tributaries.

Stage 3: Watershed delineated in stage 2 above are transferred to base map drawn at a scale of 1:50,000. The watersheds are further sub-divided into sub watersheds, which are small hydrological Units which constitutes individual tributaries of lowest order or a group of such tributaries. The size of individual watersheds can be restricted to around 5000 ha. Which is considered a viable working area for implementation of Soil Conservation and other development programs.

At each stage of delineation, the continuous drainage unit smaller than the demarcated units that drain directly into the main drainage channel may be grouped together as independent hydrologic unit. With each subsequent stage of delineation they get segregated.

Characterization of Watershed

Morphological characterization : Morphology of a catchment directly reflects upon its hydrological characteristics. In case of paucity of hydrological data, morphological parameters play an important role in predicting hydrological response of the catchment . Once the catchment is delineated to sub watershed the following morphological parameters are generally derived from the map of each sub watershed

(I) Catchment area and its perimeter.

(ii) Stream order, stream length and bifurcation ratio: The stream order is generally determined by the Horton's method. Order 1 is assigned to small, unbranched tributaries, order 2 to those streams which have first order only, order 3 to stream with second and lower orders etc. The Stream length is measured by rotameter. The bifurcation ratio is the ratio of number of streams of any given order to the number of stream of next higher order.

(iii) Drainage density: It is defined as the length of stream per unit area. This parameter reflects upon the number of hydrological characteristics of a watershed.

(iv) Compactness coefficient: It is described as a ratio of the perimeter of watershed to the circumference of the circle of area equal to watershed area.

(v) Elongation ratio: It is the ratio of the diameter of a circle of an area same as basin area to the maximum length of basin. For region of low relief values approach unity whereas values in range of 0.6 to 0.8 are generally associated with stony relief and steep slopes.

(vi) Circulatory ratio: It is the ratio of basin area to the area of a circle of same perimeter as that of basin. Value of circulatory ratios in upper in uniform range of 0.6 to 0.7 for the first and second order basins in homogeneous shales and dolomites.

(vii) Relief ratio and relative relief: The relief ratio is the ratio of the maximum basin relief to the longitudinal distance along the largest dimension of the catchment parallel to the main drainage line. Maximum basin relief is the difference between the highest and lowest alleviation of main stream. Thus, relief ratio measures overall steepness of basin. The relative relief is the ratio of maximum relief to the basin parameter.

(viii) Average slope: The Average slope of a catchment is computed as S=MN/100A , where M is the total length of contours within the watershed, N is the contour interval and A is the area of watershed. Slope at any point of the Watershed can be directly determined from the contours drawn on the map.

Hydrological Characterization

For Hydrological Characterization of watershed drainage map overlaid by isohyetal map, soil map and vegetation cover map is required. Hydrological characteristics of watershed such as rainfall, evaporation, infiltration, transpiration, soil moisture storage and ground water storage greatly influence the amount of runoff and sediment yield produced from watershed. Of these hydrological parameter runoff and sediment yield are the end product produced by interaction of rainfall with catchment characteristics. For runoff estimation, the curve number technique is most widely used. By using above listed maps curve number of any land parcel can be derived from curve number table and with the help of isohyetal map runoff can be estimated. Universal soil loss equation can be used for estimating sediment yield of the watersheds. Alternatively, morphological parameters can also be used for determining some of the hydrological characteristics of the watersheds.

Selection of Priority Watershed

The selection of priority watershed within a catchment is very important for proper implementation of soil conservation measures. Such priority areas can be demarcated on the following basis

a. Sediment production rate or sediment yield index (SYI)

b. Flood flows

c. Protection of civil areas from natural hazards etc

For catchment management the criteria based on sediment production rate or sediment yield index is most widely used. The sediment yield of catchment can be indirectly estimated by using the morphometric parameters, or it can be directly derived from the hydrological characteristics. However, suitable models should be available for that region to estimate sediment yield from morphometric parameters. In the absence of availability of models for estimating sediment yields, prioritization of watershed is done by determining probable sediment yield of different watersheds by the two methods described below:

First Method: In this method prioritization of watershed is done by comparing severity of erosion and sediment yields. The method is devised under the following steps:

1. Determine the erosion intensity of different watersheds, called as 'erosion intensity unit'. And grade them in accordance with their increasing severity. Also, find out the probable sediment yield of the watershed and grade them by order. For grading, the least eroding units are assigned by the number 1 or 0.50, while more eroding units are assigned by higher weights such as 2,3,4…..

2. Calculate the area of each erosion intensity unit within each small sub-watershed and also determine the total area of sub-watershed.
3. Multiply the area of each erosion intensity unit to its weight assigned. The obtained value is termed as weighed product. Compute, the total weighted value of each small sub-watershed by adding all together.
4. Compute, the erodibility index of sub-watershed by dividing the total weighted value obtained for sub-watershed with its total area i.e.

$$IE = T_w * 100 / T_a \qquad (1)$$

Where, IE = Erodibility index of sub-watershed (%)

T_w = total weighted value for sub-watershed

T_a = total area of sub watershed.

5. Measure the distance between erosion intensity unit and the reservoir, in which runoff is going on and assign the weight to each as per given in Table 2. This weight is added to the erodibility index of each sub-watershed. The erosion intensity units located close to the reservoir are given more weightage as compared to the ones located far off because from the nearer watershed silt load has more probability to reach the reservoir than from far off.
6. After finding the total value of weights for each sub-watershed, arrange them into 3 to 5 suitable priority classes such as :

   I) Very High ii) High iii) Medium iv) Low v) Very low

Table 2: Proposed weights as per distance from the reservoir

Distance from reservoir (Miles)	Weights
< 5	50
6-10	40
11-25	30
26-50	20
51-100	10
>100	5

Second Method: This method developed by AISLUS for prioritization of watershed within the catchment area is more refined over the previous method. In this method the sediment yield index model is used for prioritization of watershed. For computation of sediment yield indices of individual sub-watersheds the following equation is used.

$$SYI = \frac{(Ei \times A_{ie} \times D_r)}{AW} \times 100 \qquad (2)$$

Where,

SYI = Sediment Yield Index

E_i = Weighting value of erosion intensity mapping unit (this is generally above 10)

= Summation

A_{ie} = Area of the erosion intensity mapping unit in a watershed. (Watershed is sub-divided into smaller units for determining E_i)

D_r = Delivery ratio

AW = Total area of watershed (total of all A_{ie} in the watershed)

The various steps involved in the application of SYI model to catchment area are :

(i) Preparation of framework of sub watersheds through systematic codification and delineation.

(ii) Rapid reconnaissance survey on 1:50000 scale base leading to generation of map indicating erosion intensity mapping units (EIMU).

(iii) Assignment of weightage values to EIMUs based on relative sediment yield potential.

(iv) Assignment of delivery ratio to various EIMUs.

(i) Computation of final SYI values and grading of sub watersheds into very high, high, medium, lowand very low categories.

(i) Systematic delineation and codification of watersheds

Preparation of a framework of smaller hydrologic units within a catchment area through a systematic approach is a prerequisite for priority delineation surveys. It is essential to have not only a hierarchical system of delineating bigger hydrologic units into sub watersheds but a codification system also so that each sub watershed can be identified as an individual entity without loosing linkage with bigger units, i.e. catchment, sub catchment or a watershed to which it belongs.

Delineation System: As has been already explained above.

Codification system: Coding of watershed provides uniformity and fix the identity to each and every sub watershed. Coding of watershed in the river valley project is usually done by combination of letters and digits. It is carried out as indicated below:

Catchment : Connotated by capital alphabet usually first letter of catchment name. Sub catchment:Indicated by small alphabet succeeding the catchment code.
Watershed : Connotated by numerals from 1-9, succeeding sub catchment code.Sub watershed : Indicated by small English alphabets succeeding watershed code.

Thus a sub watershed symbolized as Bc3b connotes:

B - Bhavani catchment
C - cth sub catchment of Bhavani catchment
3 - 3rd watershed of Bc sub catchment
b - bth sub watershed of Bc3 watershed.

The coding should be started from the downstream end and proceed to upstream end. For this purpose, the tributaries serially from downstream to upstream are counted as they join main stream irrespective of their joining main stream i.e. either on left or right hand side of main stream.

(ii) Rapid Reconnaissance Survey for Generation of Map of Erosion Intensity Mapping Unit:

The "Erosion Intensity Mapping Units" are composite mapping units and are developed on the basis of four important characteristics, namely

(a) Physiography and slope category;
(b) Surface conditions including present land use and the conditions of such use;
(c) Broad information on soils indicating colour, depth and texture;
(d) Eroding nature of the area, mostly indicating the existing state of erosion.

A rapid reconnaissance survey of the entire area is undertaken to ascertain broad variation in geology and geomorphic landforms. Based on the appreciable differences in these attributes the entire area is divided into broad landscape units. The landscape units can be formed in terms of broad geomorphic variations such as mountainous landscape, alluvial landscape, intermontane valley etc. Each mapping unit is then traversed and based on significant differences in slope, gradients, land use, cover conditions, existing erosion and set of management practices a mapping legend is formulated. The mapping units termed as EIMU are the assemblage of associated parameters. On the basis of which the entire watershed is divided.

(iii) Assignment of Weightage Values to EIMUs

As stated above erosion intensity mapping units are determined by physiography, slope gradient, soil characteristics like surface texture, depth and colour, land-use and surface conditions. These units represent sediment detachment and are assigned weighting values. A value of 10 is assumed as static which signifies that there is equilibrium between the erosion and sedimentation, a higher value indicates erosion and less than 10 indicates deposition.

(iv) Assignment of Delivery Ratio Values:

A comparative maximum delivery ratio is determined for each mapping unit based on its inherent characters. Size, shape, drainage pattern, physiography, slope gradient, distance from the main stream/dam etc. are also considered for deriving the delivery ratio for each mapping unit in different sub watersheds.

The US Soil Conservation Service (1971) has developed a general Sediment Delivery Ratio (SDR) values versus drainage area relationship from data of earlier studies. The relationship shows that the SDR varies approximately inversely as the 0.2 power of the drainage area. Values in Table 3 may be used as an approximation. A higher value may be used when the eroding soil is very high in silt or clay and lower if the eroding soil is coarse textured.

Table 3: General Sediment Delivery-Ratio Estimates

Drainage area, km^2	***Sediment delivery ratio***
0.05	0.58
0.1	0.52
0.5	0.39
1	0.35
5	0.25
10	0.22
50	0.153
100	0.127
500	0.079
1000	0.059

(v) Computation of SYI Values and Grading of Sub-Watersheds into Different Categories:

Sub-watershed-wise areas of each of the EIMU's are computed plan metrically and sediment yield indices of the individual sub watersheds are calculated using the equation 2. A model calculation is as follows:

Watershed code	**Area of erosion intensity mapping unit (ha) (A_{ie})**	**Weighting value (E_i)**	**Delivery ratio (D_r)**	**Total Sediment yield potential ($A_{ie} . E_i . D_r$)**	**Sediment yield index (SYI)**
Da^3c	350	12	0.85	3570	26914 x 100 2224
	550	12	0.80	6600	
	12	12	0.75	108	=1210
	175	18	0.75	2363	
	787	16	0.85	10703	
	350	12	0.85	3570	
Total	2224			26914	

The detailed methodology of computing SYI's and its other aspects are presented by Karale et. al (1975), Bali and Karale (1977) and Karale (1985). After computation of SYI's the priority rating is assigned to each watershed. Highest priority rating is given to the watershed having the highest sediment yield index. Based on the sediment yield indices the characterization of watershed is done in 5 priority categories namely very high, high, medium, low and very low.

After the inter-se priorities of watershed within the catchment have been ascertained, work plan for watershed treatment is prepared, which describes the watershed and its problems. It sets forth the general sequence in which works are to be implemented, the estimated costs, economic justification and responsibilities of those participating in the project for installing, operating and maintaining the measures needed for protection and improvement of watershed. As the problems of each watershed are different, the work plan will also be different.

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3. Drainage Line Treatment Measures for Torrent Control

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Introduction

The torrent is a water-course defined as a stream with highly variable discharges, high slope gradients of the bottom, high scouring activity, transport, and deposition of sediment and frequent changes of channel dimensions, the main criterion being the formation, transport and deposition of sediment. The variation of the discharges, that is, the ratio between the minimum and maximum discharges, may be as wide as 1:5000 or even wider. Abrupt changes in torrent discharges usually occur during flood rains following a long wet period when the soil in the watershed no longer has sufficient capacity to absorb the flood rain water. It is a characteristic feature of torrents that their discharge grows rapidly to reach a maximum and subsequently drops again equally rapidly. With the high inclination of the ground, the surface runoff rapidly concentrates in the channel and can reach the lower segments of the torrent during the course of the rainfall. The key criterion of the "torrent" nature of the stream is its scouring activity by which gravel sediment is released and transported downstream. The sources of sediment include the torrent channel itself and the deposits of gravel carried there to from the steep slopes of the valleys exposed to erosion and from tributary ravines.

The scouring and transport of sediment from the torrent channel are due to its high slope and the lack of balance in flow directions. The higher the channel gradient, the greater the carrying power of the water stream which shifts gravel benches, releases further amounts of sediment and deepens the bottom. In torrent channels with non regulated flow direction, the concave banks are exposed to a high pressure conducive to extensive bank scouring and to loosening of large amounts of gravel. Water carries the sediment, raised from the torrent channel, farther downstream and deposits it again in places where the torrent has a lower slope, and hence a lower carrying power. This causes further damage because the gravel silts up both the torrent channel and the adjacent fields. Torrent if not controlled or stabilized, may go on extending and render adjoining lands degraded. Drainage Line Treatments (DLT) measures are therefore necessary for reducing the torrent gradient (or bed slope) in order to reduce flow velocity, protect banks/side slopes from undercutting (or scouring) and protect adjoining lands and forest plantations.

Torrent and stream bank control measures

Proper disposal of runoff and sediment through discharge torrent and stream bank is a must to stabilize the channel grade, avoid undercutting/scouring of bank and hence the recurrence of new slides/slips. Hill torrents and stream cause extensive damage to adjoining lands, life and property as a result of the frequent changes in their course and associated flash flows during monsoon. Spurs, retards and retaining walls etc. are used at such downstream reaches for training the torrent flow and reducing the steep gradient of torrent. Reduction in slopes reduce the velocity of flow and silt carrying capacity causing deposition of silt in torrent bed.

Planning and Selection

Survey of drainage lines/torrents is carried out to prepare longitudinal section (L-Section), Plan and cross-section (at few locations). This helps in planning different types of DLT measures. Some of the important data and information needed for planning and selecting of Drainage Line Treatment (DLT) measures are

- With the help of a cadastral and/or contour map of catchment with details (like Contours with interval of 5-10 meters, Land use map with boundary and area of each land use, Soil texture, Soil infiltration a reconnaissance survey of the affected area is undertaken to ascertain the type and extent of problems and likely causes. Gully head (i.e., starting point of the gully) should be located during investigation.
- The affected area and drainage line is marked on the map so that watershed area at a given point can be determined for computing peak discharge.
- Transect walk through the drainage line(s) may be taken up along with local community members to have their perception of causes and their needs and priorities, so that, a socially acceptable plan of treatment can be developed.
- During the field investigations and survey, depth, width and side slopes of torrents, their condition in terms of erosion, condition of natural vegetation growth, etc., are observed to help in identifying extent of problem and deciding whether the gully is still in active stage of development or stabilized through natural vegetation. This will help in identifying the needs and types of treatment and their prioritization.
- Rainfall intensities of the locality for different duration's and return periods in order to find out the peak discharge or flood peaks that might have happened in the past.

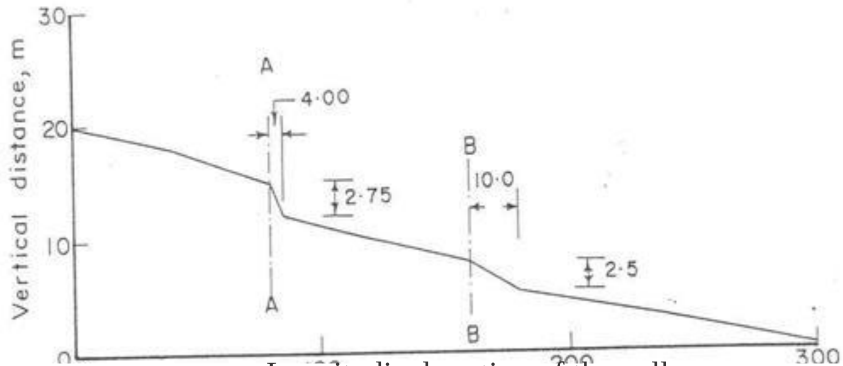
Detailed survey of drainage lines is carried out to prepare

(a) Longitudinal Section (L.S.)

(b) Cross-section (C.S.) at few selected locations, and

(c) Plan

Longitudinal section will provide torrent gradient or bed slope and points of sudden drop or fall to help plan the location, type and number of treatment measures. Cross-section will provide width and depth at required section to plan and design the structure. Plan of the drainage line would help in deciding location in conjunction with LS & CS to avoid excessive bends, select narrow sections for grade stabilizers, location of spurs.



Longitudinal section of the gully

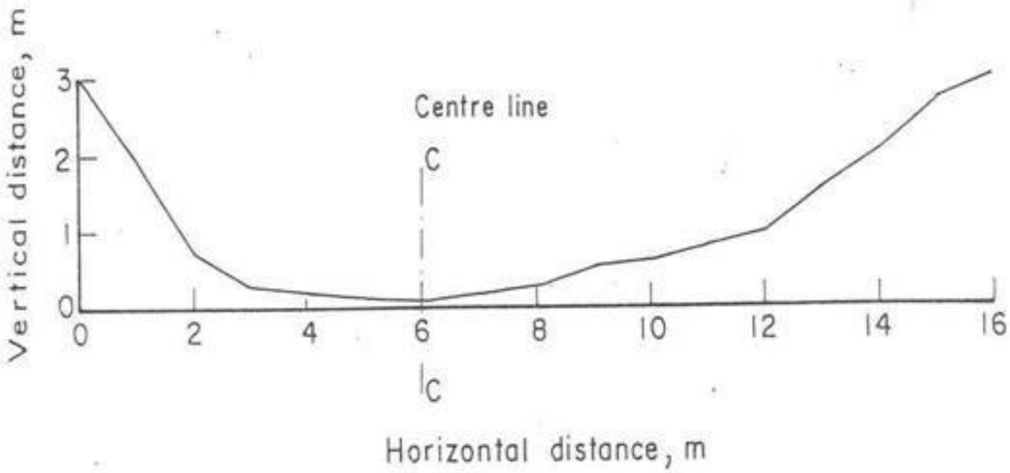


Fig. 2 Cross section at A-A

General Guidelines for Selection of Site.

- The steep and high vertical banks, away from direct impact of flood waters are generally provided with a blanket of boulder/stone rip-rap or mat, called revetment to protect it against erosion.
- On such steep high banks where protection by vegetation is not possible and valuable properties extend right up to the edge of stream bank, revetments are recommended. It can also be used in combination with retaining wall in the lower portion of the stream towards the bed.
- The degraded slopes on the gully or stream banks, near road cuts, or on steep fragile slope near the toe i.e., lower bank, earth or slope failure such as land slips are provided with retaining wall. These walls may also have direct impact of flood waters unlike revetments.
- Gabion retaining wall can be used at places with unstable foundation.
- Along the eroding bank of a stream with stable gradient where the prime objective is not to alter the alignment of the drainage line but to retard or dampen stream velocity to prevent erosion of the bank or scour of its toe, retards in the form of thick line of live hedges in very low banks, jetted posts or in the form of series of jacks can be adopted for erosion control.
- The stream banks that are affected by direct action of stream flow near the bends or in other straight reaches and where protection is not possible with retards, spurs are needed to deflect the flow of water away from the bank and thus reclaim the area.

Different types of DLTs for torrent control

1. Spurs

Spurs are the commonly used for torrent control and stream training. These structures are constructed transverse to river flow extending from one of the banks at an angle to the flow.

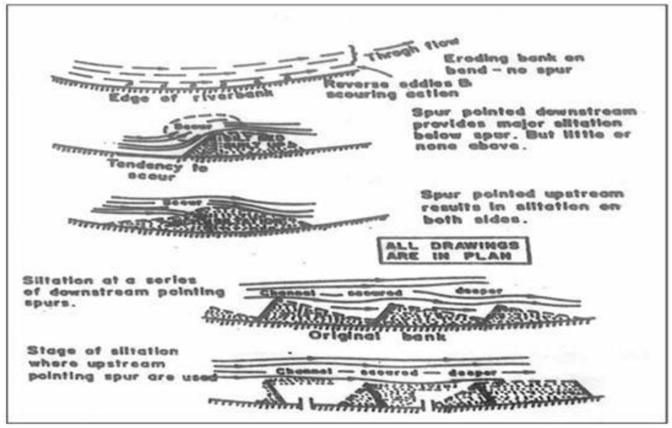
According to their function, spurs are of three types:

a) Attracting type (pointing d/s at an angle of 30- 45°),
b) Deflecting type (at 90°) and
c) Repelling type (pointing u/s, 5-20° normal to flow)

Suitability:

The functions of a spur system may be one or a combination of the following:

1. Protection of river banks (including land, road, buildings and other structures along them)
2. Reclamation of land along torrent beds, in excess of that required for the flow discharge.



Design criteria of spurs:

- Construction of spurs for river training is quite expensive.
- Plan spurs judiciously and execute optimally at the most crucial reaches along a river course.

Factors that determine the design parameters of spurs are:

- River characteristics: includes river geometry (width, flow depth, bank heights) flow velocity, flow pattern, bed slope, sediment - debris, boulders movement, river meandering and curvature etc. are parameters that may determine the design specifications of structures.
- Spur geometry: Important design considerations are length of spur, its alignment to flow shape and permeability
- Spur Length: Construct the spur in limited, causes constriction of river flow so as not to affect the river regime adversely.
- Check the length of spurs by a 'blockage ratio' b/B, where b is the projected length of spur and B is the river width. The blockage ratio $\leq$ 0.3.
- Alignment of spur: It is defined by the angle which is made by the spur with the flow direction as measured from the d/s. As the angle of the inclination of the spur along the flow direction increases, its sedimentation capacity increases but stability decreases due to greater scour.
- Attracting (d/s pointing) spurs with an angle of 30° – 45° are normally used for flow diversion whereas short and closely spaced right angled deflecting spurs are recommended for quick sedimentation along banks.

- Shape of spur: In oblique faced spurs, such as trapezoidal cross section, the scour depth is lesser due to energy dissipation of incoming flow on the sloping wall. Simple rounding of corners and edges of spurs reduces the scour considerably. The u/s nose is only affected by scour.
- Permeability of spur: gabion and vegetative spurs are more efficient, less expensive and can be made by local material. Their stability is better than the solid ones due to lesser scour around them.
- Spacing of spur: A spur protects only a certain length of the bank used in series, spaced and give a continuous effect. The recommended spacing of spurs is 3-4 times the projected spur length. For convex bank , larger spacing are adopted and a smaller one for concave bank i.e. 2 to 2.5 times the length of spurs
- Vegetative reinforcement of spurs: In the vicinity of the spur and particularly at its nose, suitable shrubs and grasses are planted to prevent scour. Arundo donax (Narkul or Nada), Vitex negundo, Ipomoea carnea (Besharam) etc. have been found useful for vegetative reinforcement of the structures.

2. Retaining Walls

A retaining wall works as revetment on steep slopes near the toe i.e. lower bank in protecting bank from erosion or deep cut on road side. It acts as a toe wall. As a rule of thumb, for gabion structures the bottom width is kept 2/3rd the height for walls up to 6 m in height with 1 m top width and for stone wall it may be kept a minimum one-third of the height. When there is surcharge, a 2 m top width may be adapted.

3. Revetments

Revetments are used where the protection by plantation is not possible and valuable properties extend right up to the edge of the stream bank. They are provided to cover the slope of the stream bank, preferably after easing out the slopes. The side slopes for these measures should not be steeper than 1.5:1 or flatter. Both vegetative (brush mat revetment) and / or mechanical measures (rock riprap) are used to cover the stream banks depending upon the site conditions. Gabion revetments, about 0.5 m thick laid on 1.5:1 or flatter slope can also be used.

4. Gabion Structures

Gabion structures are commonly used in India and elsewhere for gully control, land slips and landslides stabilization, mine spoil rehabilitation, stream bank and torrent control, etc. (Gupta and Dalal, 1967). Gabions are woven wire boxes, filled with stones/boulders. These structures retain debris and soil without impounding of water and thus support growth of vegetation in eroded/degraded lands. Gabions have a fairly long life (20-25 years), needed to stabilize the soil against erosion.

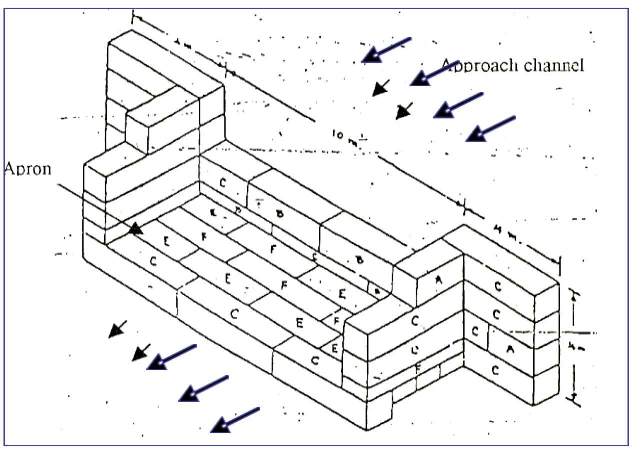
Use of Gabion

i. Retaining Walls: Gabion retaining walls are used in places of unstable foundations and where sufficient quantity of stones is available at site. Such situations are often encountered in stabilization of debris, foot of the landslides and eroded torrent and stream banks.

ii. Revetments: A revetment is a protective cover to prevent scour by water. The main function is to provide a blanket protection to the earth surface and not to withstand any thrust. The bank is eased to a

Slope of 1:1 and the 50 cm gabion is laid on the bank. The toe protection of the revetment is secured by placing 1 m x 1 m gabion boxes.

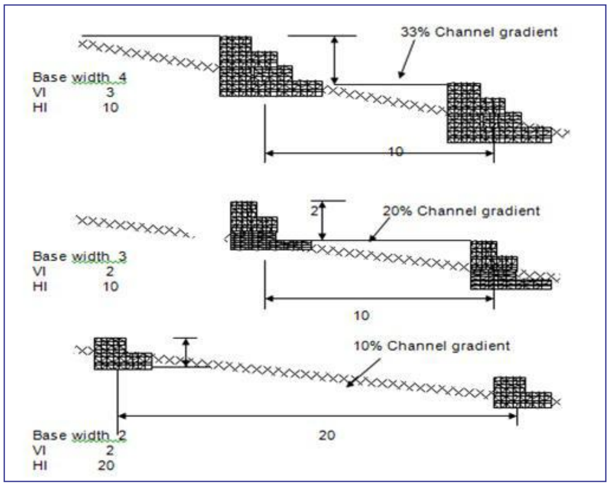
iii. Check Dams/Drop Structures: Gabions are suitable for gully control or gully plugging especially in the middle and lower reaches. These are used for different type and size varying from the smallest bed stabilization check-dam to the larger stilling basins and drop structures. Simple grade stabilization structures (called as check-dams) may consist of a wall built of gabion boxes across the stream. The spillway is formed by placing 1 m x 1 m gabion box on either ends of the wall. The check-dams where drop is more than one meter should be provided with a gabion apron to prevent scouring. The spillway may be finished with 2" thick concrete after its initial settlement, to protect the wire mesh from abrasion. Construction of a standard drop structure can be done using gabion boxes as illustrated in figure.



Conventional Type of Drop Structure Constructed with Gabions

IV. Gabion Cross Barriers- This is suitable in the higher order streams/main drainage channels in head water reaches receiving large quantities of runoff and debris flow. These barriers are useful in stabilizing the drainage line by retaining Debris.

v. Channel Lining: The lining of banks and beds of water courses may be done with ½ meter and 1/3 meter deep gabion boxes in the same manner as for revetment. The maximum slope for this type of work can be kept at 1:1 (preferably 1 ½:1). On steeper slopes the use of site reinforcements may be needed.



Structural Design of Gabion Cross Barrier on Different Channel Gradients

5. Check Dams

Permanent check dams are constructed when the benefits from such structures are justified to the cost of construction. It consists of reinforced concrete, concrete blocks, stone masonry, metal or earth. The structure's main function is to safely dispose the peak rate of runoff for a given frequency, from a higher elevation to a lower elevation. It should have arrangements to dissipate the kinetic energy of discharge within the structure in a manner and degree that will protect both the structure and downstream channel from damage. It should be constructed under the following conditions-

- Where volume and peak rate of runoff is very large and cannot be controlled by other means
- Where high degree of safety against the loss of life and property is warranted
- Site should be protected is inaccessible and regular maintenance of structure is not possible

General Requirement

- Permanent structures are used in medium to large torrents carrying more runoff, especially in the lower reaches.
- Gully heads are generally steep and may even have almost vertical fall. In such locations, if the fall or drop at gully head is limited to 3 or 4 m straight drop structure is recommended to control gully head.
- As a grade stabilization structure, permanent drop structures (masonry, reinforced concrete, gabions, earthen gully plugs) are commonly used where sudden drop or fall in the gully exists.
- Generally a stable narrow section with gentle upstream bed and broader width is preferred for drop structures.
- As a grade stabilization structure, permanent drop structures (masonry, reinforced concrete, gabions, earthen gully plugs) are commonly used where sudden drop or fall in the gully exists. Drop structures are recommended for a drop of upto 3 to 4 m.
- Generally a stable narrow section with gentle upstream bed and broader width is preferred for drop structures.
- The site should have a reasonably straight section, with no upstream or downstream curves or bends within at least 30 m of the structure.
- The spillway is so located that its centre line is in alignment with the centre line of the flowing water in the drainage line.
- If, at a particular site, it is impracticable to avoid curvature, good upstream alignment must take precedence and rip raping is provided at the bends.
- There should be no channel restrictions or obstacles in the approach channel to interfere with design flow.
- The site selected should have banks high enough to accommodate the maximum depth of flow over the structure otherwise flooding of adjoining lands and properties would take place.
- The available standard type designs of check dams for a given size of catchment needs to be modified as per the specific site condition, at least in terms of providing sufficient head wall extension for proper abutment with the banks, side walls depending on bank conditions including provision of weep holes and proper apron. Downstream protection against scouring should be given due consideration. It should also be ensured that breast walls, side walls, etc., of masonry are not constructed on freshly filled unsettled earth.

4. Land Capability Classification for Watershed Planning

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The function of watershed planning is to guide decisions on land use in such a way that the resources of the environment are put to the most beneficial use for man, while at the same time conserving those resources for the future. This planning must be based on an understanding both of the natural environment and of the kinds of land use envisaged. There have been many examples of damage to natural resources and of unsuccessful land use enterprises through failure to take account of the mutual relationships between land and the uses to which it is put.

Land evaluation and land capability classification are two ways by which the potentials of land for a particular kind of use can be known. Proper land management cannot be done without land evaluation. Land evaluation is the assessment of the potential of land for alternative uses following systematic approach. According to FAO (1976), land evaluation is the assessment of present performance of land, particularly as this affects changes in the use of land and in some cases changes in the land requirement and qualities. Land evaluation forges a link between basic survey of resources and taking of decision on land use planning and management. It puts at the disposal of users relevant information about land resources that are necessary for planning, development and taking management decisions. There are several methods of land evaluation. These methods aim at assessing land qualities or suitability for a specific land use as conditioned by important biophysical parameters.

Land

Land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. It includes the results of past and present human activity, e.g. reclamation from the sea, vegetation clearance, and also adverse results, e.g. soil salinization. Purely economic and social characteristics, however, are not included in the concept of land; these form part of the economic and social context.

A land mapping unit is a mapped area of land with specified characteristics. Land mapping units are defined and mapped by natural resource surveys, e.g. soil survey, forest inventory. Their degree of homogeneity or of internal variation varies with the scale and intensity of the study. In some cases a single land mapping unit may include two or more distinct types of land, with different suitabilities, e.g. a river flood plain, mapped as a single unit but known to contain both well-drained alluvial areas and swampy depressions. Moreover, for land evaluation they will be put into two different classes depending on their characteristics and capabilities. Land is thus a wider concept than soil or terrain. Variation in soils, or soils and landforms, is often the main cause of differences between land mapping units within a local area: it is for this reason that soil surveys are sometimes the main basis for definition of land mapping units. However, the fitness of soils for land use cannot be assessed in isolation from other aspects of the environment, and hence it is land which is employed as the basis for suitability evaluation.

If land characteristics are employed directly in evaluation, problems arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not by slope angle alone but by the interaction between slope angle, slope length, permeability, soil structure, rainfall intensity and other characteristics. Because of this problem of interaction, it is recommended that the comparison of land with land use should be carried out in terms of land qualities.

Land suitability and land capability

The term "land capability" is used in a number of land classification systems notably that of the Soil Conservation Service of the U.S. Department of Agriculture. In the USDA system, soil mapping units are grouped primarily on the basis of their capability to produce common cultivated crops, silvipasture and pasture plants without deterioration over a long period of time. Capability is viewed by some as the inherent capacity of land to perform at a given level for a general use, and suitability as a statement of the adaptability of a given area for a specific kind of land use; others see capability as a classification of land primarily in relation to degradation hazards, whilst some regard the terms "suitability" and "capability" as interchangeable.

Because of these varying interpretations, coupled with the long-standing association of "capability" with the USDA system, the term land suitability is used in this framework, and no further reference to capability is made land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses.

In this chapter, the structure of the capability classification is first described. This is followed by an account of the range of interpretative classifications recognized: qualitative, quantitative and of current or potential suitability. In accordance with the standard principles, separate classifications are made with respect to each kind of land use that appears to be relevant for the area. Thus, for example, in a region where arable use, animal production and forestry were all believed to be possible on certain areas, a separate capability classification is made for each of these three kinds of use.

The aims of land evaluation

Land evaluation may be concerned with present land performance. Frequently however, it involves change and its effects: with change in the use of land and in some cases change in the land itself.. Thus land evaluation should answer the following questions:

- How is the land currently managed, and what will happen if present practices remain unchanged?

- What improvements in management practices, within the present use, are possible?

- What other uses of land are physically possible and economically and socially relevant?

- Which of these uses offer possibilities of sustained production or other benefits?

- What adverse effects, physical, economic or social, are associated with each use?

- What recurrent inputs are necessary to bring about the desired production and minimize the adverse effects? What are the benefits of each form of use?

Land evaluation and land use planning

Land evaluation is only part of the process of watershed planning. Its precise role varies in different circumstances. In the present context it is sufficient to represent the land use planning process by the following generalized sequence of activities and decisions:

i. . recognition and delineation of the different types of land present in the area;

ii. recognition of a need for change;

iii. formulation of proposals, involving alternative forms of land use, and recognition of their main requirements;

iv. comparison and evaluation of each type of land for the different uses;

vi. selection of a preferred use for each type of land;

vii. project design, or other detailed analysis of a selected set of alternatives for distinct parts of the area;

Recognition of this need is followed by identification of the aims of the proposed change and formulation of general and specific proposals. The evaluation process itself includes description of a range of promising kinds of use, and the assessment and comparison of these with respect to each type of land identified in the area. This leads to recommendations involving one or a small number of preferred kinds of use. These recommendations can then be used in making decisions on the preferred kinds of land use for each distinct part of the area. Later stages will usually involve further detailed analysis of the preferred uses, followed, if the decision to go ahead is made, by the implementation of the development project or other form of change, and monitoring of the resulting systems.

Two-stage and parallel approaches to land evaluation

The relationships of resource surveys and economic and social analysis, and the manner in which the kinds of land use are formulated, depend on which of the following approaches to land evaluation is adopted (Fig. 1):

- a two-stage approach in which the first stage is mainly concerned with qualitative land evaluation, later (although not necessarily) followed by a second stage consisting of economic and social analysis;

- a parallel approach in which analysis of the relationships between land and land use proceeds concurrently with economic and social analysis.

The two-stage approach is often used in resource inventories for broad planning purposes and in studies for the assessment of biological productive potential. The land suitability classifications in the fires stage are based on the suitability of the land for kinds of land use which are selected at the beginning of the survey, e.g. arable cropping, dairy farming, maize, tomatoes. The contribution of economic and social analysis to the fires stage is limited to a check on the relevance of the kinds of land use. After the first et age has boon completed and its results presented in map and report form, these results may then be subject to the second et ego, that of economic and social analysis, either immediately or after an interval of time.

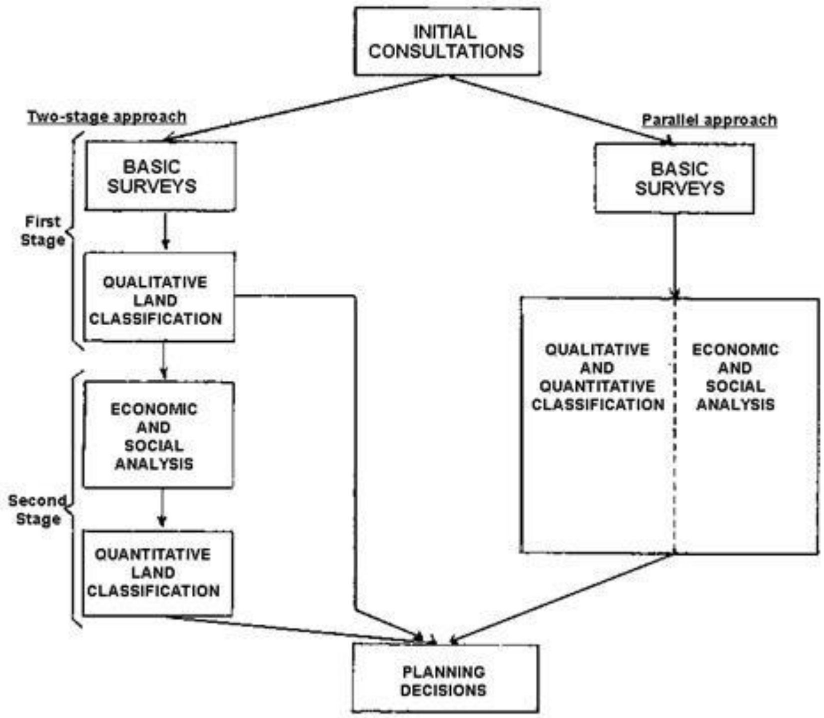

Fig. 1 Two-stage and parallel approach to land evaluation

In the parallel approach the economic and social analysis of the kinds of land use proceeds simultaneously with the survey and assessment of physical factors. The kinds of use to which the evaluation refers are usually modified in the course of the study. In the case of arable farming, for example, this modification may include selection of crops and rotations, estimates of the inputs of capital and labour, and determination of optimum farm size. Similarly, in forestry it may include, for example, selection of tree species, dates of thinning and felling and required protective measures. This procedure is mostly favoured for specific proposals in connection with development projects and at semi-detailed and detailed levels of intensity.

The parallel approach is expected to give more precise results in a shorter period of time. It offers a better chance of concentrating survey and data-collection activities on producing information needed for the evaluation. However, the two-stage approach appears more straightforward, possessing a clear-cut sequence of activities. The physical resource surveys precede economic and social analysis, without overlap, hence permitting a more flexible timing of activities and of staff recruitment.

The two-stage approach is used as a background in the subsequent text except where otherwise stated.

Land capability classification is an assessment tool which can be need by manager, engineers, and government authorities to assist in evaluating alternative practices or general designs that will overcome unfavourable soil or terrain characteristics and minimize off site effects, such as sedimentation and pollution of water ways.

Land capability classification is defined an "the systematic arrangement of land into various categories according to its capability to sustain particular land use without land degradation. The approach involves the identification and interpretation of unique land units with similar climatic, geological, landform and soil characteristics, as the basis for determining erosion risk and other land use constraints and hazards.

Influence of effective soil depth on L.C.C.(soil depth is measured by soil augur)

Soil depth modifies the rooting systems of plants which reflect on crop growth and yield. Suggested land use capability class for different soil depth classes are given below :

Soil depth	Symbol	Description	Land capability class
More than 90 cm	d5	Very deep	I
45 - 90 cm	d4	Deep	II
22.5 - 45 cm	d3	Moderately deep	III
7.5 - 22.5 cm	d2	Shallow	IV
Less than 7.5	d1	Very shallow	VI, VII

In combination with other unfavourable factors, like texture, land slope etc., the capability class is enhanced (capability reduced).

2. Influence of soil texture on L.C.C. (texture can be measure by feel method)

Soil texture has a great importance in land use capability classification as it influence the water holding capacity, permeability, drainage etc. On the basis of textural soil classes, following land capability classes are suggested:

Textureal class	Symbol	Land capability class
Sand	s	IV
Loamy sand	ls	III
Sand loam	sl	I
Loam	l	I
Clay loam	cl	I
Sandy clay loam	scl	I

Silt	si	I
Silty loam	sil	I
Silty clay	sic	II
Silty clay loam	sicl	I
Sandy clay	sc	II
Clay	c	II, III

Kankar are not harmful upto 40-50% but gravel interfere the crop growth.

3. Influence of slope on L.C.C. (slope is measure by abney level)

Land slope has a great influence on runoff and soil loss which influenced land use capability. The description of different slope classes with suggested land capability classes is as under :

Slope class	Slope range	Description	Land capability class
A	0 - 1%	Nearly level	I
B	1 - 3%	Very gently sloping	II
C	3 - 5%	Gently sloping	III
D	5 - 10%	Moderately sloping	III
E	10 -15%	Strongly sloping	IV
F	15 - 25%	Moderately steep to steep	IV
G	25 - 33%	Steep	VI
H	33 - 50%	Very steep	VII
I	> 50%	Very very steep	VII

4. Effect of erosion conditions on L.C.C. (soil erosion can be measured by expert judgement)

Features of soil erosion are mainly judged by the conditions existing in the field. Slight erosion (e_1) may be associated with sheet erosion, and moderate erosion (e_2) with sheet and rill erosion. Severe erosion (e_3) will be associated with excessive surface erosion, exposing the subsoil by tendency to form small gullies. Very severe erosion (e_4) may be associated with extensive loss of surface and sub-surface soil (25-75% B horizon). The erosion classes with their suggested L.C.C. are given below:

Erosion class symbol	Description (Degree of erosion)	Land capability class
e_1	No erosion or sligh erosion (upto 25% of A horizon is lost)	I & II
e_2	Moderate erosion (upto 75% A horizon is lost)	III
e_3	Severe erosion (A horizon lost and B horizon exposed)	IV
e_4	Very severe erosion (25-75% of B horizon lost)	VI & VII

5. Influence of climate on L.C.C.

If other soil conditions are favourable, the climate affects the land capability classification as follows:

Climate characteristics	Influence on capability classes
Humid climate with well distributed rainfall	can start from class I
Humid climate with occasional dry spells	can start from class II
Sub-humid : crop yields frequently reduced by droughts	can start from class II to III
Semi-arid	can start from class III to IV
Arid	can start from class IV

4. Effect of erosion conditions on L.C.C. (soil erosion can be measured by expert judgement)

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Provision of irrigation eliminates the harmful effect of inadequate rainfall, and hence climate no longer remains a limitation in irrigated areas.

6. Other factors

Others factors to be considered for L.C.C. are the salinity and alkalinity of the soil, soil acidity, high water table, toxicity of certain elements, stoniness etc.

Classification

The lands under different capabilities can be classified into groups, classes, sub-classes and units from higher level to lower level of generalization.

Land capability groups

Grouping of soils into different capability classes is done on the basis of intensity to which they can be utilized considering the hazards involved to produce either common cultivated crops or forest and grass vegetation, without deterioration over a long period of time.

Intensity of land uses

1.	Intensive land use	-	Cropping (Tillage involved)
	Degree of intensity	-	Three – four crops/year Two crops/year Single crop/year Occasionally cropped
2.	Non-intensive land use	-	Permanent vegetative cover (does not need tillage) e.g. – forest trees, grasses, horticulture.

Classification as adopted in India

The land capability classes range from the best and the most easily farmed land to land which has no value for cultivation, grazing or forestry, but which may be suited for wild life, recreation etc. The capability classes thus fall in two broad groups, one suited for cultivation and other not suited for cultivation. Each group is further sub-divided in four capability classes based on intensity of hazards involved and limitations of use. Capability classes are thus determined by degree of limitations in land use with hazards involved. Within land capability class, sub-classes are determined by the kinds of limitations and hazards. The sub-classes are further divided into units based on a specific management practice, which it will respond to 'unit' is the ultimate and most important sub-division in this classification system for actual planning purpose as it determines the management practice on each small piece of land. Thus lands are classified into eight land capability classes under two broad groups as :

1. Land suitable for agriculture and other uses which includes class I to class IV lands.
2. Land not suitable for agriculture but very well suited for forestry, grass land and wild life which includes class V to class VIII lands.

	Land capability class	Land use
I	(Very good land) with no limitations	Agriculture, grassland afforestation, wild life etc.
II	(Good land) with minor limitations	-do-
III	(Moderately good land) with major limitations	-do-
IV	(Fairly good land) with occasional cultivation and major limitations	-do-
V		Grass land, afforestation, wild life etc. (with no limitations)
VI	Intensity of hazards increases with limitations of land use	Grass land, afforestation, wild life etc. (with minor limitations)
VII VIII	from class V to VIII land	Grass land, afforestation wild life etc. (with major limitations) Wild life

On the map, the capability classes are indicated in different colours as - I (green), II (yellow), III (red), IV (blue), V (dark green), VI (orange), VII (brown), VIII (purple).

Land capability sub-classes

A land capability class is determined by the degree of limitations or intensity of hazard in land use. At this stage it is not usable for planning, since only degree of difficulty is known. The kind of hazard or problem has not been identified within a land capability classes. The sub-classes indicate the kind of limitation or hazard. For example in class III land we have land suited for cultivation but subject to severe hazard of water erosion due to steep slope or severe hazard of wind erosion on smooth land or severe hazard of water logging or overflow and shallow depth to bed rock. Four kinds of limitations are recognized at sub-class level as follows:

1. **Sub-class (e) - erosion**: It includes the soils where the susceptibility and past erosion damage are the major factors for placing the soils in this sub-classes. For example IIe will indicate moderate problems of erosion.
2. **Sub-class (w) - excess water** : Includes soils where excess water is the dominant hazard in their use. Poor soil drainage, wetness, high water table and overflow are the criteria for determining this sub-class. For example Iiw will need control of flooding or overflow.
3. **Sub-class (s) - soil limitations with the rooting zone** : It includes soils which have such limitation as shallowness of rooting zone, stones, low moisture holding capacity, low fertility and salinity or alkalinity. For example IIs would indicate a moderate problem of droughtness or stones affecting tillage or less than ideal effective soil depth.
4. **Sub-class (c**) - climatic limitations: Includes soils where the climate (temperature or lack of moisture) is the only major hazard in using the land due to climate.

The land capability sub-classes are expressed (mapped) by the small letters indicating the hazard which follow the land capability class Roman number e.g. IIe, IIIs, IIw etc. In case of two kinds of hazards or limitations are existing, both can be suffixed, the dominant one is shown first such as IIec. Where two kinds of limitations are equal, the sub-classes have the priority in the order of e,w,s,c, for deciding sub-class. Thus sub-classes are indicative of both degree and kind of limitation. Class I land has no sub-classes.

5. **Land capability units**: Land capability unit is the final step in the land capability classification. It is grouping of one or more individual soil mapping units having similar potentials and continuing limitations or hazards. The soils in a capability unit are sufficiently uniform to (i) produce similar kinds of cultivated crops and pasture plants with similar management practices, (ii) require similar conservation treatment and management under the same kind and condition of vegetative cover, (c) have comparable potential productivity. The capability unit provides information for planning individual tracts of land. Lands may have the same capability class and sub-class but due to individual differences may not respond to the same treatment, for example : class IIIs would show land with severe soil limitation which may arise due to one of the following reasons.

1. Limitations of effective soil depth.
2. Very heavy or light texture of soil.
3. Nature of material restricting root zone.
4. Salinity or alkalinity of soil

These four soil limitations will need different management practices. The capability units for this soil will be

$IIIs_1 : IIIs_2 : IIIs_3 : IIIs_4$

The land capability units are designated by ordinary numerals placed as subscript to the sub v-class letters in the capability notation as shown above.

Obtaining information on land capability classes and sub-class: There are two ways to obtain information on L.C.C. and sub-classes:

1. Detailed soil survey maps provide all details for land capability classification, e.g. soil series, texture of top soil, effective soil depth, land slope and degree of water and wind erosion. Apart from these soil and land characteristics, information is also available on wetness, water logging, salinity, alkalinity, stoniness, rockiness climate etc. This information can be used for the purpose of land capability classification.

2. In the absence of standard or detailed soil map, actual field survey has to be done to obtain information on all the features stated above., For this purpose, cadastral maps (village maps) or large scale topo sheets are utilized to serve as base maps. Different observations are collected as below :

Texture of top soil	-	By feel method
Effective soil depth	-	By screw auger/road cuts
Land slope	-	By hand level or Abney's level
Erosion hazard	-	By eye judgment
Salinity/Alkalinity	-	By laboratory examination

The above observations are collected and mapping units are built as below:

<u>Soil series - Texture of top soil - effective soil depth</u>

Land slope - Erosion hazard

These mapping units are recorded on survey map for land capability classification. Boundaries are marked to separate areas belonging to different mapping unit. Help is taken of the rating chart to interpret the different observations into land capability classes. A few examples of interpretation of mapping units into land capability classes and sub-classes are given below:

Mapping unit	**Soil characteristics**
D<u>KT-l-d 5</u>	DKT – Dhulkot soil series
B-e_1	
	L - Loam (texture of top soil)
	d5 - Soil depth more than 90cm (very deep)

B - 1-3% land slope

e l - sheet erosion

The interpretation into L.C.C. for above characteristics is as:

DKT - l-	Class I	
d 5	-	Class I
B	-	Class II
e_1	-	Class I

The LCC of this land is II and sub-class which determines kind of limitation will be 'e' (erosion) and 's' (soil limitation). Therefore, the mapping symbol will be IIe.

2.	**Mapping unit**	**Soil & land character**	**Interpretation**
	<u>1-d_2</u>	1 - loam	I
	B-e_2	d_2 - soil depth 7.5-22.5 cm	IV
		B - land slope 1-3%	II
		e_2 - rill erosion	III

The land capability class is IV and sub-classes are's' and 'e'. The mapping symbol will be IV s e,'s' being the sub-class more serious than 'e' in this case.

1. Sometimes soil and land characteristics other than those in the mapping symbol become importantand deciding land capability class and sub-class. These are salinity, alkalinity, water logging, flood hazard, climate etc.

<u>sl - d5</u>	Interpretation
A-e_1	
severe saline and alkali conditions)	It should have been class I land, if serious saline and alkali conditions were not present. But due to saline-alkali condition it is class IIIs land.

The area under different land capability classes are shown with different standard colours in the map as already mentioned earlier.

Method of field work in mapping for L.C.C.

1. Get familiar with the base map of the area to be surveyed.
2. A quick reconnaissance of the area is done to ascertain ridge line of the watershed and have a judgment about the physiography.

3. Survey work is started at one end of the watershed from a place easily identifiable with the help of permanent features.

2. Take observations on texture of surface soil, effective soil depth, slope, erosion and any other relevant features at 3-4 locations in an area and record observations using following table

5. Follow rating chart to determine land capability classes and sub-class.
6. Confirm boundary of the mapping units.
7. Determine L.C.C. and sub-class in the field itself, before moving to other area.
8. Minimum mappable area will depend upon the scale of the map.
9. Area occupied by each mapping unit will have following details :

a. Boundary of the area by black line
b. Mapping unit symbol.
c. Land capability class and sub-class symbol.
d. Slope direction shown by arrows with exact percentage slope denoted against them.
e. Standard colour of land capability classes.4

10. Other details on the L.C.C. map

a. Title
b. Index
c. Name and signature of surveyor with date.

Brief – acquaintance with land capability classes

Group 1. Land suitable for agriculture and other uses

Class I (Green colour): Soils in class I have no limitations. The land is nearly level and the erosion hazard is low. Soils are deep, well drained, well supplied with plant nutrients and good water holding capacity. It does not require any special soil and water conservation practices except good farming practices such as use of manures and fertilizers, liming, cover and green manure crops, crop rotations and conservation of crop residue to maintain high productivity. Soils may be used for cultivated crops, pasture, forests and wild life.

Class II (Yellow colour): Soils in class II have some limitations which reduce the choice of crops. The limitations may result due to gentle slope, moderate erosion, less than ideal soil depth, overflow damage, wetness, slight to moderate salinity or sodium, slight climatic limitations.

Soils require simple soil and water conservation practices and some attention to soil management. The may need one or more of the practices which include contour cultivation, strip cropping, contour bunds in dry farming areas graded bunds with suitable water disposal arrangement in heavy rainfall areas, crop rotations, stubble mulching, removal of stones and other good farming practices applicable to class I lands. Soils may be used for cultivated crops, pasture, forests and wild life.

Class III (Red colour) : Soils in class III have severe limitations which reduce the choice of crops. They require special conservation practices, which are more difficult and costly to apply for their management. Limitations of soils may result from the effect of moderately sloping land, high susceptibility to water or wind erosion, frequent overflow with some crop damage, slow permeability of sub-soil, wetness or water logging after drainage, shallow soil depth, hard pan or clay pan, moderate salinity or sodium, low W.H.C. and moderate climatic limitations.

These soils need contour tillage, narrow strip cropping, contour or graded buns or bench terraces with water disposal arrangements, cover crops, crop rotations, stubble mulching, grass waterways, drainage intensive irrigation, removal of large stones and correction of soil fertility. Soils can be used for cultivated crops, pasture, forest and wild life food and cover.

Class IV (Blue colour) : These lands have very severe limitations that restrict the choice of crops and require careful management and the conservation practices are more difficult to apply and maintain. The land as compared to class III will be steeper, more eroded or more susceptible to erosion, more difficult to drain or irrigate, more open, porous or excessively permeable, shallow depth, excessive wetness and water logging, severe salinity or alkalinity, adverse climate etc. The soils can be used for crops, pasture, forests and wildlife food and cover.

Group 2. Lands limited in use generally not suited for cultivation

Class V (Dark green or uncoloured) : Class V land has all the characteristics of class I land except for limitation of wetness or stoniness or rockiness climatic conditions which make it unsuitable for cultivation of crops. However, for grazing, pasture development and forestry, there are no limitations for use. This land is not subject to more than slight wind or water erosion and does not require any special soil and water conservation measures except good management practices for pastures and high returns are obtained by seeding, fertilizing, limning, contour furrows, drainage or water spreads.

Low lying areas, subject to frequent over flows, level or nearly level stony or rocky deep soils, water logged areas where drainage for cultivation is not possible but the soils are suited for grasses and trees are examples of class V lands.

Class VI (Orange colour) : Soils in class VI have severe limitations that make them generally unsuited to cultivation and limit their use mainly for pasture or forest or wild life food and cover.

Class VI land has the same limitations as class IV land except that they are more severe, the land is more steep, more eroded (gullies are often present) soils are very shallow, either too wet or too dry, stoniness, salinity or alkalinity. It has moderate limitations for grazing and forestry.

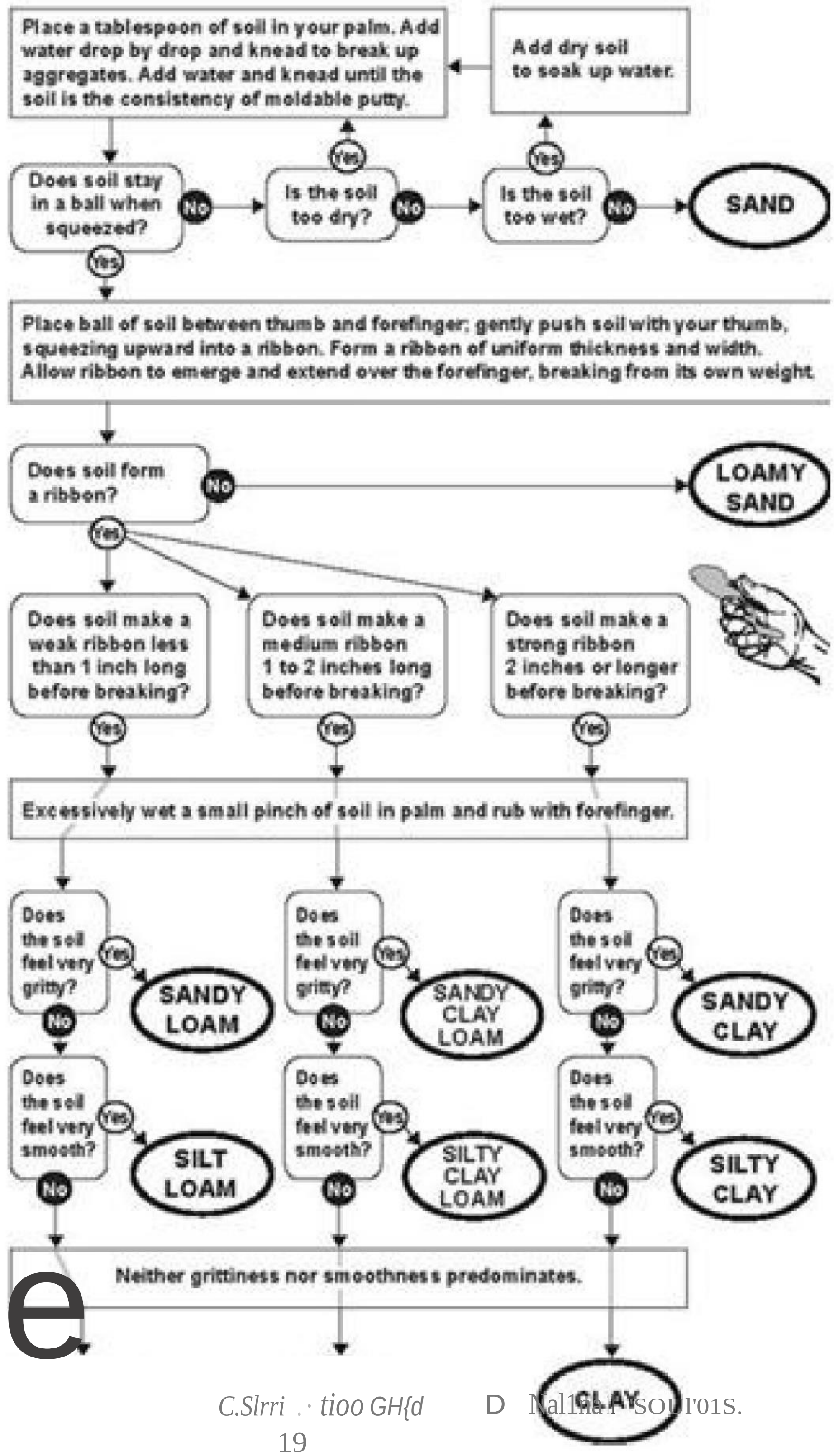
Class VII (Brown colour) : Class VII land has severe limitations for grazing and forestry. The land is very steep, very severely eroded, cut up into gullies and is either too wet or too dry. It is not feasible to apply pasture improvement and water control practices. The land is best utilized under forest and permanent vegetation and for limited grazing. It require good pasture management practices as well as careful attention for their carrying capacity, rotational grazing, deferred grazing, fencing etc.

Class VIII (Purple colour) : Examples of class VIII lands are very steep or rough or stony or barren land, bad lands, rock outcrops, sandy beaches, marshy lands, deserts, river bank land, mine tailing which do not give economical return from management. They are often kept under permanent cover to protect watersheds and other more valuable lands. These lands may yield indirect benefits from wild life, watershed protection and recreation.

In a soil conservation context, land capacity classification is based on a balance between usage and conservation measures which allow the most intensive use of the land without soil erosion and with a permanently sustained level of usage. It relates to the degree of hazards and limitations in managing the land and thus the classification is primarily concerned with erosion risk.

Table 1. Land capability class rating table

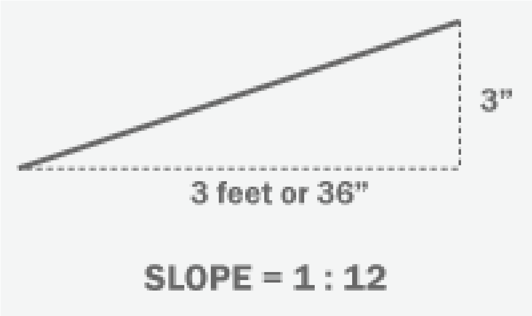
Class	**Texture**	**Soil**	**% slope o land and symbol**					**Erosion class an symbol**				
		depth(cm) and symbol	Alluvial soils	Black soils	Red soils	Deep red soils of eastern ghats, ghats and western ghats and Nilgiris	Himalayas	Effect of past erosion	Susceptibility to erosion e.g. distance from active gully heads	Permeability (mm/hr)	Conductivity (mmhos/ cm at 25ºC)	Climate
1.	sicl,cl, l, sl, sil, scl	More than 90 (ds)	0-1(A)	0-1(A)	0-1(A)	0-1(A)	0-1(A)	Upto 1/4 of top-soil lost; sheet erosion (er)	Very far away	Moderate (20-50)	0-2	Humid climate with well-distributed rainfall through out the year
II	sicl, cl, sl, sil, scl	45-90 (d4)	1-3(B)	1-3(B)	1-3(B) 3-5(C)	1-3(B) 3-5(C)	1-3(B)	Upto 1/4 of top-soil sheet erosion (er)	Minimum 60m	Moderate slow (5 -20) moderate rapid (50 - 125)	2-4	Humid climate with occasional dry spells; sub-humid crop yield frequently reduced by drought
III	sc, sic	22.5-45(d3)	3-5(C)	3-5(C)	5-10(D)	5-10(D)	3-5(C)	Upto 1/4 to 3/4	Between	Slow (1.25)	4-8	Sub-humid
	c,ls		5-10(D)			10-15(E)	5-10(D)	top-soil lost; rill erosion (e2)	6-60 m for 0.3% slope	to 5) Rapid (125-250)		Crop yield frequently reduced by drought, semi-arid
IV	c,s	7.5-22.5(d2)	10-15(E)5-10(D)	10-15(E) 15-25(F)	15-25(F) 25-33(G)	10-15(E) 15-25(F)	3/4 top - soil and upto 1/4 sub-soil lost; small gullies (e3)	-	Very slow (1.25) very rapid (25)	8-16	Semi-arid and arid	
V	Same characteristics as Class I Iand except for one or more limitations of wetness or stoniness or rockiness or adverse climatic conditions. It h as no hazard of erosion like class I land			Gullied land (c4) or sand-dunes	Marginal land (6m wide strip near gully head)		>16					
VI	7.5 or less (d1)	15-25(F)	10-15(E)	25-33(G)	33-50(H)	25-33(G) 33-50(H)		-do-	Gully sides and beds			
VII	7.5 or less (d1)	25-33(G)	15-25(F)	33-50(H)	50-100(I)	50-100(I)		Bad lands	Gully sides and abeds			
VIII	Rock	>33	>25	>50	>100	>100(J)						



Adapted from NR Conservation Service, 1997.

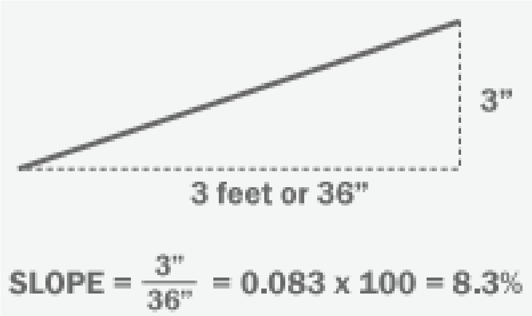
Calculating a Slope Gradient

Slope gradients are written as Y:X, where Y is a single unit in rise and X is the run. Both numbers must use the same units. For instance, if you travel 3 inches vertically and 3 feet (36 inches) horizontally, the slope would be 3:36 or 1:12. This is read as a "one in twelve slope



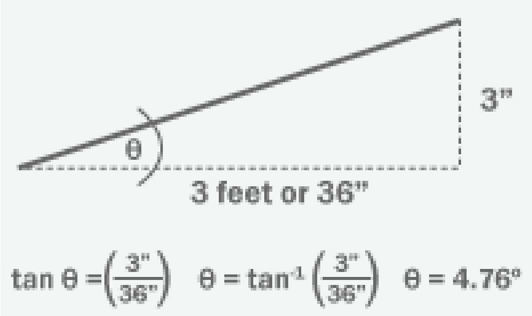
Calculating the Slope Percentage

Slope percentage is calculated in much the same way as the gradient. Convert the rise and run to the same units and then divide the rise by the run. Multiply this number by 100 and you have the percentage slope. For instance, 3" rise divided by 36" run = .083 x 100 = an 8.3% slope.



Calculating a Slope in Degrees

The most complicated way to calculate slope is in degrees and it requires a bit of high-school math. The tangent of a given angle (in degrees) is equal to the rise divided by the run. Therefore, the inverse-tangent of the rise divided by the run will give the angle.



5. Application of High Science Tools (RS, GIS and GPS) for Watershed Planning Exercise

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Introduction

Watershed management has emerged as a new paradigm for planning, development and management of land, water and biomass resources with a focus on social and environmental aspects following a participatory approach. Watershed Management is more a philosophy of comprehensive integrated approach to natural resources management. It aims at integration of social resources management with natural resource management. The approach is generally preventive, progressive, corrective and curative. Watershed management involves the judicious use of natural resources with active participation of institutions, organizations, in harmony with the ecosystem. It is a complex processes with multiple objectives and multi disciplinary multiple functions. It generates multiple benefits aggregated as productive, protective/ reclaimable, environmental, social and livelihood security, Planning plays a pivotal role in preparing Detail Project Reports and Action Plans to derive a sustainable outcome from a watershed management program.

Common Guidelines for Watershed Development Projects-2008 (Anonymous, 2008 a) emphasize use of new science and technology inputs including Remote Sensing (RS), Geographic Information System (GIS) and modeling to bring about a paradigm shift in preparing Detail Project Reports (DPRs) for implementation of the watershed development programs. Integrating and collating data from multiple sources, conventional and/or remote sensing and others, with GIS can lead to important operational applications including watershed planning. The paper presents the intricacies of planning process encompassing watershed management and use of high science tools such as GIS/RS/GPS and modeling in watershed planning and development. A centralized national watershed database system has also been discussed along with mechanism to disseminate information to watershed planners and end users.

Watershed Planning

A watershed plan recommends how watershed resources are to be protected, managed and improved, and also prescribes planning at a micro-level within the watershed. Therefore, micro-level planning requires a wide array of information and data and a variety of tools. The Common Guidelines for watershed Projects effective from April 2008 (Samra and Sharma, 2009) has emphasized; (a) clustering of small watersheds in the range of 1000-5000 ha areas to optimize transaction cost, (b) multi-tier ridge to valley planning and implementation, (c) focusing livelihoods through integrated farming systems, (d) scientific planning using new science and technology inputs including RS, GPS, GIS and modeling to bring a paradigm shift in watershed planning. To address this, greater emphasis has been laid on planning with 1 per cent allocation for DPR preparation in the Common Guidelines.

Some of the basic steps envisaged for watershed planning are (Anonymous, 2008b);

- Selection of Watershed as a manageable unit
- Bench Mark / baseline information of the region/ watershed
- Sensitizing the watershed community and existing organizations
- Participatory Rural Appraisal (PRA) to identify potential problems, perception, baseline information collection, etc.
- Institution and capacity Building & Training to facilitate decentralized planning
- Inventorying of existing watershed resources
- Preparation of a Land Capability Classification (LCC) information

- Developing an area specific Intervention/management Plan
- Implementation Plan
- Identifying and Promoting livelihood activities
- Post-execution monitoring & evaluation
- Exit plan, maintenance of watershed assets & follow-up plan to achieve sustainability

Requisite Information for Watershed Planning

Planning being an information intensive process needs to be carefully executed with collecting baseline information either from primary or secondary sources., including PRA. A major listing as follows;

A. Resource Inventory: Present Condition (Bench Mark)

- Climate
- Physiography: topography, slope, drainage
- Natural resources: Soils, geology, land use, forest, hydrology
- Animal/ livestock resources
- Socio- economic details and human resources
- Livelihood conditions

B. Status of Resource Management

- Land and crop management conditions / soil conservation practices
- Forest management (Natural / manmade)
- Water harvesting , Drainage line treatment measures
- Infrastructural facilities

Modeling in Watershed Planning Requires the Following:

- Higher resolution data at the intended watershed scale.
- Creation of spatial data base of watershed information system (WIS).
- Basic data layers used to obtain derived data layers for thematic maps; topographic (i.e., slope), soils (i.e., texture, depth, hydrologic soil groups) ,soil erosion and land degradation, etc
- Higher resolution RS data, GPS and GIS capabilities have potential in circumventing problems of conventional and time taking techniques in planning.
- Multi-data approach of integrating and collating data from conventional and/or RS & other sources with GIS now provide good opportunity for use of modeling.
- Critical area delineation using advance modeling tools (Lahlou et al., 1997) for prioritizing intervention areas.

A general approach to watershed planning is illustrated in Figure 1.

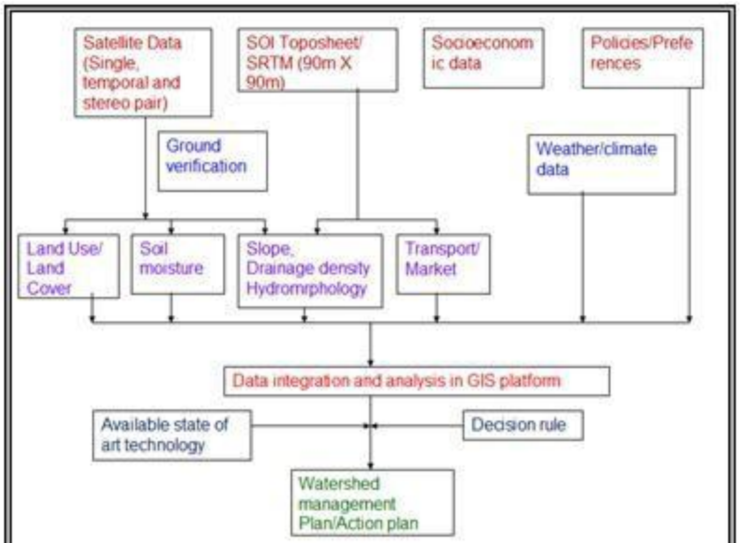


Fig.1. A schematic of Watershed management Planning process

Watershed Modelling as a Planning Tool

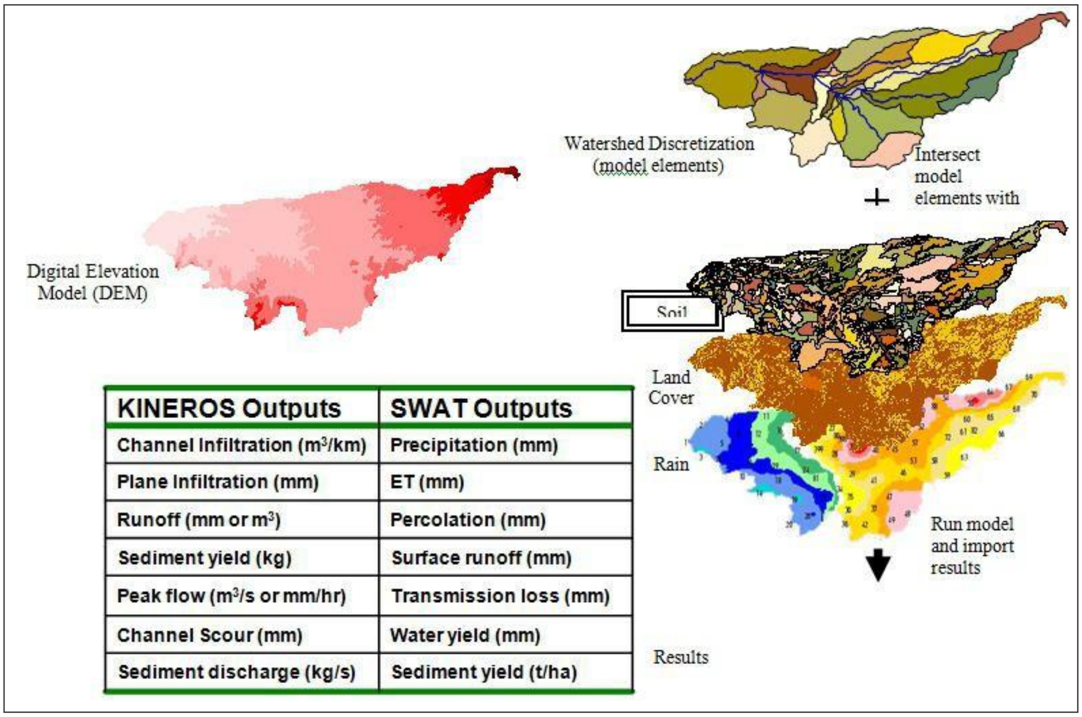
Often lack of a reliable database and scientific planning is reflected in too general strategies or prescriptions in a DPR and inappropriate selection as well as placement of interventions leading to ineffective implementation of a plan. This is attributed to various reasons such as (a) insufficient critical baseline information at the level of watershed, (b) difficulty in integration of multiple databases and their spatial manipulation, (c) lack of using scientific tools, and (d) poor capacity building at the level of the field functionaries, the actual watershed managers. Therefore, scientific planning using modern tools and techniques together with PRA has been emphasized to overcome these shortcomings (Lahlou et al., 1997). Recent advances in remote sensing, GIS based modeling and visualization capabilities coupled with the growth of Internet and the World Wide Web (Jin-Yong et al., 2005) has significantly improved analytical capabilities of landscape data in a watershed to collate the data, understand the processes and use modelling in the watershed planning. GIS application in watershed management has changed from operational support (e.g., inventory management and descriptive mapping) to prescriptive modeling and tactical or strategic decision support system.

The concept of watershed management involves holistic development of land, water, and biomass, human and animal resources for sustainable production system and livelihood improvements of the inhabitants of the watershed. Development and management of the natural resource base; soil and water, therefore remains the core of watershed planning. To manage soil and water, it is imperative to understand their relationship with the land use and transition within the confine of the hydrological boundary i.e. the watershed. Runoff estimation, soil erosion, land capability analysis are basic to planning watersheds.

Runoff can be estimated by determining land use/cover and CN for each cell or element by partitioning a watershed into parcels of land use/cover or hydrologic response units (HRUs). Each HRU or cell can be assigned curve numbers and then area weighted CN is determined for the watershed to estimate runoff by inputting rainfall data.

Identification and distribution of watershed into land capability classes (LCCs) is needed to help plan conservation measures. Data layers of soil texture, depth, drainage, and slope and erosion hazard can be used in GIS to divide watershed into LCC. This can be achieved by successive overlays of different data layers in an interactive graphic mode or writing a program or module in GIS to manipulate and automatethis process. LCC map so derived can be verified and supplemented with sample field survey including resource maps derived from PRA exercise.

Besides simple hydrologic tool of estimating runoff, process based hydrological modeling tools; offer a promising prospect to achieve this goal. GIS integrated with hydrologic models Like SWAT (Arnold et al., 1994)/ KINEROS2 (Burns et al., 2004; Semmens et al., 1994; Woolheiser et al., 1990) / PRMS/ HSPF/ AGNPS (Bingner and theurer, 2009; Chnaseng He et al., 2001) (Fig.2.). can help in estimating runoff, soil loss and sedimentation, LCC, land use planning, planning and designing of SWC interventions, assessing watershed conditions through modeling impacts of various management scenarios and identify best management practices (BMPs) as well as critical intervention areas and focusing these efforts on the targeted priority areas, instead of enforcing them uniformly in the watershed (Fig.3.).



KINEROS Outputs	SWAT Outputs
Channel Infiltration (m^3/km)	Precipitation (mm)
Plane Infiltration (mm)	ET (mm)
Runoff (mm or m^3)	Percolation (mm)
Sediment yield (kg)	Surface runoff (mm)
Peak flow (m^3/s or mm/hr)	Transmission loss (mm)
Channel Scour (mm)	Water yield (mm)
Sediment discharge (kg/s)	Sediment yield (t/ha)

Fig.2. ***Schematic of popular modeling environments SWAT and KINEROS2 to determine various watershed functions essential for watershed planning. (After Burns et al., 2004).***

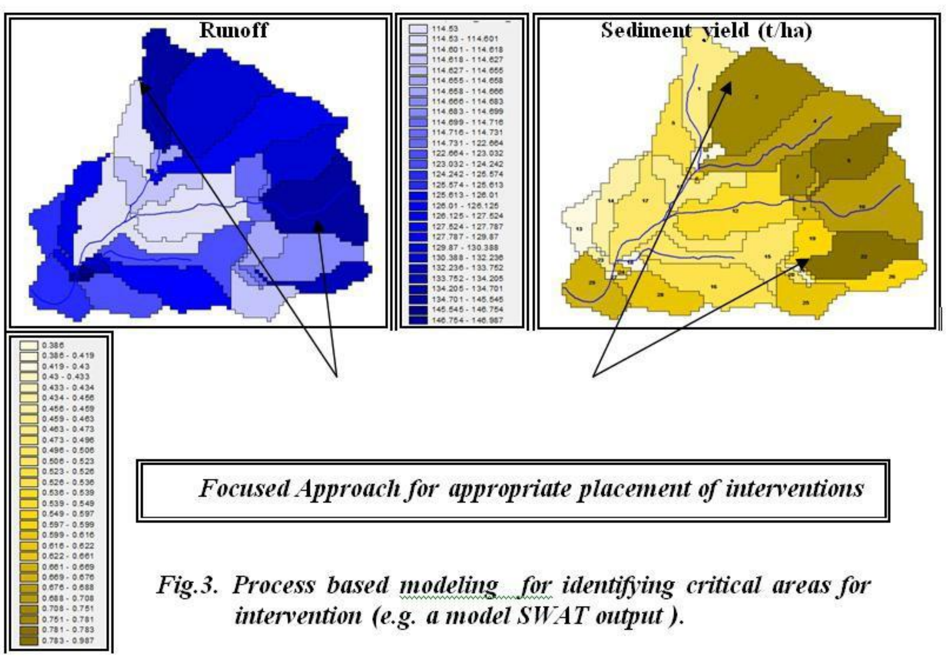


Fig.3. Process based modeling for identifying critical areas for intervention (e.g. a model SWAT output).

There is a need to prioritize critical areas needing interventions within a watershed in order to optimize investments while reasonably achieving the desired goals. Modeling provides great opportunity in this endeavor. A study conducted in CSWCRTI, Research Centre, Ooty in a Watershed (KG-4-1), using universal soil loss equation (USLE) in a distributed parametric modeling by partitioning watershed into erosion response units (ERUs), suggests that by treating only 14% of the area (where soil loss is >20 t/ha/year), 47% decrease in soil loss can be brought about and by treating 28% of the area (where soil loss is > 10 t/ha/year), nearly 68% decrease in soil loss can be obtained (Fig 4). This demonstrates the use of modeling to identify and prioritize critical intervention areas within a watershed for optimized investments. **(**Sikka and Paul, 2005**)**

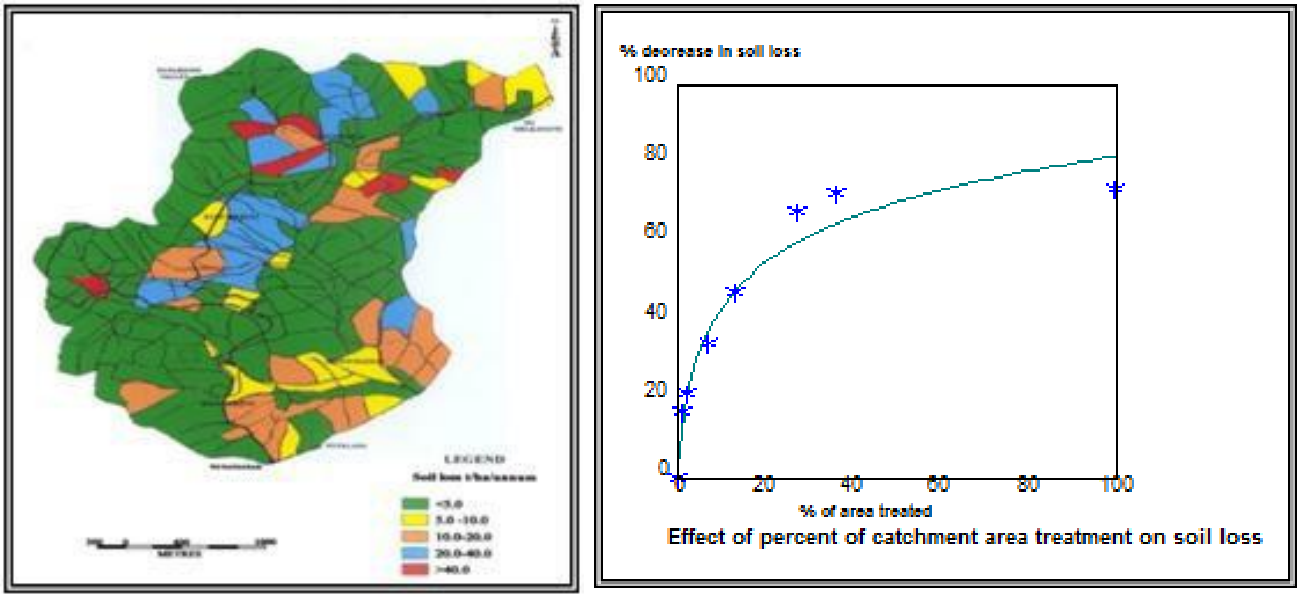


Fig.4. Partial (critical) area treatment and its effect on soil loss r in KG-4-1 watershed of Nilgiris.

Opportunities for Watershed Planning using free Resources

In the context of available resources at the watershed/local and national level, preparation of DPR in a small time span becomes difficult, as it is a time bound activity of the watershed program. Detailed survey of the watershed becomes time consuming, difficult, expensive and exhaustive. Preparation of Contour maps at the level of watershed becomes difficult. Survey of India topo sheets at the designated contour interval may not serve the purpose, especially if the watershed lies in plain areas (sometimes within the confine of watershed of interest no contour lines are available). Land use maps generated from LISS-III data also becomes costly. One of the alternatives is, therefore, to prepare those baselines quickly using GIS (open source software like Map Window, GRASS and many others) and free resources such as google earth interface (Fig.5.). CSWCRTI, Research Centre, Vasad, Gujarat has demonstrated use of google earth together with elevation data at 30 m resolution (ASTER) and 90 m resolution (SRTM) to generate useful information required for preparation of DPR for Vejalpur Rampura watershed in Gujarat (Fig.6.).

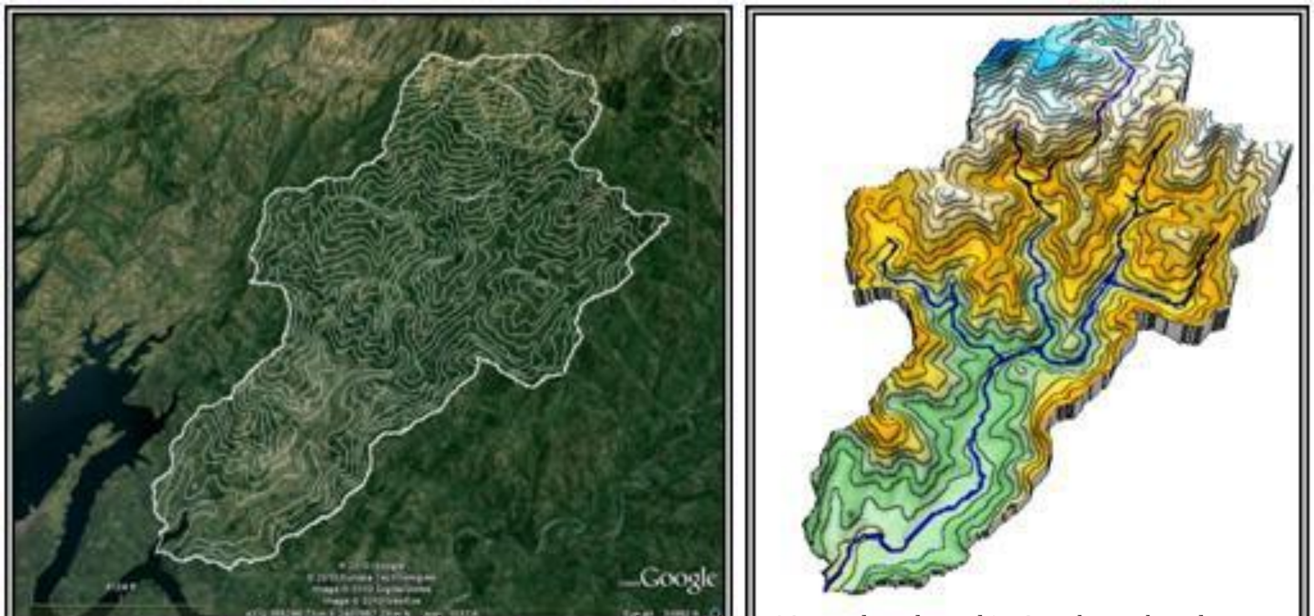


Fig.5. GIS (free open source) delineated contours derived from ASTER data draped in Google earth and a 3D DEM derived from it. (Prepared by D R Sena as an example)

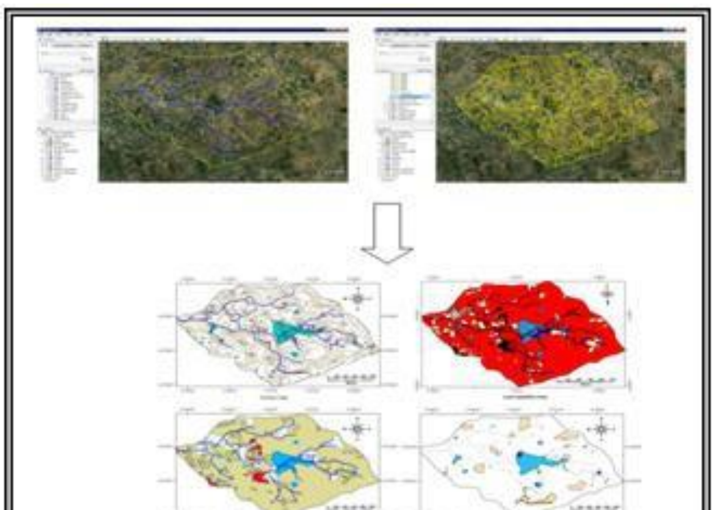


Fig 6. Google resources translated into useful baseline information for DPR preparation (CSWCRTI, 2008)

Conclusion

The core issue in watershed planning still remains the sustainable and holistic management of natural resources and its integration with production and livelihood system which affects stake holders and environment of the watershed. Scientific planning of watersheds requires use of advances in using high science tools such as GIS/RS to derive thematic and secondary information related to watershed, modeling and production/livelihood interventions. Modeling techniques integrated with GIS and mind boggling internet connectivity have vast untapped potential in watershed planning. Hydrological modeling tools need to be applied to understand the watershed functions and their transition within the confines of the hydrological boundary and plan appropriate and cost effective interventions. It is suggested to promote consortia approach evolving modular modeling framework to develop DSS and web-enabled system integrating hydrologic, agronomic and socio-economic models to GIS interface to automate or semi-automate watershed planning process. A National level watershed Information System is essentially needed to help in effective watershed planning. Promoting use of high science tools and modeling in watershed planning has to be strongly supported with carefully planned capacity building and skill development programs at different levels in the country.

6. Rain fall and Run-Off Analysis for Watershed Planning and Water budgeting, auditing and virtual water concept

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Introduction

Analysis of rainfall and runoff of a catchment is the pre-requisite for design and planning of soil and water conservation measures. Rainfall analysis implies derivation of parameters which characterize the rainfall pattern in a catchment. Hydrologic analysis of rainfall driven parameters are helpful in estimation of runoff, floods, drought and water yield. For this purpose maximum probable rainfall of different return periods are considered in safe and economic design of small and medium engineering structures.

Runoff is a rainfall driven process and depends upon bio-physical characteristics of the catchment. Runoff estimation includes its volume and peak rate of flow volume. In designing spillways and outlets or waterways, peak rate of runoff is required while for assessing the storage in earthen dam, tanks and ponds etc. the estimates of runoff volumes are required. Another important variable of interest in drainage line treatment is the flow velocity that is required for determining scour pattern in the river bed and along the banks. In this way, various characteristic parameters of Runoff are required for the design of soil and water conservation structures.

In treatment of drainage channels, mostly, surface runoff component of the total water yield of a catchment is considered. In this chapter, the most common methods of runoff computation are discussed.

Rainfall Analysis

Rainfall data in a specific area is analyzed with a view to derive such parameters that can be used in design of engineering structures. One of the most important parameter of interest is intensity of rainfall, usually expressed in millimeters per hour (mm/h). The amount of runoff is determined by the rainfall intensity, duration and amount. Very intense storms are not necessarily more frequent though these storms cause most erosion damage and floods. The design criteria, therefore, accounts for such infrequent, high intensity storms. The capacity of runoff conveyance system is based on a certain depth of rainfall expected during selected period of time. The concept of time is reflected in a statistical term called 'the return period', that gives an estimate of the probable high intensity storm which can occur in an area within a specified time.

Return period

The return period, sometimes called recurrence interval, is defined as the period of time within which the depth of rainfall for a given duration is expected to be equalled or exceeded atleast once. The probability of occurrence of an event and return period are related as

$$T = p/100$$

where, T is the return period, and **p** is the probability of occurrence of an event.

Recommended return periods for various types of structures are given in Table 1.

Table 1 Design return period for various types of structures

Type of structure	Return period, years
Storage and diversion dams having permanent spillways	50-100
Earth fill dams-storage having natural spillway	25-50
Stock water dams	
Small masonry gully control structures	25
Terrace outlets and vegetated waterways	10-15
Field diversions	10
	15

Intensity, Duration and Frequency Relationship

In order to find the design intensity for a particular location or region, intensity-duration-frequency relationships have been developed. A general expression for rainfall intensity is given as

$$I = \frac{kT^x}{(t+a)^b}$$

where, **I** is rainfall intensity (cm/h), **T** is return period (year), **t** is rainfall duration (hour), **K,x,a,b** are the constants for a specific location.

Ram Babu et al. (1979) have analyzed the rainfall for various stations and found the values of these constants. Some of the representative equations are given as follows.

Northern Zone

Agra 6293.01667.0)25.0(911.4+ξ=−tTi

Jodhpur 0369.11667.0)5.0(098.4+ξ=−tTi

Allahabad 0190.11692.0)5.0(570.8+ξ=−tTi

Lucknow 0331.11813.0)5.0(074.6+ξ=tTi

Amritsar 2962.11304.0)4.1(41.14+ξ=tTi

New Delhi 1072.11574.0)5.0(208.5+ξ=tTi

Dehradun 8000.02200.0)5.0(00.6+ξ=tTi

Srinagar 0636.12730.0)25.0(503.1+ξ=tTi

Jaipur 1172.11025.0)5.0(219.6+ξ=tTi

N. Zone 0127.11623.0)5.0(914.5+ξ=tTi

These equations should be used for areas having similar rainfall characteristics if sufficient data are not available for that particular location

Runoff Computation

There are number of methods and empirical formulae to estimate runoff. For design of structures, normally information on peak rate of runoff, volume of runoff and velocity of flow are required. The methods described as follows are used for small watersheds.

Rational Method

This method is used for the estimation of **peak rate of runoff**. It is expressed as

$$q_p = CiA/360$$

Where, q_p = peak discharge in m^3/s

C = Runoff coefficient

i = design intensity for a particular return period and duration equal to time of concentration, mm/h

A = area of the watershed, ha

<u>Discussion on Parameters</u>

Runoff Coefficient, C

C is affected by many factors. However, in the formulation of Rational method, the cover condition and design intensity are the main governing factors for the variation in C. For the parameterization of C, four hydrologic soil groups are defined (Table 2). The lumped value of C is tabulated for the soil group B (Table 3). For other soil groups the conversion factors are tabulated (Table 4). The conversion factors should be multiplied to the value of C for soil group B to get the C for other soil groups.

Table 2 Hydrologic soil groups

Soil group	Description	Final infiltration rate, mm/h
A	Lowest runoff potential, deep sand with little silt and clay	8-12
B	Moderate low runoff potential, sandy soils less deep Moderate high runoff potential, shallow soils, contains clay	4-8
C	Highest runoff potential, mostly clay and also shallow soils with impermeable sub-horizon	1-4
D		<1

Table 3 Runoff Coefficient, C for soil group B

Cover	C		
	25 mm/h	100 mm/h	200 mm/h
Row crop, poor practice	.63	.65	.66
Row crop, good practice	.47	.56	.62
Small grain, poor practice	.38	.38	.38
Small grain, good practice	.18	.21	.22
Good rotation	.29	.36	.39
Pasture, good	.02	.17	.23
Woodland, good	.02	.10	.15

Table 4 Hydrologic soil groups conversion factors

Cover	Conversion factor form group B		
	A	C	D
Row crop, poor practice	.89	1.09	1.12
Row crop, good practice	.86	1.09	1.14
Small grain, poor practice	.86	1.11	1.16
Small grain, good practice	.84	1.11	1.16
Good rotation	.81	1.13	1.18
Pasture, good	.64	1.21	1.31
Woodland, good	.45	1.27	1.40

Design intensity

Peak rate of runoff is estimated for a particular design intensity. The return period for *i* should be the same for which the structure is to be designed. For this intensity-duration-frequency relationship for a particular place is used. The duration is taken as equal to the time of concentration (t_c). t_c depends upon watershed topography and is defined as the maximum time taken by the flow to reach the watershed outlet. Generally, it is calculated by using Kirpich formula

$$t_c = 0.0195 x L^{0.77} S^{-0.385}$$

where, L is the maximum flow length, m

and S is the average gradient of channel, and is the ratio of difference in elevation of remotest point and outlet to L

$$S = \frac{\text{(elevation of remotest point - elev. of outlet)}}{L}$$

Procedure for using Rational Formula

1. Determine the area under various land uses and soil groups (A1, A2,. ..)
2. Determine the t_c
3. Determine the 1-h intensity for a given location from the maps (Fig. 1) or with following formula.

$$I_0 = \frac{P}{2}(1+1/T)$$

where, P is the amount of rainfall from the most severest storm and T is its duration.

4. Convert 1-h intensity for design frequency for duration equal to time of concentration from Fig 2. or with the following equation.

$$I_{tc} = \frac{2I_0}{t_c+1}$$

5. Determine the value of C from the table for each land use cover, soil group and design intensity.
6. Compute weighted C

$$C = \frac{A_1C_1 + A_2C_2 + ...+ A_nC_n}{A}$$

7. Compute the peak rate of runoff by using Rational formula.

Example

Estimate the peak rate of runoff expected to occur once in 25 years from 50 ha watershed located at 76° long and 25° lat with sandy loam soil. The land use is 20 ha of agricultural land, 15 ha of good grass land, and 15 ha of good forest land. The difference in elevation between highest point and outlet is 20m and maximum length of flow is 1200 m. The average slope is 3%.

$t_c = 0.37$ h

$i_{1-h} = 100$ mm/h for long 76 and lat° 25° from Fig. 1

$i_{tc} = 166$ mm/h from Fig. 2

C = (20x.36+15x.17+15x.1)/50 = 0.22

q_p = CiA/360 = 0.22 x 166 x 50 = 5.07 m^3/s

Discussion:

Using North Zone equation for i, i_{tc} = 114.8 mm/h and q_p = 3.5 cumecs, therefore estimation of i_{tc} is important for the reasonable estimation by the Rational method.

Curve Number Method

It is often required to predict **total runoff volume** that a watershed may yield during a design flood. Total volume is required in the design of flood control or water storage reservoirs.

$$Q = \frac{(P-0.2S)^2}{P+0.8S}$$

where, Q = direct runoff, mm

P = storm rainfall, mm

S = a parameter for surface retention

The parameter S is defined as

$$S = \frac{25400}{N} - 254$$

where, N = an arbitrary curve number varying from 0 to 100

The amount of rainfall (P) is also affected by duration. For design considerations, maximum runoff volume is required. It is established that minimum storm duration for flood estimation can be taken as 6 hours. But in certain conditions design rainfall for greater durations can also be taken. The 6-h rainfall for various return periods over India is given in Fig. 2

Antecedent Rainfall Conditions are explained in Table 5. The curve number N for Antecedent Rainfall Condition II are given in Table 7.

Procedure for Using SCS Curve Number Method

1.Divide the watershed area into uniform hydrologic soil cover groups.
2.Find out the antecedent moisture condition (AMC) based on 5 days total rainfall in previous days.
3.Find out the CN for each soil group from Table
4.Determine weighted curve number

$$CN = \frac{CN1xA1+CN2xA2+...+CNnxAn}{A1+A2+...+An}$$

5. If applicable, convert CN for the AMC II to other AMC from conversion factors given in Table 6.
6. Compute S
7. Compute direct runoff using the equation.

Example

Determine the estimated maximum volume of runoff for a 25-yr return period that may be expected from the watershed of example 1. Assume that antecedent moisture 5 days prior to storm was 40 mm of rainfall. Take critical duration of the storm as 6 hours.

Area (ha)	Soil group	land use	N	NA
20	B	Agriculture	72	1,440.00
15	B	Pasture good	61	915.00
15	B	Forest good	55	825.00
			Total	3,180.00

weighted curve number, N = 3180/50 = 63.60

S = 25400/63.6 - 254 = 145.37

$Q = (170-.2 \times 145.37)^2/(170+.8 \times 145.37)$

= 68.68 mm

$= 50*10000*68.68/1000 = 34340.00\ m^3$

= 34340/10000 = 3.434 ha-m

Table 5 Antecedent Rainfall Conditions

Condition	Description	5-day Antecedent Rainfall, mm
I	Low moisture condition, wilting point to dry	< 36
II	Average conditions	36-53
III	Wet moisture conditions, heavy rainfall prior to the day under consideration	> 53

Table 6 Factors to convert N for condition II to other conditions

Curve number for condition II	Factors to convert Curve Number for condition II to	
	condition I	Condition III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

Table 7 Curve Numbers for Antecedent Rainfall Condition II

Landuse or cover	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crop	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	68	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
Close-seeded	Terraced	Good	59	70	78	81
legumes or	Straight row	Poor	66	77	85	89
rotation	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85

Pasture or range	Contoured	Good		55	69	78	83
	Terraced	Poor		63	73	80	83
	Terraced	Good		51	67	76	80
		Poor	62	68	79	86	89
		Fair		49	69	79	84
Woodlots		Good		39	61	74	80
	Contoured	Poor		47	67	81	88
	Contoured	Fair		25	59	75	83
Roads	Contoured	Good		6	35	70	79
		Poor		45	66	77	83
		Fair		36	60	73	79
		Good		25	55	70	77
				74	84	90	92

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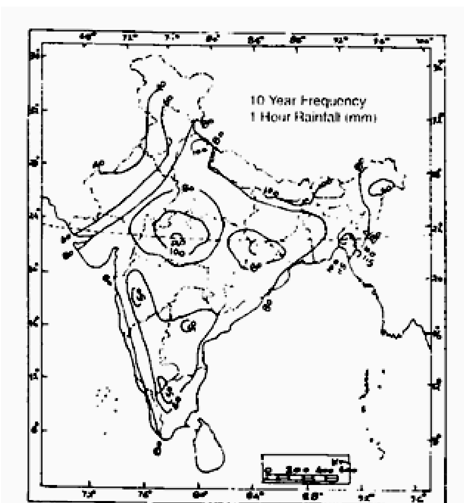

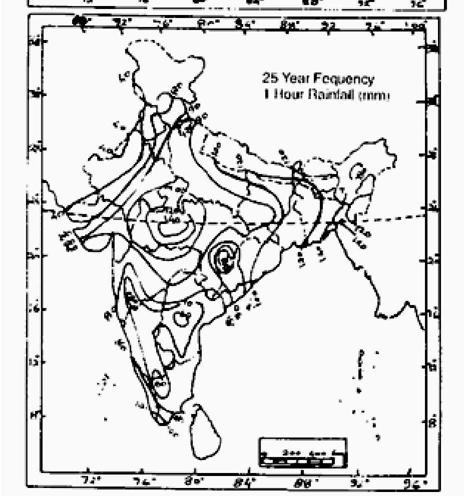

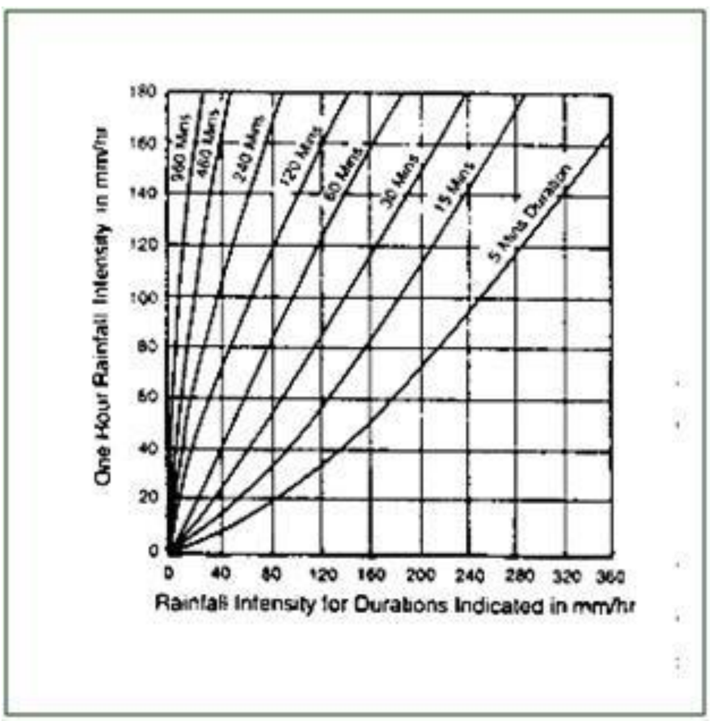

return periods (a) and relation of 1-hr intensity to intensity of other durations

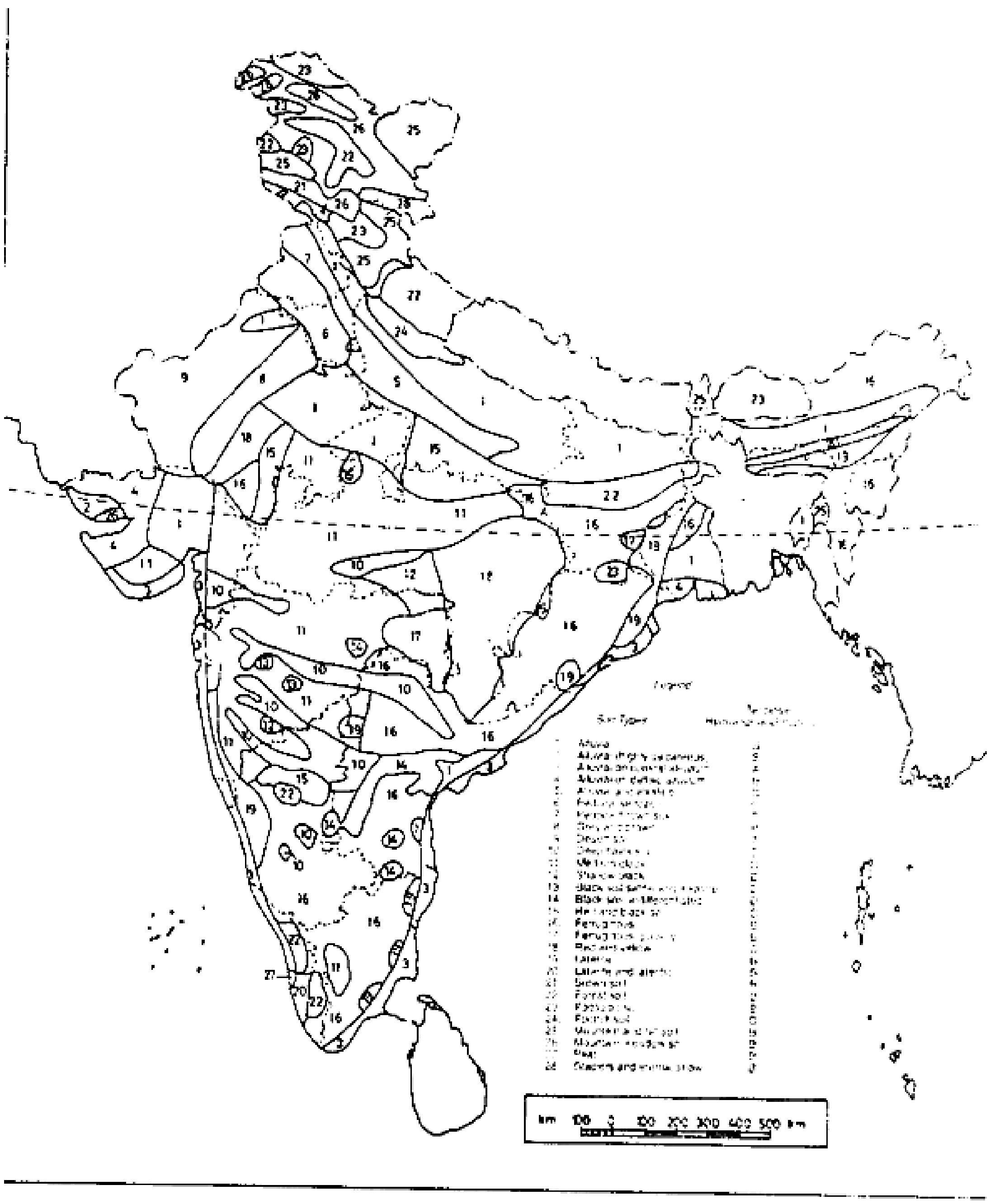

Fig. 2 Hydrologic soil groups map of India

7. Recent Advances in Vegetative Measures for Natural Resources Management

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Out of 140 m ha agriculture land in India, about 80 m ha (58%) is subjected to severe erosion. Erosion on agriculture land is primarily due to splashing of soil particle caused by impact of rain drops and due to runoff water. Vegetative cover of land plays vital role in minimizing soil erosion and runoff. Vegetative barrier technology could be nature's gift for marginal and small farmers in a major part of the country, since it is economical to establish, easy to maintain, provide direct benefits like fuel, fodder, fiber and thatching material. In Punjab many farmers have begun to use *Eulaliopsis binata* and *Saccharum Spontanium* on their field boundaries to serves demarcation material and fodder resources. It is rightly believed by these farmers that these grasses strengthen the bunds and prevent them from being breached during the monsoon when overland flows are quite high.

The other favorable consideration of vegetative measures for soil and water conservation purpose is that it provides for much needed biomass for meeting day to day needs of the rural communities in various socio-cultural and ecological regions. The National Watershed Development project for Rainfed Agriculture (NWDPRA) which is currently in operation in 2500 small pilot watersheds relies mainly on low cost vegetative measures for erosion control and in- situ moisture conservation both in arable and non-arable lands.

The Internationally aided programs, such as, Himalayan Watershed Development project in Uttar Pradesh. Pilot Watershed Development project in rainfed areas in the State of Karnataka, M.P. and Maharashtra have also laid lot of emphasis on vegetative measures. Although the vegetative measures are relatively cheaper, eco-friendly and pro-farmer, their use to minimize erosion by water requires certain conditions to be met. These include general improvement of cover and infiltration, safe transport of occasionally high volumes of water along contour bunds, waterways chutes and spilway, and stabilization of disturbed sites, such as, road side slips, canals and dam walls etc. People have started appreciating that vegetative strips on contour provide an effective filtering mechanism and reduce runoff, soil loss and help in the formation of natural terraces.

India is loosing 5336 mt. Soil, 18 bm^3 water and 10 mt plant nutrients every year in the form of water erosion. The sediment is always rich in nutrients as compared to soil of the field. The enrichment ratio varies from 1.5 to 2.5 Khybri et.al (1982) created artificial erosion by removing surface soil upto different depths in deep fertile alluvial soil of Doon Valley to evaluate erosion losses as given below:

Top soil removal and crop yield:

Top soil removal (cm)	Yield (kg/ha	
	Maize	**Wheat**
0	3576	5112
5	2883	4743
10	2440	4635
15	2161	4622
30	1490	4336

(Source: Bhardwaj, 2001)

Trees, shrubs and grass barriers are known to be beneficial for soil and water conservation have many relative advantages over structural interventions. Reinforcement by live roots which bind soil particles and underground decomposed biomass provides stability to aggregated soil. Plant detritus on the soil surface acts as a cushion for dissipating kinetic energy of rain drops. This above grand biomass upon its subsequent decomposition also add to the soil humus and increases infiltration, soil water holding capacity as well as stability of aggregates (Prakash *et al*, 1999).

The vegetative measures can be classified into two major groups:

i) Vegetative measures for arable lands.

1. Grassed contour barriers
2. Grassed water ways or grassed disposal drain
3. Agroforestsry
   - i) Agri-silviculature
   - ii) Silvi-pastoral
   - iii) Agri-silvipastoral
   - iv) Horti-silviculture
   - v) Multi purposes production system
   - vi) Boundary plantation

ii) Vegetative measures for non-arable lands.

4. Afforestation and reforestation
5. Social forestry
6. Silvi-pastoral
7. Pasture development
8. Leguminous pasture development
9. Farm and range plants
10. Meadow grasses
11. Brushwood dames
12. Stream training
13. Wattling
14. Mulching

Grasses as vegetative measures on arable lands.

Grass species have tremendous potential in soil and water conservation. The importance and selection of suitable grass species for use as live hedge was emphasized by Mullen (1939). Grass roots have a great binding influence on soil particles. Grasses improves soil structure, its biological activity and production capacity. According to Mandal (1955), grasses increased the effective organic matter of the soil, chiefly by their rapid root growth, large number of fine roots and high root biomass turnover rate.

Characteristics of vegetative barriers:

Grasses have several relative advantages for establishing vegetative barriers. They establish quickly, grow rapidly and develop fibrous root system to provide binding of soil particles. Profuse tillering habit facilitates quicker formation of a dense clump of shoots and moderates the surface flow. The choice of bushy shrubs and grasses in relation to habitat is of great importance in the formation of vegetative barriers which are being used alone or with mechanical measures on gentle slopes for erosion control (Annexure-1).

Bhardwaj (1996) reported the performance of three grass species at Dehradun (Table-1). It was concluded that the trend and performance of the three grass species was more or less similar. *Panium maximum* was more effective in the first four years after planting and after that *vetiver* performed better. In view of the necessity of having an effective barrier, *Panicum* maximum has an advantage due to its higher average tiller diameter and clump diameter.

Table 1 : Yield of grass and their attributes (7 years av.)

Particular	Guinea grass	Bhabar grass	Khus grass
Yield kg/ha (day)	1540	542	1090
Av. Height n cm	260	123	228
No. of tillers/clump	35	110	35
Av. Tiller diameter (cm)	0.76	0.25	0.58
No. of leaves/tiller	6.72	5.07	6.01
Clump diameter (cm)	17.5	17.50	16.5
No. of clurnp/m length/m	10.3	8.80	10.7
Survival (%)	79.3	67.2	82.00
Total tiller diameter (m) length	2.76	2.48	2.12
Total clump diameter (m)/m length	1.80	1.49	1.76

Grassed contour barriers:

Vegetative barriers established on contour are expected to perform as erosion diminishing mechanism with the farming system and also provide other products like fodder, fibre, industrial raw material, green manure, etc. The main soil conservation functions of these contour vegetative barriers are:

i) To break the slope length, reduce runoff velocity and increase infiltration opportunity time;
ii) Reduce the erosivity and transport capacity of runoff;
iii) Cause the deposition of erosion products, trap nutrients and induce terracing;
iv) Cause cultivation and planning operations to be carried out on contours; and
v) Stabilize contour cultivation areas on steeper slopes.

Grassed waterways:

Grassed waterways and outlets are natural or constructed waterways shaped to required dimensions and vegetated for safe disposal of runoff from a field, diversion terrace or other structures. The performance of different grass species in a grassed water way at Dehradun was evaluated by Dalai et.al (1965) where they concluded that *Pancium* repense was the best choice for this region than *Brachiaria mutica*, *cynodon plectostachyus*, *cynodon dactylon*, *paspalum notatum*, *Urochloa pullulans urochloa mosambicensis*, and *Chloris gagana grasses.*

Trees for erosion control in Arable lands:

Arable lands are more vulnerable to soil erosion as compared to forest and pastures having permanent vegetation with no or little disturbance to soil. The farm holdings are small and the farmers' first consideration is to grow food thus he can not afford to sacrifice crop yield to tree growth. Therefore, fast growing trees of economic importance can be introduced in cropped area on farm lands in form of agroforestary systems for erosion control. The species selection for agroforestry depends upon its establishment, survival, growth, ability to withstand in adverse conditions, compatibility with crops, age rotation, yield and market value for the produces. In general, choice of species depends upon biophysical and social factors more than on economic ones.

Selection of tress: While selecting MPTs for agroforestry systems, only such species should be introduced which show proper growth, with ability to increase productivity of site (Annexure -1). A good multipurpose tree species should have following attributes:

1. Fast growing and ability to produce more than one produce in form of firewood, timber, fodder, green manure on sustainable basis.
2. Minimum competition should be between crops and multi purpose trees species.
3. Well suited to the climate and soil conditions of the area.
4. Hardy, resistant, and should have erosion control characteristics.
5. MPTs having ability to fix nitrogen in addition to other productive benefits.
6. Are of social and economic values to local population and serve their requirements in terms of fuel fodder and MFPs.

Agroforestry for erosion control:

Agroforestry plays a vital role in reducing erosion, runoff and wind velocity, high evaporative conditions, flood hazard, siltation etc. in augmenting infiltration rate and ground water recharge and in improving soil fertility status. Availability of fuelwood in large quantity resulting from agroforestry will divert dung manure from hearth to the field and will, thus lead to increase agriculture production.

Agroforestry is a form of land use that successfully satisfies the needs of the crop farmers, foresters and/or stock farmers.

Multipurpose tree planting in agriculture fields:

A less systematic form of tree growing on farm lands in traditionally practiced almost everywhere in the sub-continent. The approach and uses for tree planting in un -irrigated semi-arid and arid areas is different to irrigated and humid areas. In order to meet the objectives and demands, the agroforestry system will have the following well recognized approaches/ systems.

1. Agri-silviculture Agriculture crop (and fodder crops)+fuel/fodder tree species.
2. Silvipastoral Rearing of animal+fuel/fodder tree and grass/forage species
3. Agri-silvipstoral Agriculture crops + fuel/fodder tree and forage + rearing of animals i.e. (1 & 2).
4. Horti-silviculture Fruit vegetable crops + fuel/fodder tree species.
5. Multipurpose production system Minor forest produce (medicinal plants+fuel/fodder tree species)
6. Boundary plantations MPTs on farm bunds and boundaries.

Other vegetative measures for erosion control:

i) Crop Geometry:

Crop geometry can also be oriented in such a way that erosion permitting crops or tree rows acts as barrier (bund) to reduce soil loss. Bhardwaj *et.al* (1988) found reduction in erosion losses by reducing the intra raw spacing on contour of corn plants, keeping the plant population same on 4% slope. The yield of crop was almost equal. The closer planting in the row created more effective barrier to obstruct the flow of runoff and to arrest the sediment.

ii) Live mulch and weed management:

The weeds are most effective in reducing the erosion. Bhardwaj (1998 and 1999) found that planting of corn row at 90x20 cm and weeding of 30 cm strip along the row can reduce the erosion and cost on weeding on 4% slope. When ploughed under, they supply lot of organic matter and nutrients to increase soil fertility. The weeds as a mulch can be used in three different forms namely I) live mulch, ii) surface mulch, iii) soil mulch.

iii) Bunding and strip cropping:

In a study, the effect of strip cropping and bunding on 4% runoff plots for three year was observed that both the treatments reduced runoff slightly and soil loss appreciably (18 to 11 t/ha) while performance of corn was same in all treatments (Bhardwaj, 1994). The live bunds are more effective than other practices.

iv) Hedge row (live bund)

In a long term study in Doon Valley has proved beyond bout that grasses are very effective for erosion control as compared to other measures and performance of vetiver is better especially after fourth year as compared to other two grasses Guinea and Bhabar of the locality. (Bhardwaj 1998) *Khus grass (Veteveria zizenoids) Bhabar II (Eulaliopsis binata) Gunea II (Panicum maximum).*

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Annexure -1

Grasses with potential use as vegetative barriers in different agro-ecological regions:

Andropogon gayanus, Bothriochloa pertusa, Brachiaria mutica, Brachiaria decumbens, Cenchrus pennisetiformis, Cenchrus pennisetiformis, Cenchrus ciliaris, Cenchrus setigerus, Chloris gayana, Chrysopogon fulvus, Cynodon dactylon, Dichanathium annulatum, Digitaria decumbens, Diplanche fusca, Heteropogon contortus, Imperata cylindrical, Lasirus sindicus, Iseilema laxum, Panicum antidotale, Panicum coloratum, Panicum maximum, Panicum repens, Panicum turgidum, Paspalum dilatatum, Paspalum nototum, Saccharum spontaneum, Sehima nervosum, Setaria sphacelata, Vetiveria zizanioides

Important multipurpose trees for different agro-climatic zones:

a. **Temperate Zone:** *Acacia mearnsii, Acer ceasium, Aesculus indica, Alnus nepalensis, Celtis australlis, Eucalyptus globules, Fraxinus, Floribunda, Olea cuspidate, Populus spp., Quercus spp., Robina pseudoacacia*

b. **Moist temperate zone:** Acer compbellii, Acer ceasium, Alnus nitida Robinia pseudoacacia

c. **Dry sub-tropical zone:** Acacia modesta, Albizia lebbeck, Albizia procera, Annogeissus latifolia, Azadirachta indica, Bauhinia purpurea, Dalbergia sissoo, Dendrocalamus strictus,

d. **Moist sub-tropical zone:** Alnus nitida, Anogeissus latifolia, Bauhinia purpurea,Emblica officinalis, Grewia optiva, Grewillea robusta,

e. **Dry tropical zone:** Acacia auriculiformis, Acacia catechu, Acacia nilotica, Acacia Senegal, Acacia tortilis, Ailanthus excelsa, Albizia lebbeck, Azadirachta indica, Cassia siamea, Dendrocalamus strictus,

8. Conservation Agronomy & Its Role in Integrated Watershed Management

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Introduction

Land is an important natural resource as it not only medium for plant growth but also acts as a store for water and nutrients. This land suffers maximum for soil losses and water losses, as it is cultivated very frequently for the growth of various types of crops and very often remains exposed to rain and wind which results in accelerated erosion. Soil erosion reduces the depth of soil where it takes place thus reducing the soil moisture storage and feeding zone of crops. It also simultaneously depletes a soil nutrient thus restricting the choice of crops to be grown and reduction in production in the long run. Even if basic erosion control measures like contour bunds, graded bunds are adopted, though soil and water conservation is achieved *per se*; soil erosion process continuous in the bunded area resulting into movement if soil and runoff from upstream to downstream. This can be considerably prevented by adoption of conservation agronomy practices. Soil conservation agronomic practices help to intercept raindrops and reduce the splash effects, help in better intake of water rate in soil by improvement in soil organic matter content and soil structure; help in retarding and reducing overland flow of runoff through the crop geometry, dense growing crops intercropping mixed cropping, strip cropping etc.

Contour Cultivation

The practice of up and down method of cultivation in many parts of the country is one of the causes of encouraging man made erosion. On steep slopes, this practice enables rain water to gain velocity, facilitating runoff water to erode soil. Thus the upper layer of the fertile soil is washed away. Contour farming is a system of crop husbandry in which all cultivation operations are done on contour e.g. preparatory tillage, sowing, inter-culture etc. water loss and soil erosion are reduced by contour farming.

Objectives

In regions of low rainfall, the primary objective of contour farming is to provide the greatest possible conservation of rain water, in humid regions on the other hand, the primary purpose is to reduce soil loss by water erosion, although water conservation is also highly important. The objectives in both cases are practically to reduce soil erosion and conserve moisture.

Purpose of contour farming is to place rows and tillage lines at right angles to the normal flow of surface. The resistance developed by the crop rows and by furrows, between the ridges, to the water flow thus, reduces runoff velocity and gives more time to water to infiltrate in to the soil.

Contour tillage operations thus hold part of the rain water and store it *in situ*, thus reducing runoff and soil erosion and bring about a more uniform distribution of water received through rainfall. Contour farming, in addition to reducing soil loss and increasing yields, saves on fuel in case of mechanized farming and cuts down wear and tear on machinery. The saving in fuel costs is approximately10 per cent on lands with 8 per cent slope. In case of cultivation by bullocks it is convenient and less exhausting on the animals and ploughman when working on the contour as against up and down soil slopes. Study at Dehradun show that up and down cultivation of maize gave the maximum soil loss of 28.5 tones/ha, which was reduced to 19.3 tones/ha due to contour cultivation of maize. Grass gave the leastrunoff and soil loss and cultivated fallow gave the maximum soil loss (Table 1).

Table1. Soil and water loss on 8 per cent slope under different cropping systems at Dehradun

Treatment	Rainfall (mm) (June-October)	Water loss (mm)	Water loss as % of rainfall	Soil loss (tones/ha)
(Average of 4 years, 1960-63) (8 per cent slope - Dhulkot silty clay loam)				
Up and down cultivation maize – wheat*	1.239	670	54.1	28.5
Contour cultivation maize + cowpea – wheat**	1.239	511	41.2	19.3
Cowpea – wheat	1.239	405	32.7	28.3
Giant star grass	1.239	31	2.5	1.3
Cultivated fallow	1.239	445	35.9	44.0

*Only farmyard manure applied.
** Farmyard manure and fertilizers applied.

Use of Cover Crops

Erosion from cultivated fields can be reduced if the land has enough crop canopy during the peak season. Good ground cover canopy gives protection to the land like an umbrella. Study at Dehradun show the canopy and root development of different legumes crops (Table 2).

Table2. Canopy and root development of different legumes at Dehradun

Treatment	Average canopy per cent 45 days after sowing		Average root wt (g) 65 days after sowing in 30 cm soil cubes	
	P_0	P_1	P_0	P_1
Cowpeas	90.6	89.9	4.09	3.61
Soyabean	21.2	19.5	2.30	1.64
Dhaincha	62.4	62.7	4.95	4.09
Sannhemp	48.7	45.4	3.38	4.70
Groundnut	49.2	59.0	1.71	1.86
Mung	67.3	73.2	4.67	4.39
Urd	66.7	58.2	2.33	2.40
Kulthi	18.6	27.9	1.98	1.72
Dolichos	23.3	63.8	1.40	0.77
Velvet bean	39.0	20.6	1.35	3.50
French bean	8.4	5.6	1.90	3.20
Moth	47.3	25.6	1.81	2.02

Cover crop is a close growing crop raised mainly for protection and maintenance of soil. Effectiveness of the cover crop depends on close spacing and development of good canopy for interception of rain drops so as to expose minimum soil surface for erosion.

Function of Plant Cover in Water Erosion Control

Major role of plant cover is to protect the soil from the force of falling raindrops. Raindrop impact is the primary cause of erosion on cultivated land. The raindrops have energy. They scribe the bare soil, and dislodge particles from the soil mass. These soil particles get lost through runoff.

Plant cover controls splash erosion by intercepting the raindrops and absorbing their kinetic energy.

It also protects the infiltration capacity of the soil on bare land, the beating action of rain drops break down clods and soil aggregates and form a tight layer at the surface. This sharply reduces the infiltration capacity of the soil and increases runoff. Plant cover prevents the formation of this tight surface layer.

To follow efficient cropping practices is of primary importance in preventing the effect of beating rain drops on breaking down of soil and increasing crop production. Use of legumes is the cheapest soil conservation measures to combat soil fertility losses. Study conducted on canopy produced by crops and splash erosion have shown that there is significant correlation between these two parameters higher the canopy, lesser is the splash. Thus, with good ground cover, erosion is minimized. Results show that legumes provide better cover and better protection to land against erosion as compared to open tilled crops. This has also been observed in the studies at various places. Among the legumes cowpea has been found to produce maximum canopy, followed by moong, urd and dhaincha at Dehradun.

The effectiveness of any cropping system in reducing soil and water losses depends largely upon the proportion of close growing vegetation used and the length of time and season of the year when it occupies the land. Crops that provide protective cover during the months of erosion – producing rains are especially valuable for conserving soil and water. Crops selected should not only produce good canopy but should be also of economic value to the farmers. Pulse crops, are generally suitable for such purposes.

Sowing of crops need to be done as early as possible during *kharif* season. Little delay in sowing has adverse effect on crop growth and canopy development, which is reflected in splash erosion. Sowing of crops should be done at the earliest opportunity during rainy season, both from protection and production points of view. Advantages of cover crops are:

- Protect soil from direct impact of rain and wind and thus prevents erosion.
- Resist flow of waters retard the velocity, reduces runoff and similarly reduces wind velocity on ground surface and reduces erosion in both cases.
- Improves sowing tilth by adding organic matter and by deep root system.
- Absorb available nutrients, especially if nitrates, and thus prevent their leaching. When cover crop is ploughed in it decomposes and nutrients which are released available for crops.
- May be used as off season pasture.
- Increases infiltration and water holding capacity of soils by addition of organic matter and by the action of deep root system which on decay provides channels for water intake.

Helps to maintain organic matter.

Nitrogen Fixation by Legumes Crops

Introduction of short duration pulse crops in rotation may be helpful in reducing the nitrogen requirement of cereals. The symbiotic genus rhizobium, commonly associated with the leguminosae, has been recognized for its contribution to the nitrogen fixed by legumes in the growing season which varies widely from a few Kg to 200-300 kg or even more (Berseem etc.). The shortage of fertilizer, thus, could be to some extent taken care of by the residual nitrogen left in the soil.

A large part of the nitrogen fixed is utilized by the plant for its growth and development of grains. A fairly good amount of nitrogen is also released to the soil which is made available to the succeeding crop.

Legume fixation of N is at a maximum only when the level of available soil N is at a minimum. It is generally advisable to include a small amount of N in the fertilizer of agricultural legume crops at planting time to ensure that the young seedlings will have an adequate supply until rhizobia get established on their roots. Large or continued application of nitrogen, however, reduces the activity of the rhizobia and therefore is generally uneconomic.

Strip Cropping

Crops behave differently in their capacities to produce vegetative cover and root development and consequently affect splash erosion, runoff and soil loss. Legumes, in general, as they produce good cover, are erosion resisting whereas open tilled crops like maize, cotton are erosion permitting. In order to produce minimum erosion from the field, farmers need satisfy his food requirements and at the same time produce minimum erosion. Strip cropping is the system, which meets such requirement.

Strip cropping is a system under which ordinary farm crops are planted in relatively narrow strips, across the slope of the land and so arranged that the strips of erosion permitting crops are always separated by strips of close growing or erosion resisting crops (Table 3).

Table3. Yield of maize and Soybean under difference crop mixture (Av. 4 years)

	No. of maize rows			**No. of soybean rows**			
	10:0	**8:2**	**6:4**	**5:5**	**4:6**	**2:8**	**0:10**
Maize	3690	3254	2722	2502	2557	2054	-
Soybean	-	285	358	632	900	1654	2071
Total grain production	3690	3539	3079	3215	3457	3708	2071

How do the erosion resisting strips act

1. Check the velocity of the runoff water coming from the erosion permitting strips.
2. Act as filter and arrest the eroded soil within the close growing strips.
3. Allow water to remain for a longer time in the soil and making it available to plants.
4. Give physical protection against blowing by wind.

Types of strip cropping

There are four types strip cropping:

(i) Contour strip-cropping

(ii) Field strip-cropping

(iii)Wind strip-cropping

(iv)Permanent or temporary buffer strip-cropping

(i) Contour Strip Cropping

Contour strip cropping is the growing of soil exposing and erosion permitting crop in strips of suitable widths across the slopes on contour, alternating with strip of soil protecting and erosion-resisting crops. Contour strip cropping shortens the length of the slope, checks the movement of runoff water, helps to desilt it and increases the absorption of rainwater by the soil. Further, the dense foliage of the erosion-resistant crops prevents the rain from beating the soil surface directly. It is, advisable to rotate the strip planting by sowing a non-resistant crop, following an erosion-resistant crop and vice versa.

(ii) Field Strip-Cropping

It is the planting of farm crops in more or less parallel strips across fairly uniform slopes, but not on exact contours. This type of strip cropping is found useful in the areas of undulating topography and whose contour strip cropping may not be practical.

(iii) Wind Strip-Cropping

It consists of planting tall growing crops such as *jowar*, *bajra* or maize, and low growing crops in alternately arranged straight and long, but relatively narrow, parallel strips laid out right across the direction of the prevailing wind, regardless of the contour.

(iv) Permanent or Temporary Buffer Strip Cropping

In the case of permanent or temporary buffer strip cropping, the strips are established to take care of critical, i.e. steep or highly eroded, slopes in field under contour strip-cropping. These strips do not form part of the rotation practiced in normal strip cropping and they are generally planted with perennial legumes, grassed or shrubs on a permanent or temporary basis.

Selecting Erosion Resisting Crops

The following points have to be borne in mind while selecting a suitable erosion resist in crops:

1. Intensity and critical period of rainfall.
2. Life period of the selected erosions resisting crops.
3. Canopy and root development.

The growth of the crop should be such that it develops maximum foliage so as to with stand the onslaught of heavy rains. In order to get good foliage the seed rate of erosion resisting crop may be increased according to requirements. At Dehradun cowpea have given best result.

Points to be Considered While Laying out Strip Cropping System of Cultivation

1. It should fit into the farming pattern. Selecting crop according to market, climate, and resources of the farmer.
2. It should serve as an effective cover in controlling soil and water erosion.
3. The strips should be rotated from year to year by shifting the erosion resisting crop strips upwards in a regular sequence.

Green Manuring

Green manuring can be defined as a practice of ploughing or turning into the soil uncomposed green plant tissues for the purpose of improving physical structure as well as fertility of the soil.

Types of Green Manuring:

There are two types of green manuring:

1. Green manuring *in situ*

In this system, green manure crops are grown and buried in the same field which is to be green manured. The most common green manure crops grown under this system are sunnhemp (*Crotalaria juncea*), dhaincha (*Sesbania aculata*) etc.

2. Green leaf manuring

Green leaf manuring refers to turning into the soil green leaves and tender green twigs collected from shrubs and trees grown on bunds, waste lands and nearly forest area. This system is generally followed in southern India. The common shrubs and trees used are: Glyricidia (*Glyricidia maculata*), *Sesbania speciosa*, Karonj (*Pongamia pinnata*).

Plants suitable for green manuring in situ

An ideal green manure crop should possess the following desirable characteristics.

(i) It should be a legume with good nodular growth habit indicative of rapid nitrogen fixation under even infavourable conditions.
(ii) It should have little water requirements for its own growth and should be capable of making a good stand on poor and exhausted soils.
(iii) It should have a deep root system which can open the sub-soil and top lower regions for plant nutrients.
(iv) The plant should be of a leafy habit capable of producing heavy tender growth early in its life cycle.
(v) It should contain large quantities of non fibrous tissues of rapid decomposability containing fair percentage of moisture and nitrogen.

Advantage of green manuring

(i) It adds organic matter to the soil. This stimulates the activity of soil micro-organism.
(ii) The green manure crops return to the upper soil, plant nutrients taken up by the crop from deeper layers.
(iii) It improves the structure of the soil.
(iv) It facilitates the penetration of rain water thus decreasing runoff and erosion.
(v) When leguminous plants, like sunnhemp and dhaincha are used as green manure crops, they add nitrogen to the soil for the succeeding crop.
(vi) It increases the availability of certain plant nutrient, like phosphorus, calcium, potassium magnesium and iron.

Mixed Cropping

Mixed cropping is a practice of growing more than one crop in the same field simultaneously. In mixed cropping, there is one main crop and one or two subsidiary crops. Generally, legume is used as one of the crops. This system of cropping is very extensively adopted by the farmers in India. Mixed cropping gives better cover on the land, good protection to soil from beating action of rain and protection from soil erosion, by binding the soil particles.

By far the largest area under mixed cropping is covered by grain crops. The most important mixture consists of legume and non-legume crops. These are *rabi* as well as *kharif* crop mixtures. The commonest *rabi* mixture is wheat and gram and the most prevalent *kharif* mixture is *jowar* and *arhar*. These mixtures are mainly cultivated to use the conserved sub-soil moisture.

Study conducted at different places in the country has shown that mixed cropping/inter-cropping gives less runoff and soil loss.

Advantages of Mixed Cropping

1. All the crops do not fail under adverse climatic conditions, e.g. frost kills only legumes, drought kills the shallow rooted crops. Thus the crops which do not fail provide an insurance against complete failure of the crops.
2. An epidemic attack of any insect pest or disease kills only one crop without affecting the rest of the crops.
3. The farmers grow different crops which balance their daily need or demand for cereals pulses, oil seeds etc.
4. Crop mixture provides better canopy which checks the erosion runoff weeds etc.
5. It improves or maintains the soil fertility.

Crop Rotations

Rotation of crops in an order in which the chosen cultivated crops follow one another in a set cycle on the some field ever a definite period for their growth and maturity with an objective to get maximum profit from least investment without impairing soil fertility. It is a matter of common knowledge that the crop grown year after year on the same soil depletes soil fertility. Also line sown and clean tilled crops promote soil removal. Thick growing crops protect soil agent the impacts of rain drops. They also intercept runoff. A proper rotation of crops not only maintains fertility but also helps in reducing soil erosion. A good rotation should include a cultivated row crop densely planted, small grain and a spreading legume.

Advantages of Crop Rotation

(i) Legumes or grasses in rotation will save from erosion and maintain fertility and productivity.
(ii) Improve physical conditions of the soil and in keeping the soil structure in proper condition.
(iii) Addition of atmospheric nitrogen.
(iv) Control of weeds.
(v) Control of pests and diseases.
(vi) Increase the land use efficiency.
(vii) Increase the fertilizers and irrigation efficiency.

Mulch Farming

Mulch is any material, organic or mineral in nature, such as saw dust, straw, paddy husk groundnut shell, crop residues, leaves, paper, stones, loose soil etc. which is spread on the surface of the soil in order to protect the soil from the impact of rain drops, avoid surface crusting, reduce evaporation and thereby conserve soil moisture. Mulch also serves to moderate surface soil temperature.

Mulch farming is a system of farming in which organic residues or other materials are neither ploughed into the soil nor mixed with it, but are left on the surface to serve as mulch.

Mulch farming is not only useful for reducing soil and water loss but is also useful for maintaining high soil moisture in the field. Thus mulching can be used in higher rainfall period/region for decreasing soil and water loss in low rainfall period/region for increasing soil moisture. Studies conducted at various places have demonstrated that mulching increases soil moisture and yield of crops. Wheat crop sown in *rabi* season at Dehradun, gave significantly higher yield with surface mulch.

The natural sources of mulch are agricultural byproducts, for instance, straw, stubble, corn cobs, manures, wood chips, paper or plastic film are occasionally used as mulch. In agricultural practices it is best to "grow the mulch in place", that is to use residues in the same field where they grew earlier. Study conducted at Dehradun show that mulches applied immediately after the harvest of maize increased the grain yield of wheat significantly. Straw mulching before sowing was superior giving 36% higher yield than control followed by grass mulch. However, dust mulch was found as most practical way of moisture conservation, which produced 22% higher yield than control (Table 4).

Table4. Effect of surface mulching on yield of wheat

Treatment	**Wheat yield (kg/ha)**
Control (No mulch)	2514
Paddy husk @5 t/ha	2926
Grass mulch @ 5 t/ha	3272
Dust mulch	3071
Mulching before sowing of wheat	3418

Method of Application

Mulch may be used exclusively as a soil cover, or it may be partially mixed with the ground. As a cover it is more effective in protecting the soil from the direct impact of the rain drops. However, if it is partially mixed with the soil surface, it decomposes sooner and helps to make the soil more rapidly resistant to detachment of particles.

Rate of Application

The mulch application in the field should be thick enough to protect the soil from the impact of rain drops and practically stop the soil erosion by splash. Dehradun receives heavy down-pour during *kharif* season, when maize is commonly grown on sloping lands. 4 tones/ha of grass mulch applied to this crop after sowing, considerably reduced soil and water losses on 8% slope. Soil loss decreased from 42.5 tones/ha without mulch to 6.2 tones/ha with mulch. Similarly runoff reduced from 52% of rainfall to 21% of rainfall. This clearly demonstrates the importance of mulching in reducing the problem of sedimentation and floods from the catchments. Optimum quantity of mulch does not suppress the growth of most plants and permits adequate aeration. The results of study conducted at Dehradun revealed that air dried *Leucaena* leaves mulch @ 2 t/ha may be incorporated into the soil within a period of 30-40 days of maize harvesting. The wheat yield can be obtained about 32q/ha, which is about 25% higher than the control (Table 5).

Table 5. Observed yield of wheat grain (q/ha) as influenced by various doses of mulch and its number of days of incorporation into the soil

Treatment	Year			Mean
	1990-91	1991-92	1992-93	
Doses of mulch (t/ha)				
0	30.6	24.2	23.4	26.1
2	37.3	29.2	29.7	32.1
4	38.7	30.6	33.7	34.4
6	42.2	31.4	35.0	36.2
Incorporation (days)				
0	37.0	26.4	29.1	30.9
15	38.6	29.0	31.2	32.9
30	36.3	29.9	30.8	32.3
45	36.8	30.4	30.7	33.0

Results of another study showed that mulching @ 4 t/ha reduced runoff from 37 to 15% and soil loss from 18 to 5.4 t/ha in maize at 8% slope under agro-climatic conditions of Dehradun (Table 6).

Table 6. Effect of mulching treatments on runoff, soil loss and grain yield of maize

Treatment	Runoff (%)	Soil loss (t/ha)	Maize yield (kg/ha)
Control (no mulch)	36.9	17.8	2433
Mulch @ 2 t/ha	17.9	7.3	2317
Mulch @ 4 t/ha	14.7	5.4	2395

Time of Mulching

If the ground is bare before or at the time of seeding a crop, mulch should be applied immediately to protect the soil from erosion. Early mulching proves advantages, because it not only controls erosion but also conserves moisture and improves soil structure.

Advantages of Mulch Farming

Physical

1. Less direct impact of rain crops.
2. Decreased amount and distance of splash.
3. Less dispersion of surface soil and less crusting.
4. Less internal erosion (clogging up of pores).
5. Small fluctuations in soil moisture and soil temperature.
6. Lower temperature in spring and summer.
7. Higher temperature in winter.
8. Decreased depth of frost penetration.
9. Increased aggregation of surface soil and imported soil structure.
10. Greater resistance to detachment by wind and water.
11. Greater porosity and increased water holding capacity (mulch itself holds very little water).
12. Higher infiltration capacity, increased amount of percolation.
13. Less runoff and water erosion.
14. Less evaporation

Decreased wind velocity just above the ground, less wind erosion

Chemical

1. Maintain organic matter.
2. Less loss of plant nutrients in runoff because of decreased amount of runoff.

Biological

1. Increased microbial activity near the surface because of increased energy and more uniform moisture and temperature conditions.
2. Easier establishment of crops especially the small and seed crops.

9. Role of Minor Millets Based Cropping Systems in Rainfed Area

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Minor millets have been cultivated in India since time immemorial and contributed for rural food security and sustainability. There has been marked decline in the area under these crops ever since the green revolution period and theextension of irrigation facilities. The area under minor millets in 1950 was about 8.0 m ha which hasdeclined to nearly 4.0 m ha in 2004. However, the overall production has remained almost same at
4.0 million tones being produced from far lesser area (100% reduction) due to increased productivity of these crops per unit area. The major millet growing states are Karnataka, Tamil Nadu, A.P., Orissa, Maharasthra, Jharkhand and Uttaranchal.

Six millets are cultivated in India as grain and feed crops viz.,

Common names	Botanical name
(1) Finger millet, ragi, mandua	(*Eleusine coracana* (L.) Gaertn)
(2) Barnyard millet, sawan, jhingora	(*Echinochloa frumentacea* (Roxb.) Link)
(3) Proso millet, cheena	(*Panicum miliaceum* L.)
(4) Foxtail millet, kangni	(*Setaria italica* (L.) Beauv)
(5) Kodo millet	(*Paspalum scorbiculatum* L.)
(6) Little millet, Kutki	(*Panicum sumatrense* Roth ex Roem & Schult)

Among all these millets finger millet contributes more than 50% of the total production and the area under this millet is about 50% of the total area under minor millets. Small millets as a group received least importance for genetic improvement in comparison to other cereals like rice, wheat, maize, *bajara* and sorghum. However, after the start of all India Coordinated Small Millet Improvement Program in 1980 when germ plasm unit for these crops was set up in Bangalore, rapid advancements have been made.
The salient features of these crops are:

(i) They can be grown under diverse agro-climatic conditions ranging from sea level to 1828 m above mean sea level.

(ii) They are cultivated in most adverse soil and climatic situations and they thrive well even in unproductive and barren fields where no other crops can be grown successfully. Performance risks of these crops are minimum in comparison to high yielding varieties of rice and wheat.

(iii) They constitute nutritional security to poor small, marginal and landless farmers dependent on farming in rural areas on account of their highly nutritious grains. They embody far greater mineral elements (like Ca, Fe) fibres and vitamins in comparison to more common cereals like rice, wheat or maize and are comparable with the latter in respect of protein and carbohydrates. Based on several quality parameters they are ranked superior to other cereals. Traditional cereals like *Setaria italica* and other crops like Fagopyrum are consumed by the hilly people living at higher elevations to meet their high energy requirements. In comparison to wheat and rice (1.1 g/100 fat) *Kauni* or *Setaria* has 4.3 g/100 g fat. Therefore, they are called as nutritional grains

(iv) Millets require very little plant protection measures, as they do not have serious pests and diseases afflicting them.

(v) In comparison to other pulses, oilseeds and cereals, they are less affected by insect pests during storage and they retain their viability for a long time even in sub-optimum conditions of storage. The grains dried to 10-12% moisture can be stored for many years in farm homes. The millet flour and their products also show good shelf life. Besides India, in many countries of Eurasia including China and Japan, foxtail millets, proso millet and Barnyard millets have been popular food grains for many centuries. Based on these factors, minor millets are called as famine reserves.

(vi) Proso millet and little millet are the earliest to mature during rainy season (50-60 days) and provide food grains during the lean period to the landless people living below the poverty line. These are good crops for contingency planning in events of monsoon failure.

(vii) They are very good sources of fodder to the farmers.

(viii) Soil fertility management practices of these crops are in tune with the available local resources under traditional cropping system while the HYVs of rice and wheat and other major cereals require more inputs and energy to provide the economic returns.

(ix) Utilization of family labour is equitable, dispersed and effective under traditional crops and cropping systems in comparison to mono-cropping systems of rice and wheat which require higher number of labourers in short spells.

Agro-techniques for higher productivity

1. Choice of varieties: A number of high yielding varieties of different maturity duration are available in all 6 millets (Table 1). In Karnataka, finger millet improvement started as early as 1900. In UP, the finger millet improvement was initiated as early as 1944 under the state department of agriculture and the first variety developed and released was T36B in 1949. In barnyard millet T46 and T25; Type-2 in Kodo millet and Type 4 were developed in foxtail millet. Presently research on small millets is carried out in 11 centers and 15 cooperating centers spread over 11 states. The work carried out in the past has resulted in the development and release of many new varieties for cultivation in different agro-ecological zones of the country. In finger millet, three maturity groups viz; short, medium and long duration are identified maturing in 82-106, 103-109 and 108 to 122 days respectively. Maturity of barnyard millet (87-95 days), foxtail millet (80-85 days) kodo millet (97-100 days), proso millet (75-91 days) and little millet (75-112 days) gives ample of opportunities for appropriate cropping sequences for maximizing productivity.

Table 1: Yield potential and maturity duration of some high yielding millet genotypes

Millet	Year of release	Maturity (days)	Potential yield (q ha^{-1})	Average yield (q ha^{-1}) (Farm demonstrations)
Finger millet				
VL 149	1991(N)	105-110	25-30	-
VL 146	1997 (N)	95-100	20-25	-
PES 400		100	25-30	-
VR 708*	1998(N)	75-80	20-25	18.54
GPU28	1998(S)	110-115	35-45	
Kodo millet				
i. GPUK3	1991	-	18.0 – 20.0	-
ii. PSC 1	1986 (N)	-	18.0 – 20.0	
Proso millet				
K1	1982(S)	-	9.50	9.50
GPUP 8	1999	-	25.00	-
			21.0-23.0	
Barnyard millet				
K1	1970(S)	85	5-10	-
VL29	1988 (N)	-	-	25.00
VL 172	2000 (N)	-	22.5	-
VL 181	2001 (N)	-	-	16.53
Little millet				
CO_2	1978 (S)	-	13.5	-
OLM/203 (Tarini)	2001 (N)	-	25.0	12.20
Foxtail millet			18-20	
PS4	1999 (N)	80-85	18-20	-
SiA 326	1985 (N)	-	22	-

*Photo insensitive and suitable for all seasons N = National release S = State release.

Table 2 : Recommended varieties of small millets in north India

Millet	Varieties	Average yield (q ha^{-1})
1. Finger millet	VL 124, VL 146, VL 149, PES400, KM65	1800-2800
2. Barnyard millet	VL 172, *Kanchan*	2100-2300
3. Proso millet	*Bhawna* (Early maturity)	1200-1500
4. Foxtail millet	PS4	1800-2000

Table 3: Productivity potential of some promising cultivars of traditional cereals of Uttaranchal averaged over three years, at Dehradun

	Variety	Grain yield (q/ha^{-1})	Fodder yield (q/ha^{-1})	Maturity	Plant height (cm)
Finger millet: *Mandua*					
1.	PES 400	32	95	108	117
2.	VL149	29	80	102	112
3.	VR708	33	74	80	96
4.	VL253	31	95	96	108
5.	TNAU918	32	96	116	115
6.	Sainji (Local)	20	83	114	113
Barnyard millet: *Jhingora*					
1.	VL29	15	47	87	157
2.	VL172	14	50	84	157
3.	VL188	18	67	87	158
4.	PRB9402	14	20	90	100
5.	PRB9406	20	54	80	169
6.	Atrola (Local)	11	51	83	164

Table 4 : The recommended manuring and spacing of cereals are:

	Fertilizers (Rainfed)	Spacing	Seed rate ha^{-1}
Barnyard millet	40:20	25.0 cm r-r 10 cm p-p	8-10 kg, line sowing 12-15 kg/ha, broadcasting
Finger millet	40:20:20	22.5 r-r 7.5-10.0-p-p	10 kg
Proso millet	20:20:0	25.0 cm r-r 10.0 cm p-p	10 kg (line sowing) 15 kg (broadcasting)
Little millet	20:20:0	22.5 cm between plants	8 kg (line sowing) 12 kg (broadcasting)
Foxtail millet	20:20:0	25.0-30.0 cm r-r 8.0-10.0 cm p-p	8-10 (line sowing) 15 kg (broadcasting
Kodo millet	20:20:20	22.5 cm r-r 10.0 cm p-p	15 kg (broadcasting) 10 kg (line sowing)

2. **Timely sowing:** Timely sowing is a non-cash input, which brings higher yield. In all small millets delayed sowing results in higher yields. However, the extent of reduction is marginal in foxtail millet, proso millet and little millet on account of their short maturity period and they fit well for contingency cropping. Advance preparation of land is required for timely sowing. At higher elevations in Uttaranchal, dry sowing of barnyard millet and finger millet is done in April and the seeds germinate with the pre monsoon showers with onset of monsoon in the middle of June. However, in high rainfall areas after the onset of monsoon it may become difficult to take up sowing.

3. **Better crop establishment for early vigour:** Line sowing helps better crop establishment of crops than broadcasting. It also facilitates effective inter-cultivation. Sowing with the help of seed drills is an effective technology, however it may not be easily accessible to the marginal and small farmers.

4. **Optimum plant stand:** It is a pre-requisite for higher yields. Plants spaced at optimum distance establish better on the other hand when the plants stand in dense, it reduces the early vigour and crop growth. In practice farmers use high seed rate and later they resort to thinning. Usually, it is done by ploughing and turning off of soil and large number of plants are burried in soil.

5. **Minimizing crop-weed competition:** With the onset of monsoon the crop germinates and so do the weeds. Therefore, it is important that the crop plants are identified from weeds as the latter resemble crop plants and it becomes difficult to distinguish them initially. First weeding within 3 weeks of germination is very crucial for healthy crop stand, followed by second weeding within a month. This saves nutrients, water and other inputs, which are delivered to crop plants.

6. **Balanced nutrition:** Small millets require much less fertilizers. Their nutrients requirement is usually 1/3 of what is needed for important cereals like rice and wheat (Table). Small millets respond well to fertilizer application. Balanced application of organic manure and inorganic fertilizers leads to healthy growth of crop. Split application of nitrogenous fertilizers is advantageous as it minimizes losses due to leaching and volatilization. It has been observed that seed inoculation with the combination of *Azospirillum brasilense* and *Aspergillus awamuri* improves productivity of small millets. Combination of super-phosphate and rock phosphate in equal proportion and treating seeds with phosphate solublizing fungus *Aspergillus awamuri* enhances P availability and improves productivity.

7. **Intercropping systems:** Intercrops not only help in meeting the domestic needs of the farmers but also provide fodder for animals during the lean period. They also help in giving risk cover and give stable income. Some common intercropping systems are:

Finger millet + soybean

Barnyard millet + rice bean (4:1)
Finger millet + pigeon pea
Proso millet + green gram
Kodo millet + pigeon pea
Foxtail millet + pigeon pea
Little millet + pigeon pea

8. **Recommended package of practice :** The package of practices as recommended in Table 4, ensure in relizing full genetic potential of millets.

9. **Graded technology :** The influence of graded technology on millet production under rainfed situations is presented in Table 5.

   Productivity as influenced by graded technology. Application of just 1/3 recommended doze of fertilizers enhanced the yield substantially; selection of right variety and application of fertilizers increased the yield levels.

Table 5: Influence of graded production technology on yield (q ha^{-1}) of small millets under rainfed conditions:

Treatment	Finger millet	Barnyard millet	Foxtail millet	Kodo millet	Little millet
Local var. with local practice	10.67	10.36	19.13	3.99	4.42
Local var. with recommended practice	15.77	14.39	18.67	7.90	7.25
Improved var. with local practice	12.82	13.74	25.31	5.54	5.32
Improved var. with recommended practice (full fertilizer level)	24.29	21.18	27.01	9.26	8.17
Improved var. with 1/3 doze of recommended practice	17.61	14.41	-	7.08	5.63
Improved var. with 2/3 rd doze of recommended fertilizer	20.14	17.64	-	7.90	7.19
Improved variety with recommended doze of fertilizer and plant protection measures	25.05	24.83	32.41	10.51	9.28

Quality aspects of minor millets :

The millet protein has a well-balanced amino acid profile and a good source of lysine, methionine, cystine, tryptophan and histidine. These essential amino acids are of special significance to hilly and tribal people who depend on these cereals as staple diet for protein nourishment. Barnyard millet had the highest % of crude fibre content and its consumption by the hilly people in various preparations is quite common. High non-starchy polysaccharides and dietary fibres help in prevention of constipation, lowering of blood cholesterol and slow release of glucose to the blood stream during digestion. Millets are also rich in vitamins viz; thiamine, riboflavin, protein and niacin. Lower incidence of cardiovascular diseases, duodenal ulcers and hyperglycemia (diabetes) are reported among regular millet consumers.

Table 6 : Nutrient composition of cereals (per 100g)

Cereal	Protein (g)	Carbo-hydrate (g)	Fat (g)	Crude fibre (g)	Mineral matter (g)	Calcium (mg)	Phosphorus (mg)
Wheat	11.8	71.2	1.5	1.2	1.5	41.0	306.0
Rice	6.8	78.2	0.5	0.2	0.6	10.0	160.0
Barley	11.5	69.6	1.3	3.9	1.2	26.0	215.0
Maize	11.1	66.2	3.6	2.7	1.5	20.0	348.0
Sorghum	10.4	72.6	1.9	1.6	1.6	25.0	222.0
Pearl millet	11.6	67.5	5.0	1.2	2.3	42.0	296.0
Finger millet	7.3	72.0	1.3	3.6	2.7	344.0	283.0
Proso millet	12.5	70.4	1.1	2.2	1.9	14.0	206.0
Foxtail millet	12.3	60.9	4.3	8.0	3.3	31.0	290.0
Little millet	8.7	75.7	5.3	8.6	1.7	17.0	220.0
Barnyard millet	11.6	74.3	5.8	14.7	4.7	14.0	121.0
Kodo millet	8.3	65.9	1.4	9.0	2.6	27.0	188.0

Mandua has the highest calcium % (300-350 mg/100 g grain) while *jhingora* had the highest crude fibre content and fat %, mineral %. Therefore these crops are often called as nutritious crops, which are primarily responsible for superiority of traditional diet.

Table 7 :Essential amino acids contents of millets and cereals (g/100 g of protein)

Cereal	Isolen-cing	Leucine	Lysine	Methio-mine	Cystine	Phenyla-tanine	Tyrosine	Threonine	Trypto-phan	Valine	Histi-dine
Wheat	3.3	6.7	2.8	1.5	2.2	4.5	3.0	2.8	1.5	4.4	2.3
Rice	3.8	8.2	3.8	2.3	1.4	5.2	3.9	4.1	1.4	5.5	2.4
Finger millet	4.4	9.5	2.9	3.1	2.2	5.2	3.6	3.8	1.6	6.6	2.2
Barnyard millet	8.8	16.6	2.9	1.9	2.8	2.2	2.4	2.2	1.0	6.4	1.9
Proso millet	8.1	12.2	3.0	2.6	1.0	4.9	4.0	3.0	0.8	6.5	1.9
Foxtail millet	7.6	16.7	2.2	2.8	1.6	6.7	2.2	2.7	1.0	6.9	2.1
Kodo millet	3.0	6.7	3.0	1.5	2.6	6.0	3.5	3.2	0.8	3.8	1.5

Source: 1. FAO, Nutrition studies, 1970, Rome, Italy.
2. Nutritive value of Indian foods, 1998, NIN, Hyderabad, India.

Dietetics of minor millets:

Many kinds of traditional foods are made from small millets. *Mandua* is consumed as *roti* during winter months. *Mandua* flour is mixed with wheat flour and is a good staple diet. Popped ragi flour is mixed with sugar, jaggery, ghee, milk and salt.

Except finger millet other millets resemble rice in grain morphology containing husk, bran and endosperm. Traditionally husk and bran are separated by hand pounding. Grains are consumed by cooking them in boiled like rice or mixed with milk and sugar/jaggery to water like make porridge while in south used in preparation of *idli*, *dosa*. Popping of grains in hot sand (above 200^{o}C) with continuous agitation is quite common. Finger millet malt is used to prepare bear, which is very common among Tibetan population living in India, so also in Nepal, Bhutan and Jharkhand. Proso millet grains are cooked and served to children during chicken pose attack.

Traditional staple cereals of Uttaranchal

Ragi or mandua (Eleusine colacasia (L) Gaerin.), *jhingora*, *mandua*, *jowar* (*Echinochloa prumentacea*) Roxb. Link and cheena (Panicum miliacum) are foxtail millet (*Setair italica*) Bequv and little millets (*Pasicum sume* the staple cereals of Uttaranchal State. The total production of ragi (*mandua*) was the highest among all cereals.

These traditional cereals are the integral components of hill farming system and the mainstay of sustainability in production in the hills. Farmers usually grow the local land races of these crops which are poor yielders, though they are well adapted to extremely harsh and difficult situations and characteristics of sub-sistence level of farming.

- These crops grow very well on marginal and degraded lands and require very little or no inputs at all.

- They are rich sources of minerals, proteins and vitamins hence can serve as good supplement to predominantly rice, wheat based, staple diet. Nowadays they are often called as nutri cereals.

- Small millets are devoid of stored pests and have long viability even under pan storage appropriately referred to as famine reserves. The grains dried to 10-12% moisture can be stored for many years in farm homes. The millet flour and their products also show good shelf life. Besides India, in many countries of Eurasia including China and Japan, foxtail millet, proso millet and barnyard millet have been popular food grains for many centuries.

- Their continuous cultivation helps in maintaining eco-geographic biodiversity *in situ* thereby preventing the genetic erosion and widening the food base of population.

- Continuous cultivation of these crops is an eco-friendly approach for fragile the vulnerable agro-ecosystems for sustainable crop production. Cultivation of these millet crops can lead to efficient natural resource management and ultimately to a more holistic approach in sustaining biodiversity.

10. Planning, Implementation & Maintenance Issues in Watershed Management Programs

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Watershed management is a holistic approach which aims at optimizing the use of land, water and vegetation in an area, to alleviate drought, moderate floods, prevent soil erosion, improve water availability, and increase fuel, fodder and agricultural production on a sustained basis. The issue relevant to watershed management includes environmental issues, crop and livestock production, social & cultural concerns and infrastructure planning.

Factors Associated with Success of Watershed Management

- People should be the focal point of watershed management programs and innovations should be planned with their needs in mind.
- Involvement of farmers should be as stakeholders and not be limited only to problem identification but should also include implementation and evaluation.
- Project workers should be accountable to the farmers who have contributed significant amounts of time, faith and resources.
- Watershed programs need complete holistic approach and not only for certain components.
- Integration of farmers' wisdom with improved technologies can result in appropriate and long lasting solutions.
- Success indicators should relate to the watershed as a whole.
- Farmers should have access to credit for their consumption needs as well as for small income generating activities.
- Landless and marginal farmers should be given access to the increased bio-mass in the watershed viz; priority to harvest and sell or use grasses.
- Adequate priority should be given to the provision and upgrading of skills and other services required for the landless and marginal farmers.
- Gender relations to be more equitable which requires a sharp tilt towards women.
- Priority should be given to employ vulnerable groups living in the watershed.
- Priority should be given to vulnerable groups in watershed institutions like credit groups and watershed development associations.

Objectives of Watershed Development and Management

- To promote economic development of village community dependent on watershed and

To restore ecological balance in the village environment through:

- Sustained community action for operation and maintenance of assets created.
- Simple, easy and affordable solutions built upon local knowledge and available materials.
- Emphasis to improve economic and social condition of the resource poor and disadvantaged section of the watershed community through.
  a. More equitable distribution of benefits of land and water resources development.
  b. Greater access to income generating opportunities and focus on their human resource development programs.

Participatory Approach, What is it?

Authenticity of information, what different agencies get from the farmers and farmers get from different agencies, counts much more in the research and development process. Conventional methods of surveys and information collection have certain loopholes. According to Robert chambers, in conventional surveys preference is given to factual information over people related information, poorer people are easily overlooked, labour and expense involved are not in proportion to results obtained and necessary information is elicited, analyzed and used most exclusively by outsiders. Dissatisfaction with results of such "Surveys" led to a search for more effective methods resulting in the emergence of participatory approaches viz; PALM, PAR, PRA, PRAP, PRM, PTD etc. depending upon nature of requirement like problem diagnosis, community empowerment, farmers-led research, health context; Watershed development and food security assessment.

In the areas like soil and water conservation, Agroforestry, Fishery, Wildlife conservation, Agriculture, Poverty alleviation and emancipation, health and nutrition and village and district level planning, PRA (Participatory Rural Appraisal) is used more prominently.

Participatory Rural Appraisal (PRA) is a "Way of enabling local people analyze their living conditions, share outcomes and plan their activities. The outsider is a facilitator and convenor of processes within a community, prepared to alter their situation". It is a methodology that enhances the development agents understanding of the rural reality in planning and development of projects and a greater degree of ownership and responsibility by the farmers for achieving better results and social acceptance of the progromme.

Why Participatory Approach

- It is necessary that users of resources are involved in analyzing the problem and identifying solutions since they know best of the benefits, constraints and initiatives for conservation and regeneration.
- It enables labourers, women and small farmers to analyze conditions giving them confidence to assert their priorities, to present proposals, to make demands and take action, leading to sustainable and effective programs.
- It encourages and enables expression and exploitation of local diversity.
- It is helpful in identification of research priorities and initiating participatory research with scientists more receptive to local knowledge and farmers ability to design, carryout and evaluate their own experiments.

How to Achieve Participation

- Farmers are more willing to participate in activities which meet their felt needs and priorities. The needs of all people should be taken into consideration, not just those who are accessible and co-operative.
- Farmer's idea must be taken into account to sustain their involvement.
- Farmers are more likely to participate if the actual benefits are directly tied to the participation.
- Farmers, specially those with low incomes, are more likely to participate and remain involved if the benefits are material, direct and immediate.

I. Institutional Arrangements

Community Organizers

The Project Implementing Agency (PIA) selects Watershed Development Team members of four disciplines Viz; plant science, engineering livestock and social sciences. They must be graduate in their field. During the course of various meetings with community members, the WDT members may identify village based social workers/motivators who can be involved in organizing the community. Wherever possible the youth clubs, mahila mandal, anganwadi members may also be involved in this process.

Kinds of Groups to be Constituted

Four types of groups are to be constituted at the village level namely: Self Help Group (SHG), User Group (UG), Watershed Association (WA) and Watershed Committee (WC). A proper sequence is required to be followed while organizing the groups. In order to minimize conflict among the community members, it is essential to form WC at the end after organizing the first three types of groups. This is contrary to the normal tendency where WC is formed at the beginning through a meeting of unorganized members of the gram sabha. Till the WC is organized and its office bearers like Secretary and volunteers are identified, WDT may take the assistance of village level community organizers not only for organization of Self Help Group (SHG) and Users Group (UG) but also to facilitate Participatory Rural Appraisal (PRA) exercises for preparation of strategic/detailed action plan of the watershed. Organization of above three types of groups may be completed in about 8 to 10 months after the start of the project.

Self Help Groups

By and large Self Help Groups (SHG) shall include those who are landless or have marginal size of land holding. Such community members may be motivated to get organized into small homogenous groups (preferably with 15 to 20 members in each case) based upon their livelihoods, social affinity, compatibility etc. Credit and thrift activity may be used for organizing them into groups. Preference may be given to groups with women members of the households as they have been found to be highly successful in management of credit and thrift activity.

Self Help Groups may be organized with the help of village level community organizers. These organizers should be thoroughly trained in the concept of SHG, management of credit and thrift activity, group dynamics and maintenance of records through focused exposure visits to successful examples as well as through skill oriented training programs. Such visits and trainings may be arranged also for representative members of the proposed SHG. The expenses towards visits and skill development courses may be met out of funds under training component. The expenses towards honorarium for community organizers may however be charged out of the funds under community organization component. The above honorarium may be provided against specific jobs to be carried out by the organizers, namely; facilitation of monthly meetings on a fixed day, preparation of proceedings, maintenance of records for credit and thrift activity, training of group representatives regarding the above aspects etc.

The primary purpose of organizing the SHGs is not only to involve them in the implementation of the project activity but also to strengthen them as a social and functional unit in order that they may effectively manage their own need based activities (even if these are not within the framework of watershed project). Hence, at a micro level the basis for formation of these groups need be both common interest or activity and also social affinity and compatibility.

User Groups (UG)

User Groups shall include those members who are land owners within the identified watershed area. Such land-owning community may also be motivated to get organized into small homogenous groups. Like SHG, the UG may also be organized around credit and thrift activity with the help of locally available trained community organizers. These groups may be of women members or men members or both depending upon their availability, willingness etc. As in the case of SHG, the expenses for exposure visit and training of community organizers/group representatives may be met out of the training budget whereas honorarium to the community organizers may be provided out of the community organization budget.

Experience indicates that it is preferable to organize UG also as per their social affinity and compatibility even if they are to manage a particular community asset. Such members learn the value of group work and would be able to manage the community structures through occasional meetings of concerned members as and when the need arises.

Watershed Association

After the organization of SHGs/UGs, the WDT shall call for a General Body meeting of all members of the above groups and also other participants representing the households within the watershed area, who have not yet become member of the SHG and UG. The watershed Association will be the General Body comprising all members of the watershed Community who agree to participate in the watershed development project. This body would be formally registered under Societies Registration Act. The WA shall evolve its own working procedures after electing its President. It will meet preferably once in a month, to discharge the functions entrusted to it as per the guidelines. All decision making power would vest with the WA. The WA would not only approve the Strategic Plan and Annual Action Plan but also carry out review of progress during implementation phase.

Watershed Committee

The WA shall in its first General Body meeting, nominate four representatives from the Self Help Groups and five from the User Groups as members of the Watershed Committee. The Gram Panchayat and the WDT will be requested to nominate one each of their members as representatives. While making nominations, it will be ensured that the Watershed Committee (WC) has at least two women members and the SC/ST community is adequately represented. The WA will decide on its own procedures for nomination of the members of the WDT by rotation, which shall be simple and easy. However, members of the WDT shall be present during the meeting of the General Body of WA in which nominations to the WC are approved.

The President of the WA may also be Chairperson of the WC. The WC shall perform all the functions that are entrusted to it in the guidelines for which it will work out its own procedures in consultation with the WDT. The Watershed Committee shall act as the executive body of the WA and carry out the day-to-day activities of the watershed development project subject to overall supervision and control of Watershed Association.

Functioning of WC and WA improves significantly if its members belong to mature UG and SHG. Hence, it is useful to stagger formation of WC/WA until the UG/SHG are suitably organized. It may be appropriate if membership of WA is given to all those persons who are direct participants in the watershed program so that decision-making process is influenced by these members. This may include members ofUG and SHG and other land owners whose land is covered under the identified watershed. It may be desirable if a nominal annual membership fee is charged from the WA member so that their involvement becomes active.

Watershed Secretary and Volunteers

After its constitution, the WC with the assistance of the project leader of the WDT, shall identify one secretary and 2 to 3 volunteers residing within the village on honorary basis/contract basis, who shall be able to carry out the required jobs. Watershed Secretary should preferably be a graduate from the same village or at least from some nearby village and he should agree to live in the watershed village during project period. The WC shall fix the honorarium to be paid to the watershed secretary and volunteers, as well as the manner in which these should be paid – either on a fixed monthly basis or linked to performance of specific duties. The Watershed Secretary is primarily responsible for maintaining records related to physical and financial progress, disbursement of wages to the labourer, purchase of material, supervision of the work of volunteers, maintaining the measurement book etc. The volunteers are expected to initiate implementation of works, provide markings at the site, supervise the quality, measure its progress, maintain measurement book, maintain register regarding use of materials, employment of labourers etc., besides assisting the watershed Secretary in various responsibilities.

Training to Watershed Secretary, Volunteers and Members of WC

Watershed Secretary, Volunteers and the Members of WC will be oriented by the WDT regarding participatory planning progress followed so far, for preparation of detailed action plan and their role in consolidation of the proposals into a comprehensive watershed development plan for approval by WA and the district head.

II. **Participatory Rural Appraisal**

a. Rapport Building:

It is an entry point to take the village people in confidence. It includes introduction explanation about purpose of the visit, idea in brief about the project and how it can benefit the farmers. To make the interaction more fruitful it is necessary that you behave according to their culture viz; pay respect to old aged persons and also do not try to impose your ideas over their views.

b. Historical Timeline

It gives background idea of important happenings in the past and the respective changes or developments accordingly in the village viz; establishment of village, introduction of roads, electricity, television, radio, vehicle, school, irrigation facilities, crops grown, animal reared, occurrence of drought, flood or famine and the changes in the culture and peoples attitude over the period of time.

Year	Activity
1700	Village was established
1800	Village Path (Churki rasta) was constructed through Sharamdan by the
1960	First Radio was purchased in the villages
1964	Tank for drinking was constructed
1980	Road from Leodiyal to Pawki devi was constructed
1982	Grazing was stopped in the village area due to lack of Civil Soyam l and,
1987	Village was electrified
1987	Severe drought occurred
1990	Heavy hailstorm occurred in the area
1991	Civil Soyam plantations by the forest department.
1994	High yielding varieties of crops were introduced
1995	Primary School was opened.
1995	Chemical fertializers were introduced
1998	Diesel Chakki for wheat was installed
2003	First Television was purchased in the village

c. Social Map

Generally in village condition mapping is done with chalk or Rangoli on the ground or on cemented floor if available, by the farmers itself according to the instructions given by the facilitator. Social map includes an outline of village boundary, roads, location of forest, community land agricultural land, habitation, schools, temple, mosque, hand pump, Panchayat Bhawan and other infrastructures available in the village. It also gives an idea about human population, livestock population, size of land holdings, caste and religion wise distribution of farm families and level of education in the village.

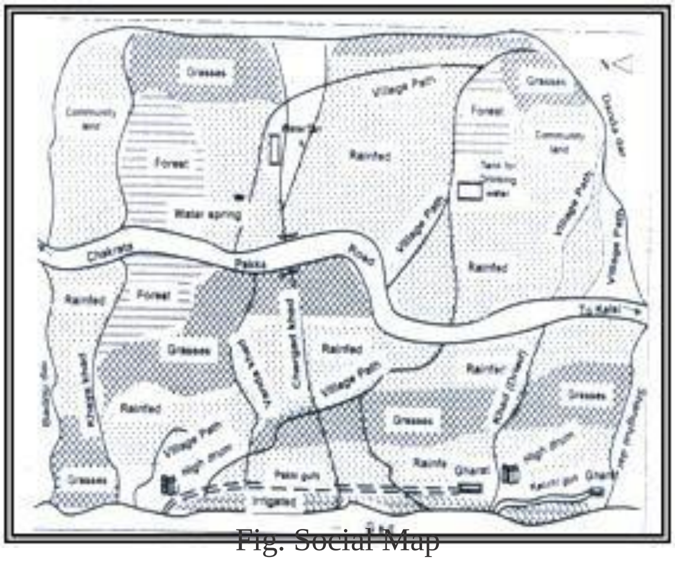


Fig. Social Map

d. Resource Map

In resource map, farmers indicate village boundary with total geographical area, location and area under forest, community land and agricultural land (irrigated, rainfed), soil types, different sources of drinking water (well, hand pumps etc.) and irrigation water (Ponds, guhls, water springs, tube wells, canal etc.).

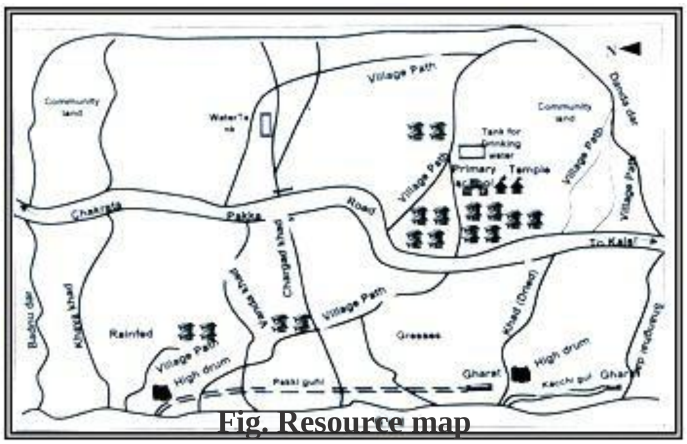
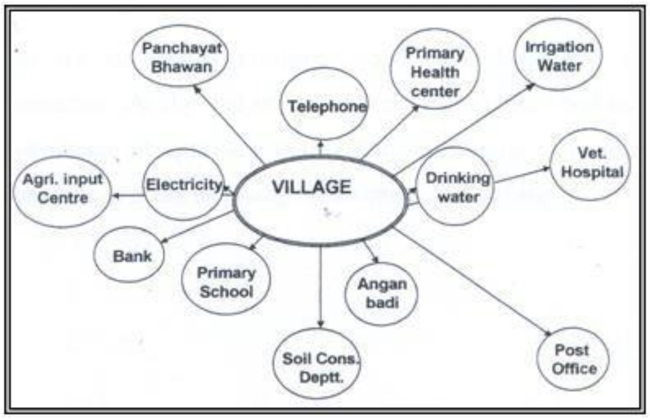


Fig. Resource map

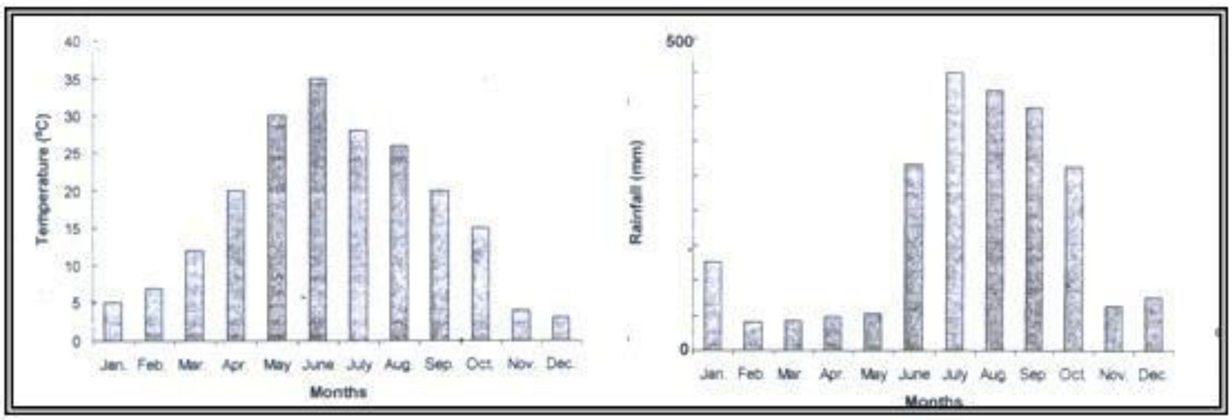
e. Venn Diagram

Venn diagram shows the existing key institutions and their importance and role for socio-economic development of the village. Each institution is represented by a circle. The size of circle shows the significance of the organization. The degree of overlapping from the village circle indicates level of involvement in the village development. If size of circle is bigger, it shows that services of that institution is very much important / required for the village and at the same time if circle is nearer to village circle, it shows that services of that institution is very much available in the village. Small size of circle shows less importance and more distance from village circle shows less evolvement of that institution in village development activities.



f. Seasonal Analysis

It gives an idea of weather condition prevailing over, crops grown and farming practices followed during different months of the year. It also helps in identifying the irrigation water, fuelwood, fodder and labourer availability and requirements. Occurrence of insect-pest and diseases in crops and livestock in different months of the year are also identified in the said exercise.



g. Priority Ranking

Different criteria and attributes are ranked in matrix by giving scoring to a particular aspects. They are ranked on the basis of fixed scoring or free scoring methods according to their relative importance. For example what are the crops, trees, fodder or animals are more suited in their environment and why.

Farmers preferences for fruit trees (Max. score for each attribute = 10)

Fruit	**Botanical name**	**Preference attributes**			**Tota l**	**Rank**
		Production	**Market**	**Timber**		
Mango	*Mangifera indica*	10	05	06	21	I
Guava	*Psedium guajava*	07	06	00	13	IV
Aonla	*Embelica*	08	07	02	17	III
Peach	*Prunus persica*	06	05	02	13	IV
Lemon	*Citrus spp.*	09	08	01	18	II
Banana	*Musa paradisica*	04	06	00	10	VI
Papaya	*Carrica papaya*	06	06	00	12	V

h. Transact Walk

This exercise enables the outsider to have knowledge of different aspects of ecology of the village and verify the information provided by the villagers, by direct observation.

Particulars	**High hills**	**Mid hills**	**Down hills**
Vegetation	Oak, Chir, Sal	Lantana	Asian, dhaura Sal, Sahtul, Sandan
Grasses	Gorda, ulendu, Tachla, Panho, Luenj Baboon, Musul	Gorda, tachla Pano, Ulendu	Gorda, baboon
Soil	Kateel, Doyam and Rainfed, Poorly terraced	Abbal & tachla Pano, Ulendu	Abbal and Doyam Well terraced, Partially irrigated
Crops	Maize, Paddy, Madna, Ginger, Colocasia, Barley, Mustard, Lentil, Jhingora	Maize, paddy, wheat, lentil, onion, garlic, mustard, potato madua, jhingora	Paddy, wheat, ginger, peas, lentil, mustard, madua, jhingora
Horticulture	Guava, Peach, Peer, Walnut, Plum, Citrus	Mango, Bannana, Citrus, Papaya, Peach	Mango, Litchi, Citrus, Bannana, Papaya
Livestock	Sheep, goat, cow	Buffalo, cow, sheep, goat	Buffalo, cow, sheep, goat

Water sources	Seasonal water springs	Seasonal water springs	Perennial water stream
Land use	Forest, community land, kateel	Habitation, Kateel, cultivable land	Cultivable land, habitation, kateel

i. Problem Identification and Prioritization

RBQ = Rank Based Quotient

$$\frac{Fi\,(n+1-i)}{Nxn} \times 100$$

Where: Fi = Frequency of farmers for the ith rank of problem

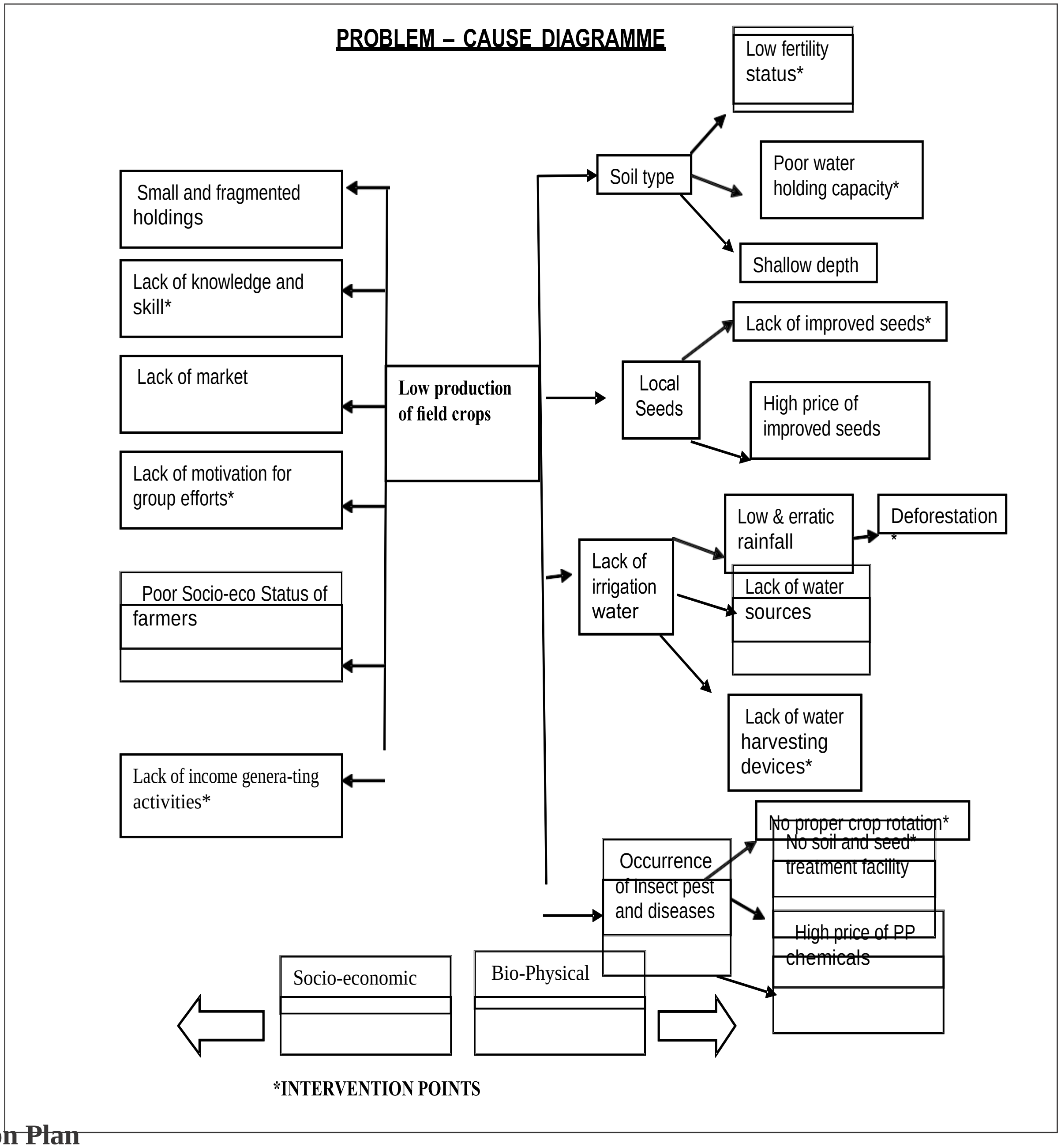
n = No. of ranks

N = No. of farmers

(n=10)

III. Participatory Planning and Implementation

Planning is done based on problems identified and prioritized. To know the different causes responsible for different problems, problem-cause diagram is prepared separately for all the problems, after thorough discussion with the farmers. Accordingly, to eliminate the causes, technological interventions (keeping in view the natural, physical and social resources available, seasonality, preference rankings etc.- check with informations collected through PRA & other secondary sources) are proposed and implemented.



Action Plan

1. Low fertility status of soil

T1= Farmers practice

T2= Technological option –I

Technological option –II

Technological option –III

……………………and likewise for all the intervention points.

100. Benefit Cost Analysis of Watershed Management Programs

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Benefit-Cost Analysis (BCA) is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits in order to assess the developmental / welfare change attributable to it. BCA estimates and totals up the equivalent money value of benefits and costs to a community of projects to establish whether they are worthwhile.

Benefit-Cost Analysis helps in selection of a project or projects. It helps in accepting or rejecting a single project, selects one out of several projects, and select several out of many projects as per budget constraint. It is useful in preparing estimates of the resources required to perform a project work, and developing appropriate measures of project success and basis for comparing projects.

Scope of Economic Evaluation

Project evaluation is both, ex-ante and ex-post. Ex-ante evaluation is done before actual implementation of the projects so as to assess its economic feasibility in advance and to know whether the particular project is capable of solving the basic objective of the plan. Ex-post evaluation is done after the project has been completed so as to know if the project actually achieved its objectives and also to help in post-mortem of the project such that deficiencies in the present project are not made for future ones.

There are one or many mid-term evaluations in between ex-ante and ex-post evaluations (concurrent) such that one can know the way things are happening during the project implementation period i.e. whether the project implementation and its outcome is going on the stipulated path or not. Such method of evaluation of the project would help in putting the project implementation process in right direction and hence help in reducing the gap between what was anticipated and what is actually obtained out of the project concerned.

Identification of Benefits/Outputs and Inputs

The first step in this is to identify those benefits, enlist them and group them into following broad categories. The quantification of benefits that arise or likely to arise from watershed development projects is generally treated as difference in the benefits from 'before' and 'after' project.

Economic Benefits: Those benefits which can be measured in physical terms and can be valued at market price e.g. crop production, production from trees, horticultural plants, grasses, animal product, income and its distribution.

- Additional crop production from increased irrigation potential through soil and water conservation.
- Additional crop production by converting degraded/waste land into arable land, introducing new crop technology, etc.
- Additional production from trees, horticultural plants, grasses, etc.
- Additional income from fish etc. through developed water resources.

Protective or ecological benefits: Includes such as area protected against erosion e.g. gulling, loss in area, increase the life span of dam and other environmental benefits.

- Prevention of loss due to floods/droughts
- Protection of land against erosion e.g. gulling
- Increase the life span of dam
- Increase in recreational value

Environmental benefits:

- Bio-diversity maintenance
- Protection of soil, water and air quality
- Better micro climate

Externalities/Secondary benefits: Includes those benefits, which accrued outside the project and termed as secondary benefits or technological externalities. For economic analysis of the project these benefits must be accounted so that they can be properly attributed to the project investment.

The broad category of inputs use is the use of the factors of production (land, labour and capital) over and above the level of use without the project. In this first and foremost aspect is to list the inputs, quantification of input required, along with its time of requirement.

- Manpower (managers, engineers, subject matter specialists, extension specialists, construction labour, agriculture labour etc.)
- Animal power (bullocks, mules etc.)
- Equipment (construction, gauging and maintenance equipment, tractors, cultivators, harvesters, threshers etc.)
- Purchased raw material (seed, fertilizers, manures, pesticides, water, fuel, construction material etc.)
- Cost of renting land, water body etc., if any

Valuing Inputs and Output

The inputs used and outputs produced by watershed development programs differ in physical terms. Therefore, without price age attached to input used and output produced, it will not be possible to judge economic efficiency of the watershed development projects. The price may be market price (when perfect competition is there), shadow price (when imperfect competition is there), surrogatemarket price (when input used and output produced has no market value itself, but there exist clear substitute for them for which market value exist) or cost price (assign some value on the basis of personaljudgement).

For any (and each) input or output, a constant price which is average of 5 years prices (before the project initiation) of that input or output, instead of current prices, are used for valuation in case of ex-ante BCA. For ex-post BCA, the average of price of the project period i.e. the active operation phase is used for any (and each) input or output. This is done to remove the price effect i.e. price changes occurring in the market on which the watershed development project has no control. Price Indices can be used to find prices of different years if price of any one year of the period of evaluation is known.

Technical Data Collection

- For evaluation purpose, all basic data at all stages i.e. from initiation to completion of the project are required (bench mark survey of before-after project approach).
- Proper sampling technique is to be adopted for ensuring representation of the whole project area.
- For collection of data, a suitable questionnaire should be adopted.
- The change in all parameters is then compared with the original status obtained through benchmark survey.
- The various cost as well as benefit components such as productive, protective, environmental etc. should be computed.

Period of Analysis

It is the economic life of the project (financial analysis from private point of view) or the life till benefits and costs occurred (economic analysis from social point of view). Two importance factors which decide the economic life of the projects are: (i) the expected useful physical life of the project and (ii) the level of discount rate lower will be the life span).

Methods of Economic Evaluation

The basic objectives of economic evaluation(s) is to measure the project worth by comparing the values of goods and services produced or conserved with the cost incurred after taking into account all effects of action taken. There are two broad categories of measures of project worth (i) undiscounted measures and (ii) discounted measures of project worth.

Undiscounted Measures of Project Worth: In these measures, time value of money is not taken into account. The following measures are categorized under this:

- Undiscounted sum of benefits per unit of initial capital investment.
- Net average rate of return: It is sum of differences of undiscounted benefits and undiscounted costs of project years divided by useful life of the project.

Discounted Measures of Project Worth: They account for the time value of money. This is achieved through discounting. The discount rate is yet another name for the rate of interest society should charge itself for the opportunity cost of time. Time is the most irretrievable loss for all. As time goes on, opportunities are inevitably lost. Therefore, one wishes to use time as efficiently as one can. The appropriate rate of discount is that rate which represents the rate of return on alternative investment of equal degree of risk. The measures that come under this are described below:

Net Present Value (NPV)

This is simply the discounted value of gross benefits minus the discounted value of costs. The general formula for NPV is:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

where, Bt = Benefits at time t; Ct = Costs at time t
i = Discount rate (%); t = Life of project

Decision rule: Accept the project of NPV > 0, otherwise reject. Higher the NPV better is the project. Select that project which has highest NPV.

Benefit Cost Ratio (BCR)

It is defined as the ratio of present value of gross benefits to the present value of total costs.

$$BCR = \sum_{t=1}^{n} \frac{B_t/(1+i)^t}{C_t/(1+i)^t}$$

Decision rule: If BCR $\geq$ 1.0 accept the project, otherwise reject. The project with higher B:C ratio are selected on the basis of their ranking based on BCR till the budget is exhausted. For a set of mutually exclusive alternatives choose the most costly alternative if the incremental benefits costs ratio exceeds unity; otherwise choose the less costly alternatives.

Internal Rate of Return (IRR)

It is the rate of discount which makes the present value of benefits equal to present value of costs. IRR is the discount rate r, such that

$$\sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} = 0$$

IRR can be calculated as follows:

Last discount rate which yields a positive present value	+	The present value for the discount rate which gave the lowest positive total present value --- The sum, without regard to sign, of the above number plus the present value for the discount rate which yielded the first negative present value.	x	Difference between the two discount rates mentioned in this formula	=	IRR

Decision rule: Select the project of $r \geq i$, otherwise reject. 'r' is internal rate of return and i is rate of interest to be paid on the money to be invested.

Sensitivity Analysis

Benefits and costs estimates are projected for future events. They can never be forecasted with certainty. This uncertainty is more pronounced in the case of projects depending on forestry, crop production and engineering structures like farm ponds. All these aspects of production depend mainly on climatic parameters, which are highly unpredictable. In order to judge the economic feasibility of a project in the face of uncertainty, sensitivity analysis is undertaken. “Sensitivity” of a project may be understood as how “sensitive” the benefit-cost ratio of a project is if the parameters of B:C analysis changes. The following parameters are alternated for sensitivity analysis.

Project life: If the project happens to be independent on the economic life of one or a few structures such as farm ponds and reservoirs, etc., re-work out B:C ratio by reducing the project life.

Discount rate: In order to know, how sensitive the project is with respect to financial policies (i.e. increase or decrease the interest rate, etc.), re-workout the project work at higher rate of discount than adopted.

Prices of input & output: Increase the cost by a certain portion without changing output prices and re-workout B:C ratio.

Political uncertainty: If there is a fear of closure of a project in between the complete project life, calculate the project worth for many assumed project lives.

Cost Benefit Decision Tree

Decision	Dependence	Constraints	Criterion
Accept or reject one project	→	→	Accept if NPV > 0 or BCR ≥ 1.0, or IRR ≥ Appropriate discount rate
Select one of several projects	→	→	Select project with greatest NPV
Select several out of many projects	Independent	Budget constraint	Select in order of BCR till budget is exhausted.
		No budget constraint	Select all projects with NPV > 0.
	Dependent	Budget constraint	Select feasible projects with greatest NPV till budget is exhausted.
		No budget constraint	Select all projects with NPV > 0.

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